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TECHNICAL SUPPORT DOCUMENT: ENERGY EFFICIENCY PROGRAM FOR CONSUMER PRODUCTS AND COMMERCIAL AND INDUSTRIAL EQUIPMENT:

PORTABLE AIR CONDITIONERS

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U.S. Department of Energy
Assistant Secretary
Office of Energy Efficiency and Renewable Energy
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CHAPTER 1. INTRODUCTION

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CHAPTER 1. INTRODUCTION

1.1 PURPOSE OF THE DOCUMENT

This technical support document (TSD) is a stand-alone report that provides the technical analyses and results supporting the information presented in the final rule for portable air conditioners (ACs).

1.2 OVERVIEW OF STANDARDS FOR PORTABLE AIR CONDITIONERS

The Energy Policy and Conservation Act (EPCA) of 1975, Pub. L. 94-163 (42 United States Code (U.S.C.) 6291–6309), established an energy conservation program for major household appliances. Part A of title III of EPCA (42 U.S.C. 6291–6309) establishes the "Energy Conservation Program for Consumer Products Other Than Automobiles", which covers consumer products and certain commercial products (hereinafter referred to as "covered products").[a] EPCA authorizes the U.S. Department of Energy (DOE) to establish technologically feasible, economically justified energy conservation standards for covered products or equipment that would be likely to result in significant national energy savings. (42 U.S.C. 6295(o)(2)(B)(i)(I)–(VII))

In addition to specifying a list of covered residential products and commercial equipment, EPCA contains provisions that enable the Secretary of Energy to classify additional types of consumer products as covered products. For a given product to be classified as a covered product, the Secretary must determine that (1) classifying the product as a covered product is necessary for the purposes of EPCA; and (2) the average annual per-household energy use by products of each type is likely to exceed 100 kilowatt-hours (kWh) per year. (42 U.S.C. 6292(b)(1))

On July 5, 2013, DOE published in the *Federal Register* a proposed determination that portable ACs satisfy the criteria for classification as a covered product (hereinafter referred to as the "July 2013 NOPD"). 78 FR 40403. In a final determination of coverage published in the *Federal Register* on April 18, 2016, DOE classified portable ACs as covered consumer products under EPCA. 81 FR 22514, 22516–22517.

For the Secretary to prescribe an energy conservation standard pursuant to 42 U.S.C. 6295(o) and (p) for covered products added pursuant to 42 U.S.C. 6292(b)(1), he or she must also determine that (1) the average household energy use of the products has exceeded 150 kWh per household for a 12-month period; (2) the aggregate 12-month energy use of the products has exceeded 4.2 terawatt-hours; (3) substantial improvement in energy efficiency is technologically

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[a] For editorial reasons, upon codification in the U.S. Code, Part B was re-designated Part A.

feasible; and (4) application of a labeling rule under 42 U.S.C. 6294 is unlikely to be sufficient to induce manufacturers to produce, and consumers and other persons to purchase, covered products of such type (or class) that achieve the maximum energy efficiency that is technologically feasible and economically justified. (42 U.S.C. 6295(l)(1))

1.3 PROCESS FOR SETTING ENERGY CONSERVATION STANDARDS

Under EPCA, when DOE is studying new or amended standards, it must consider, to the greatest extent practicable, the following seven factors (42 U.S.C. 6295 (o)(2)(B)(i)):

1) the economic impact of the standard on the manufacturers and consumers of the affected products;

2) the savings in operating costs throughout the estimated average life of the product compared to any increases in the initial cost or maintenance expense;

3) the total projected amount of energy savings likely to result directly from the imposition of the standard;

4) any lessening of the utility or the performance of the products likely to result from the imposition of the standard;

5) the impact of any lessening of competition, as determined in writing by the Attorney General, that is likely to result from the imposition of the standard;

6) the need for national energy conservation; and

7) other factors the Secretary considers relevant.

Other statutory requirements are set forth in 42 U.S.C. 6295(o)(1)–(2)(A), (2)(B)(ii)–(iii), and (3)–(4).

DOE considers stakeholder participation to be a very important part of the process for setting energy conservation standards. Through formal public notifications (*i.e.*, *Federal Register* notices), DOE actively encourages the participation and interaction of all stakeholders during the comment period in each stage of the rulemaking. Beginning with the framework document and during subsequent comment periods, interactions among stakeholders provide a balanced discussion of the information that is required for the standards rulemaking.

Before DOE determines whether to adopt a proposed energy conservation standard, it must first solicit comments on the proposed standard. (42 U.S.C. 6295(m)(2)(B)) Any new or amended standard must be designed to achieve significant additional conservation of energy and be technologically feasible and economically justified. (42 U.S.C. 6295(o)(2)(A)) To determine whether economic justification exists, DOE must review comments on the proposal and determine that the benefits of the proposed standard exceed its burdens to the greatest extent practicable, weighing the seven factors listed above. (42 U.S.C. 6295 (o)(2)(B)(i))

After the publication of the framework document, the energy conservation standards rulemaking process involves three additional formal public notices, which DOE publishes in the *Federal Register*. The first of the rulemaking notices is a notice of public meeting (NOPM), which is designed to publicly vet the models and tools used in the preliminary analysis for the rulemaking and to facilitate public participation before the notice of proposed rulemaking (NOPR) stage. The second notice is the NOPR, which presents a discussion of comments received in response to the NOPM and the preliminary analyses and analytical tools; analyses of the impacts of potential new or amended energy conservation standards on consumers, manufacturers, and the Nation; DOE's weighting of these impacts of new or amended energy conservation standards; and the proposed energy conservation standards for the product. The third notice is the final rule, which presents a discussion of the comments received in response to the NOPR; the revised analyses; DOE's weighting of these impacts; the new or amended energy conservation standards DOE is adopting for the product; and the compliance dates of the new or amended energy conservation standards.

In May 2014, DOE published in the *Federal Register* a notice of data availability (NODA) (hereinafter referred to as the "May 2014 NODA"), in which it evaluated available industry test procedures to determine whether their methodologies may be suitable for incorporation in a new DOE test procedure, in the event that DOE determined that portable ACs are a covered product. DOE conducted testing on a range of portable ACs to determine typical cooling capacities and cooling energy efficiencies based on the existing industry test methods and other modified approaches. 79 FR 26639, 26640 (May 9, 2014). The May 2014 NODA document is available at: http://www.regulations.gov/#!documentDetail;D=EERE-2014-BT-TP-0014-0001.

DOE uses public meetings as an opportunity to inform and facilitate involvement of interested parties in the rulemaking process. The analytical framework presented at the public meetings describes the different analyses, such as the engineering analysis and the consumer economic analyses (*i.e.*, the life-cycle cost (LCC) and payback period (PBP) analyses), the methods proposed for conducting them, and the relationships among the various analyses.

Table 1.3.1 Analyses Under the Process Rule

Preliminary Analyses	NOPR	Final Rule
Market and technology assessment	Revised preliminary analyses	Revised NOPR analyses
Screening analysis	Life-cycle cost sub-group analysis	
Engineering analysis	Manufacturer impact analysis	
Energy use determination	Emissions impacts analysis	
Markups for equipment price determination	Monetization of emissions analysis	
Life-cycle cost and payback period analysis	Utility impact analysis	
Shipments analysis	Employment impact analysis	
National impact analysis	Regulatory impact analysis	
Preliminary manufacturer impact analysis		

In response to the July 2013 NOPD and May 2014 NODA, interested parties commented on numerous issues related to the analyses listed in Table 1.3.1. DOE attempted to address these issues during the preliminary analysis and summarized the comments and DOE's responses in chapter 2 of the preliminary TSD.

As part of the information gathering and sharing process for the engineering analysis and manufacturer impact analysis, DOE organized and held interviews with manufacturers of the portable ACs considered in this rulemaking. DOE selected companies that represented production of all types of products, ranging from small to large manufacturers, and included Association of Home Appliance Manufacturers (AHAM) member companies. DOE had four objectives for these interviews: (1) solicit manufacturer feedback on inputs to the engineering analysis; (2) gather feedback on topics related to the preliminary manufacturer impact analysis; (3) provide an opportunity, early in the rulemaking process, for manufacturers to express concerns to DOE; and (4) foster cooperation between manufacturers and DOE.

DOE incorporated the information gathered during the interviews with manufacturers into its engineering analysis (chapter 5) and the preliminary manufacturer impact analysis (chapter 12) of the preliminary TSD.

DOE developed spreadsheets for the LCC, PBP (chapter 8), and national impact analyses (chapter 10) for portable ACs. DOE developed an LCC spreadsheet that calculates the LCC and PBP at various energy efficiency levels. DOE also developed a national impact analysis spreadsheet that calculates the national energy savings (NES) and national net present values (NPVs) at various energy efficiency levels. This spreadsheet includes a model that forecasts the impacts of new energy conservation standards at various levels on product shipments. All of these spreadsheets are available on the DOE website for portable ACs at: https://www1.eere.energy.gov/buildings/appliance_standards/standards.aspx?productid=65 .

On February 27, 2015, DOE published the NOPM and availability of preliminary TSD for portable ACs (hereinafter referred to as the "February 2015 Preliminary Analysis"). 80 FR 10628. The preliminary TSD provided technical analyses, results, and detailed descriptions of all of the analyses discussed in the paragraphs above. The preliminary TSD is available at document ID EERE-2013-BT-STD-0033-0007 on http://www.regulations.gov.

Following the publication of the NOPM and the preliminary TSD, DOE held a public meeting on March 18, 2015, to facilitate discussion about the February 2015 Preliminary Analysis. In addition to the public meeting, DOE accepted written comments until April 28, 2015, to allow interested parties to provide new comments or elaborate on any comments made at the public meeting.

After receiving these comments, DOE revised the preliminary analyses for the NOPR phase of this rulemaking based on the feedback from interested parties. DOE organized and held a second round of interviews with manufacturers to gather additional feedback on the rulemaking analyses.

In addition to revising the various preliminary analyses, DOE also performed a consumer subgroup analysis, manufacturer impact analysis, utility impact analysis, employment impact analysis, and regulatory impact analysis for the NOPR stage of this rulemaking.

On June 13, 2016, DOE published the NOPR and announcement of public meeting (hereinafter referred to as the "June 2016 NOPR"). 81 FR 38397. To detail the supporting technical analyses and results, DOE posted the NOPR TSD for review on April 29, 2016, available at document ID EERE-2013-BT-STD-0033-0018 on http://www.regulations.gov.

DOE subsequently held a public meeting on July 20, 2016, to review and facilitate discussion about the June 2016 NOPR analyses, and provided a written comment period until August 12, 2016, to again allow interested parties to provide new comments or elaborate on any comments made at the public meeting. In response to requests from multiple interested parties, DOE extended the comment period deadline to September 26, 2016. DOE considered comments received in response to the June 2016 NOPR in developing the final rule analyses.

1.4 STRUCTURE OF THE DOCUMENT

This final rule TSD outlines the analytical approaches used in this rulemaking. The final rule TSD consists of 17 chapters (including an environmental assessment and regulatory impact analysis) and supporting appendices.

Chapter 1	Introduction: provides an overview of the appliance standards program and how it applies to this rulemaking, and outlines the structure of the document.
Chapter 2	Analytical Framework: describes the analytical process and methods.
Chapter 3	Market and Technology Assessment: characterizes the market for the considered products and the technologies available for increasing product efficiency.
Chapter 4	Screening Analysis: identifies all the design options that improve efficiency of the considered products, and determines which technology options are viable for consideration in the engineering analysis.
Chapter 5	Engineering Analysis: discusses the methods used for developing the relationship between increased manufacturer production cost and increased efficiency.
Chapter 6	Markups Analysis: discusses the methods used for establishing markups for converting manufacturer production costs to customer product costs.
Chapter 7	Energy Use Analysis: discusses the process used for generating energy-use estimates for the considered products as a function of standard levels.
Chapter 8	Life-Cycle Cost and Payback Period Analysis: discusses the effects of standards on individual customers and users of the products and compares the LCC and PBP of products with and without new efficiency standards.
Chapter 9	Shipments Analysis: estimates shipments of the products over the 30-year analysis period that is used in performing the national impact analysis (NIA).
Chapter 10	National Impact Analysis: assesses the national energy savings, and the national net present value of total consumer costs and savings, expected to result from specific, potential energy conservation standards.
Chapter 11	Consumer Subgroup Analysis: discusses the effects of standards on different subgroups of consumers.
Chapter 12	Manufacturer Impact Analysis: discusses the effects of standards on the finances and profitability of product manufacturers.

Chapter 13	Emissions Impact Analysis: discusses the effects of standards on power sector emissions and site combustion emissions of carbon dioxide (CO_2), nitrogen oxides (NO_X), sulfur dioxide (SO_2), and mercury (Hg); and estimates the impacts of two additional greenhouse gases, methane (CH_4) and nitrous oxide (N_2O).
Chapter 14	Monetization of Emissions Reduction Benefits: discusses the monetary values used for monetizing the reduced emissions resulting from the standards.
Chapter 15	Utility Impact Analysis: discusses certain effects of the considered on electric and gas utilities.
Chapter 16	Employment Impact Analysis: discusses the effects of standards on national employment.
Chapter 17	Regulatory Impact Analysis: discusses the impact of non-regulatory alternatives to efficiency standards.
Appendix 7A	Correlating Weather Station Data to Sample Buildings
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CHAPTER 2. ANALYTICAL FRAMEWORK

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CHAPTER 2. ANALYTICAL FRAMEWORK

2.1 INTRODUCTION

Section 6295(o)(2)(A) of the Energy Policy and Conservation Act (EPCA), Pub. L. 94-163, 42 U.S.C. 6291 *et seq*. requires the U.S. Department of Energy (DOE) to establish energy conservation standards that achieve the maximum improvement in energy efficiency that is technologically feasible and economically justified. This chapter describes the general analytical framework that DOE uses in developing such standards, and in particular, potential new energy conservation standards for portable ACs. The analytical framework is a description of the methodology, the analytical tools, and the relationships among the various analyses that are part of this rulemaking. The methodology that addresses the statutory requirement for economic justification, for example, includes analyses of life-cycle cost; economic impact on manufacturers and users; national benefits; effects, if any, on utility companies; and impacts from any lessening in competition among manufacturers.

Figure 2.1.1 summarizes the analytical components of the standards-setting process. The focus of the figure is the third column, labeled “Analyses.” The columns labeled “Key Inputs” and “Key Outputs” lists the types of data and information required for each analysis. Some key inputs come from public databases; DOE collects other inputs from interested parties or other knowledgeable experts within the field. The figure shows how the analyses fit into the rulemaking process and how they are related to one another. Arrows connecting analyses show the types of information that feed from one analysis to another.

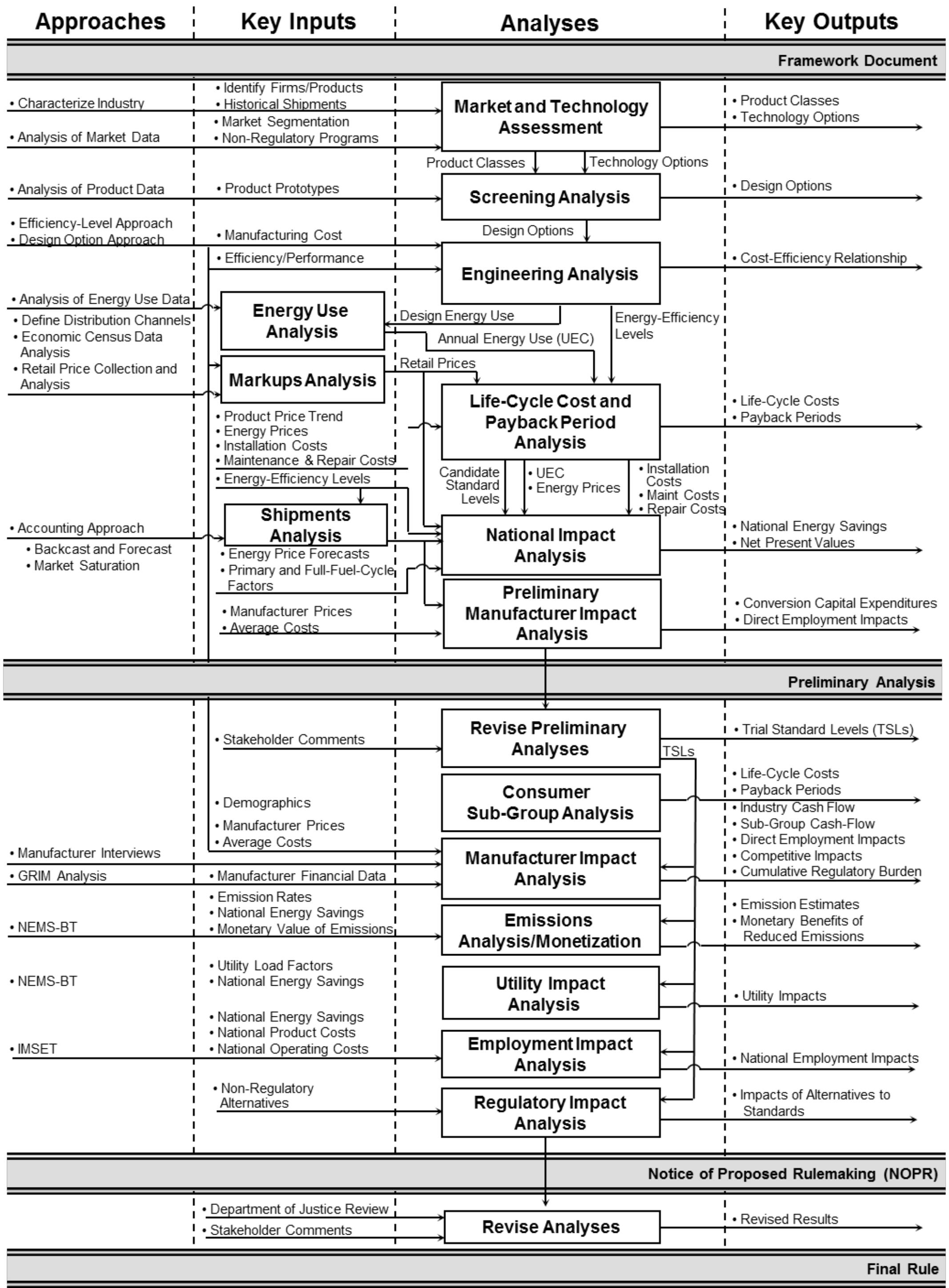

Figure 2.1.1 Flow Diagram of Analyses for the Rulemaking Process

The analysis performed as part of this final rule and reported in this final rule technical support document (TSD) are listed below.

- A market and technology assessment to characterize the relevant product markets and technology options, including prototype designs.

- A screening analysis to review each technology option and determine if it is technologically feasible; is practical to manufacture, install, and service; would adversely affect product utility or product availability; or would have adverse effects on health and safety.

- An engineering analysis to develop cost-efficiency relationships that show the manufacturer's cost of achieving increased efficiency.

- A markups analysis to develop markups throughout the distribution channel(s), relating the manufacturer production cost (MPC) to the cost to the consumer.

- An energy use analysis to determine the annual energy use of the considered products with and without standards for a representative group of users.

- A life-cycle cost (LCC) and payback period (PBP) analysis to calculate the savings in operating costs at the consumer level throughout the life of the considered products compared with any increase in the installed cost for the products likely to result directly from imposition of a standard.

- A shipments analysis to forecast product shipments, which then are used to calculate the national impacts of standards on energy, net present value (NPV), and future manufacturer cash flows.

- A national impact analysis (NIA) to assess the aggregate impacts at the national level of proposed energy conservation standards for the considered products, as measured by the NPV of total consumer economic impacts and the national energy savings (NES).

- An LCC subgroup analysis to evaluate variations in consumer characteristics that might cause a standard to disproportionately affect particular consumer subpopulations.

- A manufacturer impact analysis to estimate the financial impact of standards on manufacturers and to calculate impacts on costs, shipments, competition, employment, and manufacturing capacity.

- An emissions impacts analysis to assess the impacts of new energy conservation standards on the environment.

- An emissions monetization to assign values to the benefits associated with emissions reductions.

- A utility impact analysis to estimate the effects of new standards on electric utilities.

- An employment impact analysis to assess the aggregate impacts on national employment.

- A regulatory impact analysis to examine major alternatives to new energy conservation standards that potentially could achieve substantially the same regulatory goal at a lower cost.

For this rulemaking, DOE began the process by publishing a notice of proposed determination (NOPD) in the Federal Register on July 5, 2013 (the "July 2013 NOPD"), which included DOE's tentative determination that portable ACs fulfill the criteria for being added as a covered product pursuant to 42 U.S.C. 6292(b)(1). 78 FR 40403, 40404. On April 18, 2016, DOE published a final determination (the "April 2016 Final Determination") that portable ACs qualify as a covered product such coverage is necessary or appropriate to carry out the purposes of EPCA, and the average U.S. household energy use for portable ACs is likely to exceed 100 kilowatt-hours (kWh) per year. 81 FR 22514. The July 2013 NOPD and April 2016 Final Determination are available in docket ID EERE-2013-BT-STD-0033 on http://www.regulations.gov.

On February 27, 2015, DOE published an energy conservation standards notice of public meeting and notice of availability of the preliminary TSD for portable ACs (the "February 2015 Preliminary Analysis"). In the preliminary analysis, DOE conducted in-depth technical analyses in the following areas: (1) engineering; (2) markups to determine product price; (3) energy use; (4) life-cycle cost and payback period; and (5) national impacts. DOE also conducted, and included in the preliminary TSD, several other analyses that supported the major analyses or were expanded upon for the subsequent NOPR and this final rule. These analyses included: (1) the market and technology assessment; (2) the screening analysis, which contributes to the engineering analysis; and (3) the shipments analysis, which contributes to the LCC and PBP analysis and national impact analysis (NIA). In addition to these analyses, DOE began preliminary work on the manufacturer impact analysis and identified the methods to be used for the consumer subgroup analysis, the emissions analysis, the employment impact analysis, the regulatory impact analysis, and the utility impact analysis. 80 FR 10628. The preliminary TSD that presented the methodology and results of each of these analyses is available at document ID EERE-2013-BT-STD-0033-0007 on http://www.regulations.gov.

Interested parties submitted comments in response to the analyses and results presented in the preliminary TSD. On June 13, 2016, DOE published a notice of proposed rulemaking (NOPR) in the *Federal Register* to address these comments, update the analyses presented in the February 2015 Preliminary Analysis, provide the results of additional rulemaking analyses, and propose new energy conservation standards for portable ACs. 81 FR 38397. The NOPR TSD provides the technical analyses and results that support the information presented in the NOPR for portable ACs. The NOPR TSD is available at document ID EERE-2013-BT-STD-0033-0018 on http://www.regulations.gov. Interested stakeholders provided feedback on the NOPR analyses, which DOE has incorporated in the analyses for this final rule.

The following sections provide a general description of the different analytical components of the rulemaking analytical plan. DOE has used the most reliable data available at the time of each analysis in this rulemaking. All data will be available for public review.

2.2 MARKET AND TECHNOLOGY ASSESSMENT

The market and technology assessment characterizes the relevant product markets and existing technology options, including working prototype designs, for the considered products.

2.2.1 Market Assessment

When DOE begins an energy conservation standards rulemaking, it develops information that provides an overall picture of the market for the products considered, including the nature of the products, the industry structure, and market characteristics for the products. This activity consists of both quantitative and qualitative efforts based primarily on publicly available information. The subjects addressed in the market assessment for portable ACs include manufacturers, trade associations, and the quantities and types of products sold and offered for sale. DOE examined both large and small and foreign and domestic manufacturers. Finally, DOE reviewed other energy efficiency programs from utilities, individual States, and other organizations.

DOE reviewed relevant literature and interviewed manufacturers to develop an overall picture of the portable AC industry in the United States. Industry publications and trade journals, government agencies, and trade organizations provided the bulk of the information, including (1) manufacturers and their market shares; (2) shipments by product type; (3) detailed product information; and (4) industry trends. The analysis developed as part of the market and technology assessment is described in chapter 3 of this final rule TSD.

2.2.2 Technology Assessment

DOE typically uses information relating to existing and past technology options and prototype designs as inputs to determine what technologies manufacturers may use to attain higher performance levels. In consultation with interested parties, DOE develops a list of technologies for consideration. Initially, these technologies encompass all those it believes are technologically feasible.

DOE developed its list of technologically feasible design options for portable ACs through consultation with manufacturers, and from trade publications and technical papers. Because many options for improving product efficiency are available in existing units, product literature and direct examination provided additional information.

Chapter 3 of this final rule TSD includes the detailed list of all the technology options identified for potential efficiency improvements in portable ACs.

2.3 SCREENING ANALYSIS

The screening analysis examines various technologies as to whether they: (1) are technologically feasible; (2) are practicable to manufacture, install, and service; (3) have an adverse impact on product utility or availability; and (4) have adverse impacts on health and safety. DOE developed an initial list of efficiency-enhancement options from the technologies identified as technologically feasible in the technology assessment. Then DOE, in consultation with interested parties, reviewed the list to determine if these options are practicable to manufacture, install, and service, would adversely affect product utility or availability, or would have adverse impacts on health and safety. In the engineering analysis, DOE further considered efficiency enhancement options that it did not screen out in the screening analysis. Chapter 4 of this final rule TSD contains details on the screening analysis for portable ACs.

2.4 ENGINEERING ANALYSIS

The engineering analysis establishes the relationship between the manufacturer production cost (MPC) and the efficiency of portable ACs. The purpose of the analysis is to estimate the incremental MPCs for a product that would result from increasing efficiency above the baseline model. This relationship serves as the basis for cost/benefit calculations in terms of individual consumers, manufacturers, and the nation. Chapter 5 of this final rule TSD discusses the product classes DOE analyzed, the representative baseline units, the incremental efficiency levels, the methodology DOE used to develop the MPCs, the cost-efficiency curves, and the impact of efficiency improvements on the considered products.

The engineering analysis considered technologies not eliminated in the screening analysis, although certain technologies were not analyzed for the reasons set forth in chapter 5 of this final rule TSD, namely due to insufficient information available on the specific efficiency gains, the inability of the existing DOE test procedure to measure any reduction in energy use, or manufacturers were more likely to pursue other currently implement features that are more cost effective. DOE considered the remaining technologies, designated as design options, in developing the cost-efficiency curves.

DOE typically structures its engineering analysis around one of three methodologies: (1) the design-option approach, which calculates the incremental costs of adding specific design options to a baseline model; (2) the efficiency-level approach, which calculates the relative costs of achieving increases in energy efficiency levels without regard to the particular design options used to achieve such increases; and/or (3) the reverse-engineering or cost-assessment approach, which involves a "bottom-up" manufacturing cost assessment based on a detailed bill of materials derived from tear-downs of the product being analyzed.

DOE used a combination of these approaches for this rulemaking, as described in further detail in chapter 5 of this final rule TSD, where DOE details the methodology and results of the analysis used to derive the cost-efficiency relationships.

2.5 MARKUPS ANALYSIS

DOE analyzed product markups to convert the manufacturer costs estimated in the engineering analysis to customer prices, which then were used in the LCC and PBP and the manufacturer impact analyses. DOE calculated markups for baseline products (baseline markups) and for more efficient products (incremental markups). An incremental markup relates the change in the MPC of higher-efficiency models (the incremental cost increase) to the change in the retailer or distributor sales price.

To develop markups, DOE identified how the products are distributed from the manufacturer to the customer. After establishing appropriate distribution channels, DOE used data from sources that included the financial filings of manufacturers and distributors to determine how prices are marked up as the products pass from the manufacturer to the customer. Chapter 6 of this final rule TSD provides details on DOE's development of markups for portable ACs.

2.6 ENERGY USE ANALYSIS

DOE assessed the energy savings potential from higher-efficiency portable ACs in order to develop energy savings values to be used in the LCC and subsequent analyses. The goal of the energy use characterization is to generate a range of energy use values that reflect real-world use of portable ACs in American homes and businesses. By incorporating data on how portable ACs actually are used by U.S. consumers, DOE can estimate the energy that would be consumed (or potentially saved) by products having various efficiency levels. As part of the energy use analysis, certain engineering assumptions and data are required, including how often the product is operated and in which mode of operation (cooling, fan-only, standby, and off), installation conditions, and climate conditions.

Critical to DOE's energy use analysis was room AC data from the Energy Information Administration's (EIA's) 2009 *Residential Energy Consumption Survey* (*RECS* 2009) and 2012 *Commercial Buildings Energy Consumption Survey* (*CBECS* 2012), the most recent surveys available at the time of DOE's analysis. Both surveys collect nationally representative information related to consumers' appliance use and energy consumption, including the use of window- or wall-mounted room ACs. The two surveys collect data on annual energy costs for cooling, along with climate-related characteristics. DOE's assumptions include the following considerations.

- Ownership of a window- or wall-mounted room AC used in a *RECS* 2009 household or *CBECS* 2012 enterprise could be used to approximate the ownership of a portable AC.
- The portable AC was installed according to manufacturer instructions (for example, a dual-duct portable AC would have both ducts installed and properly insulated).

- The number of operating hours spent in cooling mode for a window- or wall-mounted room AC used in a *RECS* household or *CBECS* enterprise could be used to approximate the hours a portable AC spends in cooling mode.
- The upper limit of total hours of portable AC operation in either cooling or fan-only mode were estimated assuming that a portable AC would be operated only in months having five or more cooling-degree days that exceed 65 degrees Fahrenheit (°F).
- The average capacity at each efficiency level reflects the full range of capacities at that efficiency level.

The energy use analysis requires DOE to establish a range of total annual operating hours as well as hours for each mode of operation (cooling or fan-only). DOE utilized *RECS* 2009 and *CBECS* 2012 data to establish the upper limit of portable AC annual operating hours for both modes of operation. To estimate annual portable AC use and energy consumption, DOE began by assigning each *RECS* household and *CBECS* commercial enterprise that uses a room AC to one of the 321 weather stations operated by the National Oceanic and Atmospheric Administration (NOAA). DOE identified which weather station best matched the heating and cooling degree-days in the *RECS* 2009 data set or the *CBECS* 2012 data set. The climate data obtained from NOAA's National Climatic Data Center helped DOE determine the maximum amount of time the portable AC would be operated annually and apportion the annual electricity use for portable ACs in various geographic areas among the months of the year. DOE assumed a portable AC would be operated only in months having five or more cooling-degree days that exceed 65 degrees Fahrenheit (°F).

DOE was able to use *RECS* 2009 and *CBECS* 2012 room AC data to estimate the range of annual operating hours a portable AC spends in cooling mode based on the method used in DOE's 2011 final energy conservation standards rulemaking for room ACs. DOE assumed the operating hours calculated for households and businesses having a room AC represent operating hours spent in cooling mode for a portable AC unit. The energy use of a portable AC during cooling mode was calculated using the method for determining rated seasonally adjusted cooling capacity and efficiency stipulated in the DOE test procedure for representative units at each efficiency level. The distribution of operating hours spent in fan-only mode is based on an analysis of field-metered data (Burke *et al.*[a]), in which DOE assumed that fan-only time was proportional to cooling-mode time.

Chapter 7 of this final rule TSD provides more detail about DOE's approach to characterizing energy use of portable ACs.

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[a] T. Burke, *et al.*, *Using Field-Metered Data to Quantify Annual Energy Use of Portable Air Conditioners*, Lawrence Berkeley National Laboratory, Report No. LBNL-6868E (December 2014). Available at: www.osti.gov/scitech/servlets/purl/1166989. (Last accessed March 15, 2016).

2.7 LIFE-CYCLE COST AND PAYBACK PERIOD ANALYSIS

In determining whether an energy efficiency standard is economically justified, DOE considers the economic impacts of potential standards on customers. The effects of new or amended standards on individual customers usually include a reduction in operating cost and an increase in purchase price. DOE used the following two metrics to measure customer impacts.

- Life-cycle cost (LCC), the total customer cost of a product, generally throughout the life of the product. The LCC calculation includes total installed cost (manufacturer selling price, distribution markups, sales tax, and installation costs); operating costs (energy, repair, and maintenance costs); product lifetime; and a discount rate. Future operating costs are discounted to the time of purchase and summed over the lifetime of the product.
- Payback period (PBP), a measure of the amount of time it takes customers to recover the assumed higher purchase price of more energy efficient product through reduced operating costs. Inputs to the calculation of payback period include the installed cost to the customer and first-year operating costs.

In determining the LCC and PBP, DOE used data regarding engineering performance, energy use, and markups. DOE generated LCC and PBP results using a simulation approach in which certain key inputs to the analysis consist of probability distributions rather than single-point values. That analytical technique produces outcomes that also can be expressed as probability distributions. As a result, the analysis produces a range of LCC and PBP results, which enables DOE to identify the fraction of customers achieving LCC savings or incurring net cost at each considered efficiency level. Chapter 8 of this final rule TSD describes the LCC and PBP analysis.

2.8 SHIPMENTS ANALYSIS

DOE projected future shipments of portable ACs based on an analysis of key market drivers. Projections of shipments are needed to calculate the potential effects of standards on national energy use, NPV, and future manufacturer cash flows. DOE generated shipments projections for each product class. The projections estimate the total number of portable ACs shipped each year during the 30-year analysis period (2022–2051). To create the projections, DOE combined current-year shipments with results of a shipments model that incorporates key market drivers for portable ACs. Chapter 9 of this final rule TSD provides additional details on the shipments analysis.

2.9 NATIONAL IMPACT ANALYSIS

The NIA includes the NES and the NPV of total customer benefit for the efficiency levels considered for portable ACs. To make the analysis more accessible and transparent to all interested parties, DOE prepared a Microsoft Excel spreadsheet model to project NES and the national customer economic costs and savings resulting from potential new standards. The spreadsheet model uses as inputs typical values (as opposed to probability distributions). To assess the effect of input uncertainty on NES and NPV results, DOE is able to conduct sensitivity analyses by operating the model using various input variables.

Several inputs for determining NES and NPV depend on the distribution of product efficiencies. For the no-new-standards case, DOE uses efficiency distributions developed using shipments data supplied by manufacturers. Because the evidence suggests that there is no trend toward greater interest in higher portable AC efficiency, DOE assumed that the no-new-standards case distribution would remain constant throughout the analysis period. For this analysis, DOE used a roll-up scenario to establish the product market shares by efficiency level for the year in which compliance with new standards would be required. Under a roll-up scenario, all products that perform at efficiency levels lower than a prospective standard are moved, or rolled-up, to the minimum performance level allowed under the standard. Product efficiencies that exceed the new standard level do not change. To project efficiencies for the no-new-standards case, DOE made assumptions regarding future improvements in efficiency, assuming an annual increase in efficiency of 0.25 percent between 2022 and 2051.

2.9.1 National Energy Savings

The inputs for determining the NES for each efficiency level are: (1) annual energy consumption per unit, (2) shipments, (3) product stock, (4) national energy consumption, and (5) site-to-primary energy and full-fuel cycle conversion factors. DOE calculated national energy consumption by multiplying the number of units, or stock (by vintage, or age) by the unit energy consumption (also by vintage). DOE calculated annual NES based on the difference in national energy consumption for the no-new standards case (without new efficiency standards) and for each efficiency level being considered. Cumulative energy savings are the sum of the NES for each year.

2.9.2 Net Present Value of Customer Benefits

The inputs for determining NPV of the total costs and benefits experienced by consumers are: (1) total annual installed cost, (2) total annual savings in operating costs, (3) a discount factor, (4) present value of costs, and (5) present value of savings. DOE calculated net savings each year as the difference in total savings in operating costs and total increases in installed costs between the no-new-standards case and each standards case. DOE calculated savings over the life of each product class, accounting for differences in yearly energy rates. DOE calculated NPV as the difference between the present value of operating cost savings and the present value of total installed costs. DOE used a discount factor based on real discount rates of 3 percent and 7 percent to discount future costs and savings to present values.

DOE calculated the difference in total installed cost between the no-new-standards case and each standards case (*i.e.*, after standards take effect). Because the more efficient products bought in the standards case usually cost more than products bought in the no-new-standards case, cost increases appear as negative values in the NPV.

DOE expressed savings in operating costs as decreases associated with the lower energy consumption of products bought in the standards case compared to the no-new-standards efficiency case. Total savings in operating costs are the product of savings per unit and the number of units of each vintage that survive in a given year.

Chapter 10 of this final rule TSD provides additional details regarding the national impact analysis.

2.10 CUSTOMER SUBGROUP ANALYSIS

The customer subgroup analysis evaluates economic impacts on particular groups of customers who might be affected adversely by the energy conservation standards proposed for the considered equipment. DOE evaluates impacts on subgroups of customers primarily by applying the LCC spreadsheet model to analyze the LCC impacts and PBP for those customers. For this rulemaking, DOE analyzed users of variable frequency drives as a subgroup. For this rulemaking, DOE analyzed as subgroups: (1) low-income households; and (2) small businesses. Chapter 11 of this final rule TSD describes the consumer subgroup analysis.

2.11 MANUFACTURER IMPACT ANALYSIS

The MIA assesses the impacts of new energy conservation standards on manufacturers of the considered products. Potential impacts include financial effects, both quantitative and qualitative, that might lead to changes in the manufacturing practices for these products. DOE identified these potential impacts through interviews with manufacturers and other interested parties.

DOE conducted the MIA in three phases, and further tailored the analytical framework based on interested parties' comments. In Phase I, an industry profile was created to characterize the industry, and a preliminary MIA was conducted to identify important issues that required consideration. In Phase II, an industry cash flow model and an interview questionnaire were prepared to guide subsequent discussions. In Phase III, manufacturers were interviewed, and the impacts of standards were assessed both quantitatively and qualitatively. Industry and subgroup cash flow and NPV were assessed through use of the Government Regulatory Impact Model (GRIM). Then impacts on competition, manufacturing capacity, employment, and cumulative regulatory burden were assessed based on manufacturer interview feedback and discussions. DOE discusses its findings from the MIA in chapter 12 of this final rule TSD.

2.12 EMISSIONS IMPACT ANALYSIS

The emissions analysis consists of two components. The first component estimates the effect of potential energy conservation standards on power sector and site (where applicable) combustion emissions of carbon dioxide (CO_2), nitrogen oxides (NO_X), sulfur (SO_2), and mercury (Hg). The second component estimates the impacts of potential standards on emissions of two additional greenhouse gases, methane (CH_4) and nitrous oxide (N_2O), as well as the reductions to emissions of all species due to "upstream" activities in the fuel production chain. These upstream activities comprise extraction, processing, and transporting fuels to the site of combustion. The associated emissions are referred to as upstream emissions.

The analysis of power sector emissions uses marginal emissions factors that were derived from data in Annual Energy Outlook 2016 (*AEO 2016)*. The methodology is described in chapter 13 and 15 of the TSD.

Combustion emissions of CH_4 and N_2O are estimated using emissions intensity factors published by the EPA: GHG Emissions Factors Hub.[b] The FFC upstream emissions are estimated based on the methodology described in chapter 15 of the TSD. The upstream emissions include both emissions from fuel combustion during extraction, processing, and transportation of fuel, and "fugitive" emissions (direct leakage to the atmosphere) of CH_4 and CO_2.

The emissions intensity factors are expressed in terms of physical units per MWh or MMBtu of site energy savings. Total emissions reductions are estimated using the energy savings calculated in the national impact analysis.

The Annual Energy Outlook *(AEO)* incorporates the projected impacts of existing air quality regulations on emissions. *AEO 2016* generally represents current legislation and environmental regulations, including recent government actions, for which implementing regulations were available as of the end of February 2016.

2.13 MONETIZATION OF EMISSIONS REDUCTION BENEFITS

DOE considers the estimated monetary benefits likely to result from the reduced emissions of CO_2, CH_4, N_2O and NO_X that are expected to result from each of the standard levels considered.

To estimate the monetary value of benefits resulting from reduced emissions of CO_2, DOE uses the most current Social Cost of Carbon Dioxide (SC-CO_2) values developed and/or agreed to by an interagency process. The SC-CO_2 is intended to be a monetary measure of the

[b] Available at: http://www2.epa.gov/climateleadership/center-corporate-climate-leadership-ghg-emission-factors-hub.

incremental damage resulting from greenhouse gas (GHG) emissions, including, but not limited to, net agricultural productivity loss, human health effects, property damage from sea level rise, and changes in ecosystem services. Any effort to quantify and to monetize the harms associated with climate change will raise serious questions of science, economics, and ethics. But with full regard for the limits of both quantification and monetization, the SC-CO_2 can be used to provide estimates of the social benefits of reductions in CO_2 emissions.

The Interagency Working Group on Social Cost of Carbon selected four sets of SC-CO_2 values for use in regulatory analyses. Three sets of values are based on the average SC-CO_2 from the three integrated assessment models, at discount rates of 2.5, 3, and 5 percent. The fourth set, which represents the 95th percentile SC-CO_2 estimate across all three models at a 3-percent discount rate, was included to represent higher-than-expected impacts from climate change further out in the tails of the SC-CO_2 distribution. The values grow in real terms over time.[c] To calculate a present value of the stream of monetary values, DOE discounts the values in each of the four cases using the discount rates that had been used to obtain the SC-CO_2 values in each case.

In 2016 the Interagency Working Group issued a report that presents social cost estimates for CH_4 and N_2O as a way for agencies to incorporate the social benefits of reducing CH_4 and N_2O emissions into benefit-cost analyses of regulatory actions.[d] DOE uses these values in the current analysis.

DOE recognizes that scientific and economic knowledge continues to evolve rapidly as to the contribution of CO_2 and other GHG to changes in the future global climate and the potential resulting damages to the world economy. Thus, these values are subject to change.

DOE also considers the potential monetary benefits of reduced NO_X emissions attributable to the standard levels it considers. DOE estimated the monetized value of NO_X emissions reductions using benefit per ton estimates from the *Regulatory Impact Analysis for the Clean Power Plan Final Rule*, published in August 2015 by EPA's Office of Air Quality

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[c] Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866, Interagency Working Group on Social Cost of Carbon, United States Government (May 2013; revised July 2015) (Available at: http://www.whitehouse.gov/sites/default/files/omb/inforeg/scc-tsd-final-july-2015.pdf).

[d] United States Government–Interagency Working Group on Social Cost of Greenhouse Gases. Addendum to Technical Support Document on Social Cost of Carbon for Regulatory Impact Analysis under Executive Order 12866: Application of the Methodology to Estimate the Social Cost of Methane and the Social Cost of Nitrous Oxide. August 2016. https://www.whitehouse.gov/sites/default/files/omb/inforeg/august_2016_sc_ch4_sc_n2o_addendum_final_8_26_16.pdf.

Planning and Standards.[e]

2.14 UTILITY IMPACT ANALYSIS

To estimate the impacts of potential energy conservation standards on the electric utility industry, DOE used published output from the NEMS associated with *AEO 2016.* NEMS is a large, multi-sectoral, partial-equilibrium model of the U.S. energy sector that EIA has developed over several years, primarily for the purpose of preparing the *AEO*. NEMS produces a widely recognized forecast for the United States through 2040 and is available to the public.

As of 2014, DOE is using a new methodology based on results published for the *AEO* Reference case, as well as a number of side cases that estimate the economy-wide impacts of changes to energy supply and demand. DOE estimates the marginal impacts of reduction in energy demand on the energy supply sector. In principle, marginal values should provide a better estimate of the actual impact of energy conservation standards. DOE uses the side cases to estimate the marginal impacts of reduced energy demand on the utility sector. These marginal factors are estimated based on the changes to electricity sector generation, installed capacity, fuel consumption and emissions in the *AEO* Reference case and various side cases. The methodology is described in more detail in chapter 15 of this final rule TSD.

The output of this analysis is a set of time-dependent coefficients that capture the change in electricity generation, primary fuel consumption, installed capacity and power sector emissions due to a unit reduction in demand for a given end use. These coefficients are multiplied by the stream of electricity savings calculated in the NIA to provide estimates of selected utility impacts of new or amended energy conservation standards.

2.15 EMPLOYMENT IMPACT ANALYSIS

The adoption of energy conservation standards can affect employment both directly and indirectly. Direct employment impacts are changes in the number of employees at the plants that produce the covered products. DOE evaluates direct employment impacts in the MIA.

Indirect employment impacts may result from expenditures shifting between goods (the substitution effect) and changes in income and overall expenditure levels (the income effect) that occur due to standards. DOE defines indirect employment impacts from standards as net jobs eliminated or created in the general economy as a result of increased spending driven by increased product prices and reduced spending on energy.

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[e] Available at www.epa.gov/cleanpowerplan/clean-power-plan-final-rule-regulatory-impact-analysis. See Tables 4A-3, 4A-4, and 4A-5 in the report.

The indirect employment impacts are investigated in the employment impact analysis using the Pacific Northwest National Laboratory's "Impact of Sector Energy Technologies" (ImSET) model.[8] The ImSET model was developed for DOE's Office of Planning, Budget, and Analysis to estimate the employment and income effects of energy-saving technologies in buildings, industry, and transportation. Compared with simple economic multiplier approaches, ImSET allows for more complete and automated analysis of the economic impacts of energy conservation investments.

2.16 ANALYSIS OF NON-REGULATORY ALTERNATIVES

In the final rule stage, DOE prepares an analysis that evaluates potential non-regulatory policy alternatives, comparing the costs and benefits of each to those of the proposed standards. DOE recognizes that non-regulatory policy alternatives can substantially affect energy efficiency or reduce energy consumption. DOE bases its assessment on the actual impacts of any such initiatives to date, but also considers information presented by interested parties regarding the potential future impacts of current initiatives.

CHAPTER 3. MARKET AND TECHNOLOGY ASSESSMENT

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CHAPTER 3. MARKET AND TECHNOLOGY ASSESSMENT

3.1 INTRODUCTION

This chapter provides an assessment of the portable air conditioner (AC) industry in the United States. The U.S. Department of Energy (DOE) developed the market and technology assessment presented in this chapter primarily from publicly available information. This assessment is helpful in identifying the major manufacturers and their product characteristics, which form the basis for the engineering and the life-cycle cost (LCC) analyses. Present and past industry structure and industry financial information help DOE in the process of conducting the manufacturer impact analysis (MIA).

3.2 PRODUCT DEFINITION

There is no definition of portable ACs included in the Energy Policy and Conservation Act (EPCA) of 1975, Pub. L. 94-163, 42 United States Code (U.S.C.) 6291 *et seq*. However, on April 18, 2016, DOE published a final coverage determination (hereinafter referred to as the April 2016 Coverage Determination) that established the following product definition in the Code of Federal Regulations (CFR) at 10 CFR 430.2:

> *Portable air conditioner* means a portable encased assembly, other than a "packaged terminal air conditioner," "room air conditioner," or "dehumidifier," that delivers cooled, conditioned air to an enclosed space and is powered by single-phase power. It includes a source of refrigeration and may include additional means for air circulation and heating.
>
> 81 FR 22514, 22519–22520.

3.3 PRODUCT CLASSES

When evaluating and establishing energy conservation standards, DOE generally divides covered products into product classes by the type of energy used or by capacity or other performance-related features that affect efficiency. Different energy conservation standards may apply to different product classes. (42 U.S.C. 6295(q)) Because portable ACs are newly covered under EPCA, product classes have not yet been established within this product type. For this final rule, and during the earlier rulemaking stages, DOE considered whether it should separate portable ACs into product classes based on two characteristics: duct configuration and capacity.

Portable ACs are available with various types of duct configurations that affect product performance, including: single-duct, dual-duct, and spot cooler. DOE's portable AC test procedure at 10 CFR part 430, subpart B, appendix CC (appendix CC) characterizes the performance of only single-duct and dual-duct portable ACs and, therefore, this final rule analysis focuses only on single-duct and dual-duct portable ACs.

Single-duct units draw all of the condenser inlet air from the conditioned space without the means of a duct, and discharge the hot condenser outlet air to the unconditioned space through a duct. Dual-duct units draw some or all of the condenser inlet air from the unconditioned space through a duct, and may draw additional condenser inlet air from the conditioned space. The condenser outlet air is discharged to the unconditioned space by means of a separate duct. Single-duct units typically create more net negative pressure within the conditioned space than dual-duct units, leading to more infiltration airflow from outside the conditioned space. Under the testing conditions and efficiency metric calculations in appendix CC, DOE did not observe a correlation between duct configuration and efficiency.

Furthermore, DOE evaluated whether there is any consumer utility associated with the different duct configurations. DOE considered whether all installation locations would be able to accommodate both single-duct and dual-duct units. Based on discussions with manufacturers and a review of the market and the range of possible window connections, DOE concludes that no installation location would preclude the use of either duct configuration. In particular, all window fixtures are of sufficient width to accommodate connections to two ducts. DOE also investigated whether duct configuration may affect noise performance of a portable AC. Based on a review of published noise data, DOE did not find a correlation between noise levels and duct configuration. DOE also estimated from its engineering analysis that a dual-duct portable AC would be less than 5 pounds heavier than a comparable single-duct unit with the same capacity. With wheels on all units, portability of a dual-duct unit is not reduced when relocating the unit within the home. DOE further determined that the additional duct for dual-duct units results in shipping packages that are slightly larger than for single-duct units, with a corresponding impact on shipping costs and consumer portability prior to unpacking. However, DOE determined that the size differences do not significantly impact product availability or consumer utility during operation.

Because DOE found that neither efficiency nor consumer utility would be affected by duct configuration, DOE concludes that duct configuration does not warrant separate product classes.

Although DOE did not separate portable ACs into product classes based on duct configuration for this final rule, in a test procedure final rule published on June 1, 2016 (81 FR 35241; hereinafter the “June 2016 TP Final Rule”) DOE established the following definitions for single-duct and dual-duct portable ACs in 10 CFR 430.2 to account for their different testing requirements:

> *Single-duct portable air conditioner* means a portable air conditioner that draws all of the condenser inlet air from the conditioned space without the means of a duct, and discharges the condenser outlet air outside the conditioned space through a single duct attached to an adjustable window bracket.

Dual-duct portable air conditioner means a portable air conditioner that draws some or all of the condenser inlet air from outside the conditioned space through a duct attached to an adjustable window bracket, may draw additional condenser inlet air from the conditioned space, and discharges the condenser outlet air outside the conditioned space by means of a separate duct attached to an adjustable window bracket.

81 FR 35241, 35264.

Additionally, DOE determined that portable AC efficiencies are a function of product capacity. Higher-capacity units typically achieve higher efficiencies than lower-capacity units when measured according to the test method codified in 10 CFR 430, subpart B, appendix CC (appendix CC). In the test procedure rulemaking, DOE observed from its test data that this relationship between efficiency and capacity is consistent across the full range of measured capacities for products that implement the same technologies. Additionally, DOE did not identify any inherent differences in efficiency for various discrete ranges of capacity that would produce a different efficiency-capacity relationship. Therefore, DOE is not establishing separate portable AC product classes based on capacity. Instead, DOE is establishing energy conservation standards for portable ACs based on equations that relate efficiency to capacity.

In sum, because DOE did not identify any inherent efficiency difference or consumer utility associated with duct configuration, and because a single efficiency-capacity relationship exists for all portable AC capacities, DOE considered a single portable AC product class for the final rule analyses.

3.4 PRODUCT TEST PROCEDURES

DOE initiated a test procedure rulemaking by publishing a notice of data availability (NODA) on May 9, 2014 (hereinafter the "May 2014 NODA"), to request feedback on potential testing options. 79 FR 26639. In the May 2014 NODA, DOE presented data from investigative testing according to the Association of Home Appliance Manufacturers (AHAM) PAC-1-2009, "Portable Air Conditioners" (AHAM PAC-1-2009) and American National Standards Institute (ANSI)/American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) Standard 16-1983 (RA 99), "Method of Testing for Rating Room Air Conditioners and Packaged Terminal Air Conditioners" (ANSI/ASHRAE Standard 16-1983), with certain modifications to allow testing of portable ACs. DOE also presented an alternate test approach, in which testing would be conducted according to ANSI/AHAM PAC-1-2009, but the calculations for capacity and energy efficiency ratio (EER) would account for any heat transferred to or from the conditioned space due to infiltration air or a warm or cold product case and ducts.

Based on feedback received in response to the May 2014 NODA and on further investigative testing, DOE published a NOPR on February 25, 2015, to propose and describe the development of a DOE test procedure for portable ACs (hereinafter the "February 2015 Test Procedure NOPR"). 80 FR 10212. The proposed test procedure was consistent with the alternate approach described in the May 2014 NODA; however the February 2015 Test Procedure NOPR referenced the recently updated version of the PAC-1 standard, AHAM PAC-1-2014 “Portable Air Conditioners” (AHAM PAC-1-2014). The 2014 version of the standard includes minor revisions to the indoor and outdoor conditions from the 2009 version to fully harmonize with the Canadian Standards Association (CSA) test procedure. After careful review of both versions of AHAM PAC-1, DOE did not expect the revisions to that test procedure to have a significant impact on test results.

In the February 2015 Test Procedure NOPR, DOE also proposed a combined energy efficiency ratio (CEER) that would account for portable AC performance in each available operating mode; however, DOE conducted the preliminary analysis for energy conservation standards based solely on portable AC performance in cooling mode, in terms of cooling capacity and cooling energy efficiency ratio (EER_{cm}), as determined by the method proposed in the February 2015 Test Procedure NOPR. DOE focused on cooling mode for the preliminary analysis because cooling is the primary function of portable ACs.

Based on feedback received in response to the February 2015 Test Procedure NOPR and following further analysis, DOE published a supplemental notice of proposed rulemaking (SNOPR) (hereinafter referred to as “November 2015 TP SNOPR”) on November 27, 2015, in which it proposed various revisions to the proposals in the February 2015 Test Procedure NOPR. DOE proposed a revision to the indoor and outdoor cooling mode test conditions to align with the AHAM PAC-1-2009 test conditions, an additional test condition for cooling mode testing, removal of case heat transfer measurements and heating mode testing with subsequent updates to the CEER metric, and a clarification to the test unit placement within the chamber, in addition to other technical corrections. These proposed revisions improved repeatability, reduced test burden, and ensured the test procedure was representative of typical consumer usage. DOE also proposed to reference the most current version of AHAM PAC-1 (AHAM PAC-1-2015) for cooling mode testing provisions where it had previously referenced AHAM PAC-1-2014 in the February 2015 Test Procedure NOPR, because DOE determined that these two versions are identical. 80 FR 74020.

After reviewing comments received in response to the November 2015 TP SNOPR, DOE published the June 2016 TP Final Rule, which established the portable AC test procedure located in appendix CC. 81 FR 35241 (June 1, 2016). The test procedures in appendix CC are consistent with the November 2015 TP SNOPR proposals, with revisions to: 1) adopt a lower value for the duct convection heat transfer coefficient; 2) slightly revise the proposed definitions of “single-duct portable air conditioner” and “dual-duct portable air conditioner” and withdraw the proposed definition for “spot cooler;” 3) require that any single-duct or dual-duct portable ACs that may be configured in both single-duct or dual-duct configurations must be tested in both configurations; and 4) incorporate clarifying edits to the duct installation instructions and duct surface area calculation.

DOE based its analysis for energy conservation standards in this final rule on seasonally adjusted cooling capacity (SACC) and CEER, as determined according to the appendix CC test procedure.

3.5 MANUFACTURER TRADE GROUPS

DOE recognizes the importance of trade groups in disseminating information and promoting the interests of the industry that they support. To gain insight into the portable AC industry, DOE researched various associations available to manufacturers, suppliers, and users of such equipment.

AHAM[a], formed in 1967, aims to enhance the value of the home appliance industry through leadership, public education and advocacy. AHAM provides services to its members including government relations; certification programs for a range of consumer products including, in part, room ACs, dehumidifiers, and room air cleaners; an active communications program; and technical services and research. In addition, AHAM conducts other market and consumer research studies. AHAM also develops and maintains technical standards for various appliances to provide uniform, repeatable procedures for measuring specific product characteristics and performance features.

3.6 MANUFACTURER INFORMATION

The following section details information regarding domestic manufacturers of portable ACs, including estimated market shares (section 3.6.1), industry mergers and acquisitions (section 3.6.2), potential small business impacts (section 3.6.3), and product distribution channels (section 3.6.4).

3.6.1 Manufacturers and Market Shares

The majority of single-duct and dual-duct portable ACs are manufactured overseas by three major manufacturers. These products are then imported to the United States and sold under a variety of brands belonging to both appliance manufacturers and importers. Additionally, some foreign original equipment manufacturers (OEM) engage in the direct sale of portable ACs into the U.S. market under their own brands.

DOE estimates that there are approximately 27 entities selling single-duct and dual-duct portable ACs in the United States. Table 3.6.1 lists these manufacturers and importers.

Table 3.6.1 Portable AC Original Equipment Manufacturers and Importers*

Bigwall Enterprises Inc.**
Danby**
DeLonghi America Inc.
Electrolux**
Friedrich**
GD Midea Air Conditioning Equipment Co. Ltd.

[a] For more information, please visit www.aham.org.

Grainger**
Gree Electric Appliances Inc., of Zhuhai
Haier America Trading LLC**
Hisense Kelon Electrical Holdings Co. Ltd.
Honeywell International Inc.**
LG Electronics Inc.**
Living Direct**
Luzerne Trading Company Inc.**
Motors and Armatures Inc.**
New Widetech Electric Co. Ltd.
NewAir**
Ningbo Bole Electric Appliance Co. Ltd.
Royal Sovereign International, Inc.**
Sealed Unit Parts Co (SUPCO)**
Sears Holding Corporation**
Sharp Electronics
Sunpentown International Inc.**
Whynter LLC**
Wilco-USA Inc. (Climax Air) **
Yoau Electrical Co.,Ltd
Zhejiang Aoli Electric Appliance Co. Ltd.

*These manufacturers and importers represent the entities DOE has identified that would be regulated under any energy conservation standards resulting from this rulemaking.
**These companies do not manufacture the products covered by this rulemaking; instead they source products from OEMs and rebrand them.

Using publicly available data and interview feedback, DOE estimates that the majority of portable ACs are manufactured overseas by three major OEMs. Of the entities responsible for the sale of portable ACs in the United States, DOE estimates that Haier America[b] and LG each comprise more than 20 percent of the portable AC market, while De'Longhi America[c] and Danby each hold approximately a 10 percent share of the market. Other players in the portable AC industry have 5 percent market share or less.

3.6.2 Mergers and Acquisitions

Recent merger and acquisition activities relating to the U.S. portable AC market include the joint venture formed between Chinese manufacturer Gree and U.S.-based SoleusAir in 2011, which led to the creation of Gree USA, headquartered in City of Industry, CA. Gree USA manufactures its own brands of heating, ventilation, and air conditioning (HVAC) products and OEM private labels, and sells directly to wholesalers. This collaboration has facilitated Gree's presence in the United States.[1] Also in 2011, LG Electronics acquired LS Mtron's Air-

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[b] A wholly-owned subsidiary of Haier Group (China).

[c] A subsidiary of De'Longhi S.p.A. (Italy).

Conditioning unit, and in November 2012, Corinthian Capital Group acquired Friedrich Air Conditioning Co. from U.S. Natural Resources Inc. According to one source, Texas-based Friedrich supported the sale so that it could "aggressively expand."[2]

In 2013, Motors and Armatures (d.b.a. MARS), a commercial and residential HVAC/refrigeration motors and components supplier acquired Heat Controller, Inc., a commercial and residential HVAC equipment (including portable ACs) supplier.[3] Also in 2013, Haier America became a wholly owned subsidiary of Haier Group, which, for Haier, "signifies a continued focus and commitment to serving [its] customers in the Americas."[4]

On June 6, 2016, Qingdao Haier Co., Ltd confirmed its acquisition of GE's appliance division from GE for $5.6 billion. Haier stated that "[i]investing and growing in the U.S. is a key part of Haier's strategy, and the acquisition of GE Appliances will help us accelerate that expansion." Haier Group, Qingdao Haier's parent company, claims to be the world's leading home appliance manufacturer, with global revenues exceeding $30 billion in 2015.[5]

On March 17, 2016, Toshiba Corporation (Toshiba) and Midea Group Co., Ltd. (Midea) announced that they had signed a Memorandum of Understanding on Toshiba's sale to Midea of a majority interest in its home appliance business, which would continue to develop, manufacture, and market white goods under the Toshiba brand name.[6]

3.6.3 Small Business Impacts

DOE considers the possible impact of energy conservation standards on small businesses. The products covered by this rulemaking are classified under the North American Industry Classification System (NAICS) code 333415: Air-Conditioning and Warm Air Heating Equipment and Commercial and Industrial Refrigeration Equipment Manufacturing. The U.S. Small Business Association (SBA) defines a small business as a company that has fewer than 1,250 employees for this NAICS code. The 1,250-employee threshold includes all employees in a business's parent company and any other subsidiaries.

Using this classification in conjunction with information from industry databases, the SBA member directory, and reports from vendors such as Dun & Bradstreet, DOE identified one entity involved in the design and distribution of portable ACs in the United States that qualifies as a small business. However, based on available information, DOE does not believe that this company is a manufacturer.

3.6.4 Distribution Channels

Understanding the distribution channels through which portable ACs are sold is an important facet of the market assessment because it helps to define the constraints or motivators manufacturers face from their customer base. DOE gathered information regarding the distribution channels for portable ACs from publicly available sources, as well as from interviews with manufacturers.

Because major OEMs of single-duct and dual-duct portable ACs are based overseas, the distribution channel for these products is often multi-tiered. In one arrangement, foreign OEMs sell their products to a sourcing company with a greater U.S. presence, which in turn sells the products directly to retailers or, to a lesser extent, distributors. Alternatively, OEMs sell their products under their own brands either to distributors or directly to retailers. In either arrangement, these retailers include large discount stores, home improvement stores, and department stores.

3.7 REGULATORY PROGRAMS

The following sections detail current or proposed regulatory initiatives for portable ACs.

3.7.1 California's Regulations

The California Energy Commission (CEC) regulates "spot air conditioners," which it defines as "an air conditioner that discharges cool air into a space and discharges rejected heat back into that space, where there is no physical boundary separating the discharges." The metric used for spot ACs is the cooling efficiency ratio (CER), obtained by dividing the sum of the cooling capacity and the fan electrical input in British thermal units per hour (Btu/h) by the electrical input power in watts, using ANSI/ASHRAE 128-2001.[d] California currently requires only reporting of CER, cooling capacity, input power, and fan input power in its product database, and does not have energy efficiency regulations for spot ACs.

3.7.2 Canada's Proposed Energy Conservation Standards

Canada's energy efficiency regulations proposed to establish energy conservation standards for portable ACs in 2009, based on a minimum energy efficiency that would be determined as a function of cooling capacity.[7] These proposed standards, based on testing according to CSA C370 "Cooling Performance of Portable Air Conditioners" (CSA C370)[e], which have not been adopted, were defined in terms of a minimum spot cooling efficiency (SCE, equivalent to EER) for air-cooled portable ACs with cooling capacities less than 36,000 Btu/h according to the following equation:

$$SCE = 7.76 + 0.0164 \times C/1000$$

where C is the cooling capacity in Btu/h.

[d] California Code of Regulations, Title 20, Division 2, Chapter 4, Article 4, Sections 1602(d) and 1604(d).

[e] CSA standards are available for purchase online at: http://shop.csa.ca/.

Natural Resources Canada (NRCan) estimated that at the time of the proposal, approximately 90 percent of portable ACs on the market in Canada would have met this minimum SCE requirement.

3.8 SHIPMENTS

On July 5, 2013, DOE published in the *Federal Register* a notice of proposed determination of coverage, in which it estimated that 973.7 thousand units were shipped in North America in 2012, with a projected growth to 1,743.7 thousand units by 2018, representing nearly 80-percent growth in 6 years.[8] 78 FR 40403. DOE maintained these estimates in the final determination of coverage published in the *Federal Register* on April 18, 2016. 81 FR 22514.

3.9 PRODUCT RETAIL PRICES

DOE used the CEC Appliance Efficiency Database[f] and web-based research to compile a database of portable AC products available in July 2014. DOE identified a total of 251 portable AC models that encompass 36 different brands. Of these, DOE was able to collect consumer retail price data for 118 single-duct units and 26 dual-duct units using the websites of five types of retailers: "big box" stores, discount department stores, wholesale clubs, manufacturer websites, and online appliance retailers (*e.g.*, AJ Madison).

Figure 3.9.1 and Figure 3.9.2 summarize the data collected by DOE. These figures generally suggest that retail price is positively related to capacity for both single-duct and dual-duct portable ACs. The consumer retail prices for single-duct portable ACs ranged from $150 to $998, with a model-weighted average of $446. Single-duct portable ACs are available with manufacturer-rated capacities ranging from 1,000 Btu/h to 14,000 Btu/h, with a model-weighted average capacity of 9,400 Btu/h.

[f] The California Energy Commission Appliance Efficiency Database reports data for "spot ACs": www.appliances.energy.ca.gov/AdvancedSearch.aspx

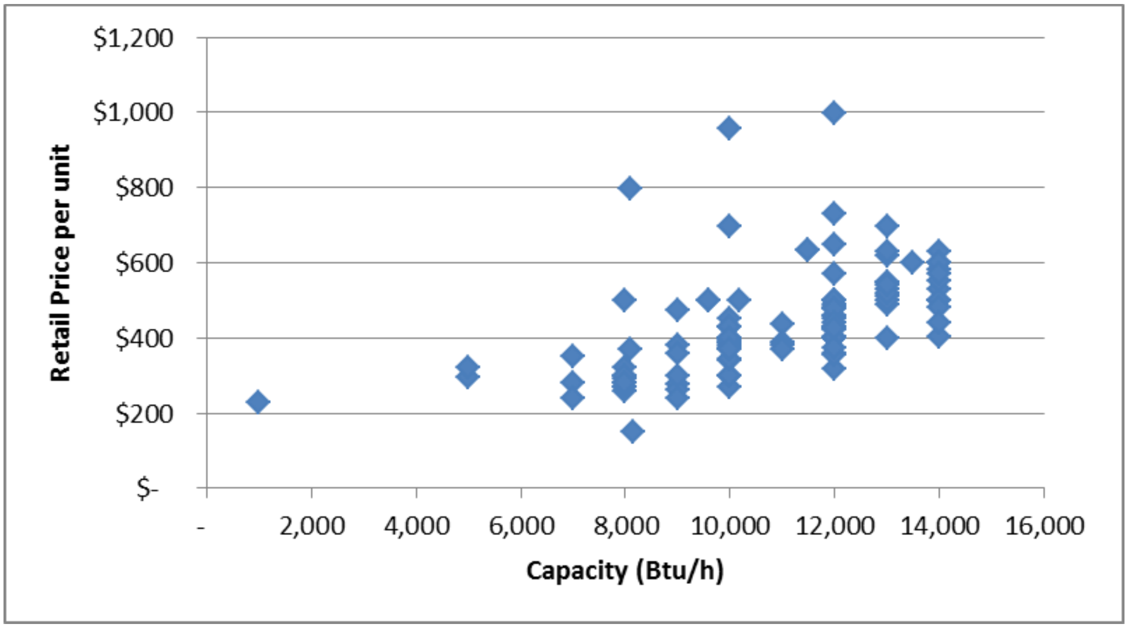

Figure 3.9.1 Retail Price versus Capacity for Single-Duct Portable ACs

The consumer retail prices for dual-duct portable ACs ranged from $351 to $799, with a model-weighted average of $497. Dual-duct units range in manufacturer-rated capacity from 9,000 Btu/h to 14,000 Btu/h, with a model-weighted average capacity of 11,500 Btu/h.

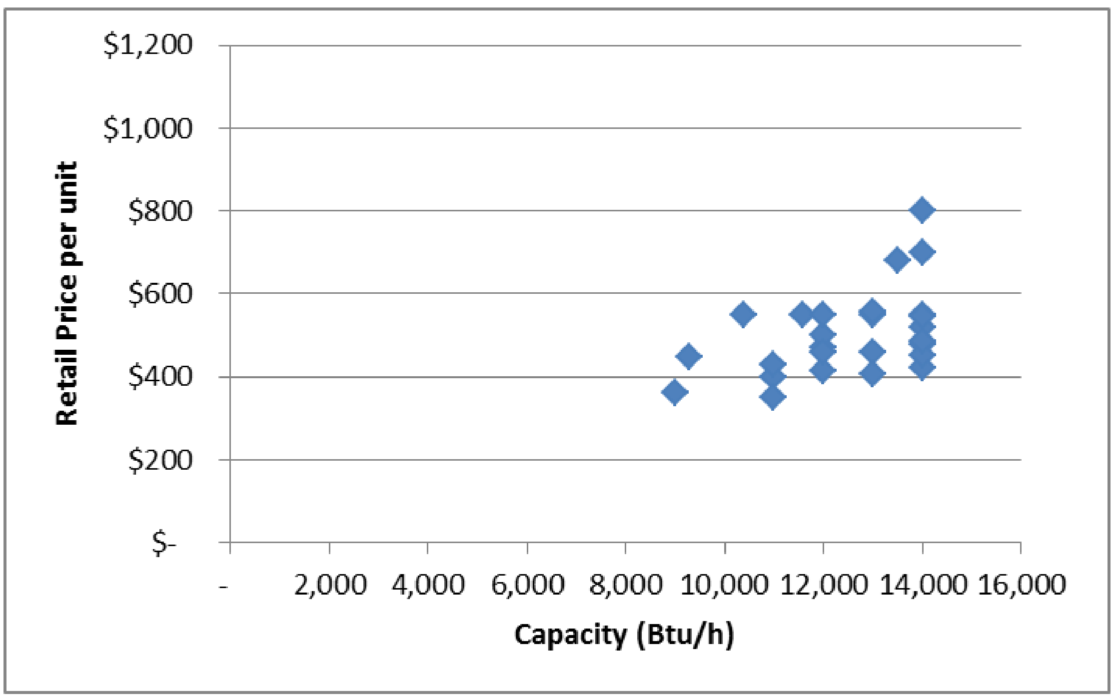

Figure 3.9.2 Retail Price versus Capacity for Dual-Duct Portable ACs

3.10 INDUSTRY COST STRUCTURE

DOE developed the cost structure for the industry classification associated with the portable AC industry from publicly available information from the U.S. Census Bureau's *Annual Survey of Manufactures* (*ASM*) and *Economic Census*, and the U.S. Securities and Exchange Commission (SEC) 10-K reports filed by publicly-owned manufacturers.

Table 3.10.1 presents the employments levels and payroll for NAICS code 333415 for air-conditioning and warm air heating equipment and commercial and industrial refrigeration equipment manufacturing. DOE converted the payroll data to constant 2015 dollars using the Producer Price Index (PPI) published by the U.S. Bureau of Economic Analysis.[g] Both employment and earnings for the industry decline between 2007 and 2009 with levels remaining largely flat through 2011, slightly increasing in 2012 and 2013, and slightly declining in 2014. The percent change in production and total industry employees tracks relatively closely with the percent change in payroll for all employees.

Table 3.10.1 Air-Conditioning and Warm Air Heating Equipment Manufacturing Industry Employment and Earnings[9]

Year	Production Workers	All Employees	Total Payroll (*2015 $ Mil*)
2014	61,725	84,706	$4,113
2013	64,615	88,828	$4,217
2012	63,292	86,110	$4,058
2011	61,696	84,327	$4,018
2010	61,304	83,597	$4,190
2009	60,322	86,005	$4,167
2008	70,622	96,636	$4,454
2007	74,728	101,485	$5,102
2006	74,909	102,354	$5,516
2005	76,011	98,097	$5,284

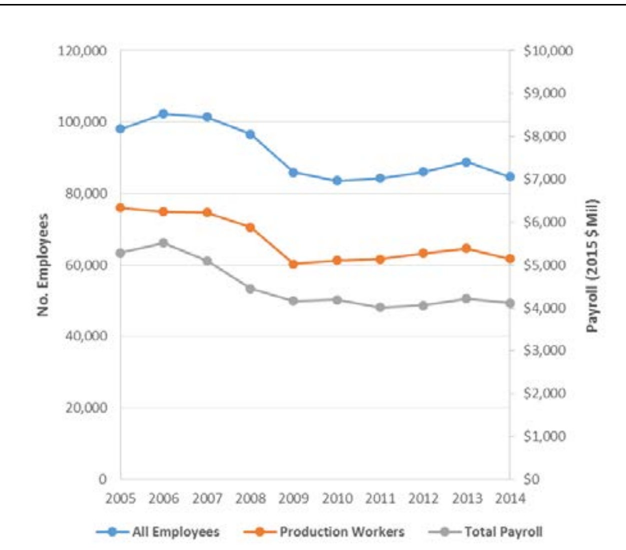

Table 3.10.2 shows the cost of materials and industry payroll as a percentage of value of shipments for the air-conditioning and warm air heating equipment and commercial and industrial refrigeration equipment manufacturing industry from 2005–2014. Material prices as a percentage of value of shipments have increased slightly over the first 7 years, with small fluctuations from year to year, with a slight decrease from 2011 to 2014. The cost of payroll for production workers as a percentage of value of shipments has decreased slightly since 2005. Finally, over the 10-year period, the cost of non-production payroll has remained relatively constant, with fluctuations from year to year.

[g] Available online at http://www.bls.gov/ppi/

Table 3.10.2 Air-Conditioning and Warm Air Heating Equipment Manufacturing Industry Materials and Wages Cost[10]

	Cost as a Percentage of Value of Shipments (%)		
Year	**Materials**	**Payroll for Production Workers**	**Payroll for All Other Employees**
2014	51.6%	7.7%	5.3%
2013	53.5%	7.6%	5.3%
2012	53.2%	7.6%	5.1%
2011	55.1%	7.5%	5.2%
2010	52.9%	7.8%	5.7%
2009	55.1%	7.9%	6.0%
2008	54.6%	8.1%	5.4%
2007	55.6%	8.2%	5.3%
2006	53.2%	8.9%	4.9%
2005	53.8%	8.5%	5.3%

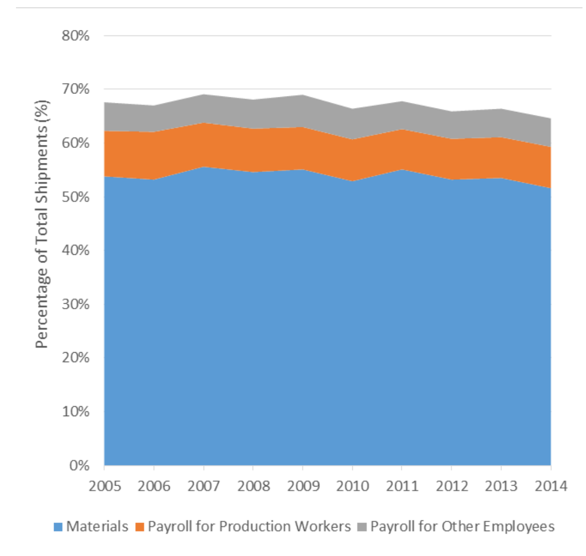

Table 3.10.3 presents the portable AC industry cost structure derived from SEC 10-K reports of publicly-owned manufacturers. DOE averaged the financial data from 2008–2014 of U.S.-based appliance manufacturers to obtain an industry average. Each financial statement entry is presented as a percentage of total revenues.

Table 3.10.3 Industry Cost Structure Using SEC Data[h], Average 2008–2014

Financial Statement Entry	**Percent of Revenues**
Cost of sales	72.8%
EBIT	6.8%
Selling, general and administrative	18.0%
Capital expenditure	2.5%
Research and development	1.7%
Depreciation	2.1%
Net plant, property and equipment	10.6%
Working capital	16.7%

A detailed financial analysis is presented in the MIA (chapter 12 of this final rule TSD). This analysis identifies key financial inputs including cost of capital, working capital, depreciation, capital expenditures, *etc*.

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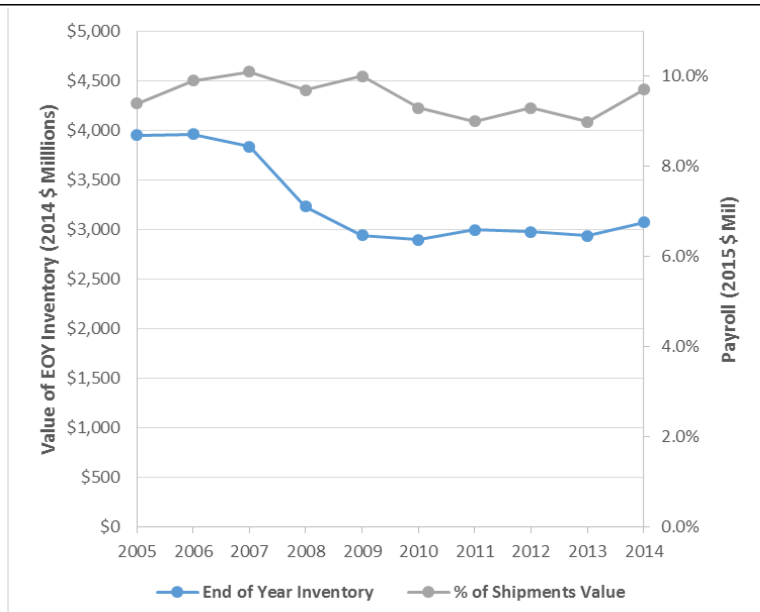
[h] SEC 10-K filings are available at: www.sec.gov/edgar/searchedgar/companysearch.html

3.11 INVENTORY LEVELS AND CAPACITY UTILIZATION RATES

Table 3.11.1 shows the year-end inventory for the air-conditioning and warm air heating industries, according to the *ASM*. The value of the end-of-year (EOY) inventories has significantly decreased compared to the period from 2005 to 2007. Since that time, the value of the EOY inventories has remained relatively constant, with variations from year to year. The EOY inventory as a percentage of shipments value has remained more constant over the 10-year period, with variations from year to year.

Table 3.11.1 Air-Conditioning and Warm Air Heating Equipment Manufacturing Industry Inventory Levels[11]

Year	**End-of-Year Inventory** (*2015 $ Mil*)	**EOY inventory as % of Shipments Value**
2014	$3,074	9.7%
2013	$2,936	9.0%
2012	$2,981	9.3%
2011	$3,000	9.0%
2010	$2,900	9.3%
2009	$2,942	10.0%
2008	$3,236	9.7%
2007	$3,840	10.1%
2006	$3,962	9.9%
2005	$3,954	9.4%



DOE obtained full production capacity utilization rates from the U.S. Census Bureau's *Survey of Plant Capacity* from 2004–2006. After 2006, the Census Bureau discontinued this survey and began a new *Quarterly Survey of Plant Capacity Utilization*. However, this survey does not collect utilization data beyond the 4-digit NAICS code for the ventilation, heating, air-conditioning, and commercial refrigeration equipment[i] industry. Table 3.11.2 presents utilization rates for this umbrella industry.

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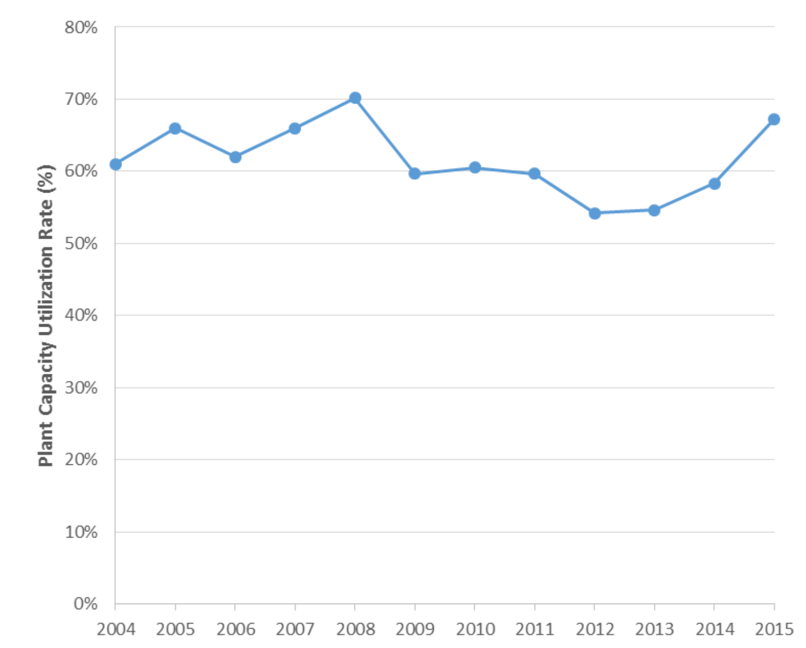
[i] "Ventilation, heating, air-conditioning, and commercial refrigeration equipment" is the umbrella NAICS category 3334 that includes NAICS code 333415 for "air-conditioning and warm air heating equipment and commercial and industrial refrigeration equipment."

Table 3.11.2 Full Production Capacity Utilization Rate for Ventilation, Heating, Air-Conditioning, and Commercial Refrigeration Equipment[12, 13]

Year	Plant Capacity Utilization Rate (%)
2015	67%
2014	58%
2013	55%
2012	54%
2011	60%
2010	61%
2009	60%
2008	70%
2007	66%
2006	62%
2005	66%
2004	61%



Full production capacity is defined as the maximum level of production an establishment could attain under normal operating conditions.[j] In the *Survey of Plant Capacity* reports, the full production utilization rate is a ratio of the actual level of operations to the full production capacity. The full production utilization rate for ventilation, heating, air-conditioning, and commercial refrigeration manufacturers reached a peak in 2008, at 70 percent, and hit a low of 54 percent in 2012. Following the low in 2012, utilization rates have since increased.

3.12 TECHNOLOGY ASSESSMENT

This section provides a technology assessment for portable ACs. Contained in this technology assessment are details about product characteristics and operation (section 3.12.1), an examination of possible technological improvements (section 3.12.2), and an overview of available efficiency information (section 3.12.3).

3.12.1 Portable AC Operations and Components

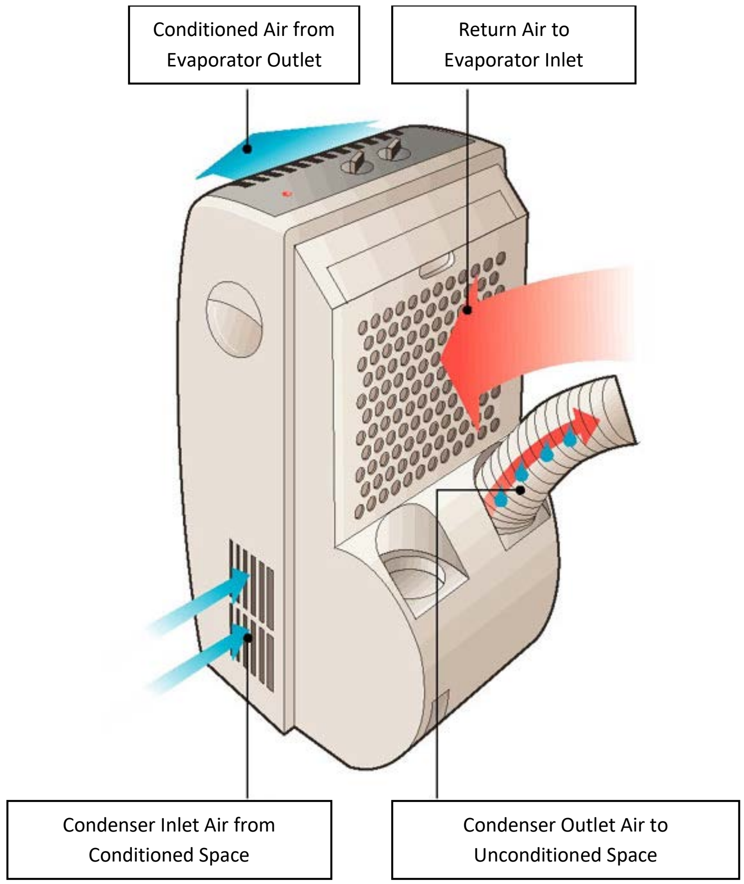
Single-duct and dual-duct portable ACs are self-contained, refrigeration-based products that provide cool air to a conditioned space and reject heat outside of the conditioned space. Similar to room ACs, these products remove both latent and sensible heat from the ambient air;

[j] See: www.census.gov/manufacturing/capacity/definitions/index.html

however, unlike room ACs, they are not permanently installed through a wall or in a window. Portable ACs are typically designed with wheels to allow for moving the units from room to room, weigh between 50 and 90 pounds, and are generally 28 to 36 inches tall.

Portable ACs operate with a similar refrigeration circuit as for room ACs or dehumidifiers, but with a different air flow pattern. Components of the refrigeration system include an evaporator, expansion valve or capillary tube, a condenser, and a compressor. Single-duct and dual-duct portable ACs typically operate as follows:

1. A circulating blower draws air from the conditioned space via an intake grille;
2. The air is pulled across an evaporator heat exchanger that is cooled by the electrically-powered vapor-compression refrigeration system;
3. The evaporator cools the air, and moisture from the air condenses on the evaporator and drips down across the hot condenser heat exchanger, where some or all of it evaporates and the excess is collected in a drip pan below the condenser;
4. The cooled, drier evaporator air is exhausted to the conditioned space;
5. At the same time, a blower draws air in a separate flow stream across the hot condenser heat exchanger;
    a. Single-duct units draw condenser inlet air from the conditioned space;
    b. Dual-duct units draw some or all of the condenser inlet air from outside the conditioned space through a duct, and may draw additional condenser inlet air directly from the conditioned space;
6. Certain units with an “auto evaporative” feature deliver any accumulated condensate back onto the condenser heat exchanger by means of a slinger wheel or pump to evaporate as much of it as possible; and
7. The warm, moist condenser outlet air containing evaporated condensate from the conditioned air stream is discharged outside the conditioned space via a duct.



Source: Adapted from kingersons.com[14]

Figure 3.12.1 Single-Duct Portable Air Conditioner Operation Schematic

The intake of condenser air from the conditioned space and its exhaust outside the conditioned space results in a net negative pressure in the conditioned space. In turn, this results in air infiltration to the conditioned space from other locations. Because all of their condenser air is drawn from the conditioned space, single-duct units typically create more net negative pressure within the conditioned space than dual-duct units, leading to more infiltration airflow from outside the conditioned space.

3.12.2 Portable AC Technology Options

DOE identified several possible technologies that manufacturers may use to improve the efficiency or performance of portable ACs. Many of these technology options were initially identified during the residential dehumidifier and room AC energy conservation standards rulemakings because of their similarities to portable ACs. The technology options for portable ACs are listed in Table 3.12.1 and described in greater detail later in this section.

Table 3.12.1 Technology Options for Portable ACs

Increased Heat-Transfer Surface Area
1. Increased frontal coil area
2. Increased depth of coil (add tube rows)
3. Increased fin density
4. Add subcooler to condenser coil
Increased Heat-Transfer Coefficients
5. Improved fin design
6. Improved tube design
7. Spray condensate onto condenser coil
8. Microchannel heat exchangers
Component Improvements
9. Improved compressor efficiency
10. Improved blower/fan efficiency
11. Low-standby-power electronic controls
12. Ducting insulation
13. Improved duct connections
14. Case insulation
Part-Load Technology Improvements
15. Variable-speed compressors
16. Thermostatic or electronic expansion valves
Alternative Refrigerants
17. Propane and R-32
Reduced Infiltration Air
18. Airflow Optimization

Increased Heat Transfer Surface Area

Improving the overall heat transfer surface area of the condenser and evaporator coils would result in improved efficiency of the refrigeration system. With a larger surface area, a coil can transfer the same amount of heat as a smaller coil while using a higher (in the case of an evaporator) or lower (in the case of a condenser) refrigerant temperature. This decreases the pressure difference between the two sides of the refrigerant cycle, lowering the necessary compressor power input.

Manufacturers have multiple options to increase the heat transfer surface area, including increasing cross-sectional area, heat exchanger depth, and fin density. While these heat exchanger changes all improve coil heat transfer, there are some additional tradeoffs. Operating the evaporator coil at a higher temperature in cooling mode may limit the unit’s ability to dehumidify the cool air stream, a significant component to increasing comfort in the conditioned space. Increasing cross-sectional area and heat exchanger depth will increase unit weight and possibly case size, thereby increasing the unit manufacturing and shipping cost and may reduce consumer portability. Increasing heat exchanger depth and fin density both require increasing blower capacity to offset the greater pressure drop for the airstream passing over the heat exchanger. Additionally, a greater fin density could result in more water retention in the evaporator, or accumulation of dust and dirt leading to decreased heat transfer over time.

Subcoolers are added between the condenser coil outlet and the capillary tube inlet and are either submerged near the condenser in the condensate produced by the evaporator or sent through a heat exchanger with the cooler refrigerant gas coming off of the evaporator. Adding a subcooler effectively increases the size of the condenser coil as it further cools the refrigerant coming out of the condenser. However, it may be difficult to incorporate subcoolers within the portable AC case, and they may have limited efficiency improvements.

Increased Heat-Transfer Coefficients

Manufacturers may make further improvements to the evaporator or condenser beyond increasing surface area to improve the heat transfer capability of the heat exchangers. Different fin designs, including louvered or slit-type fins, result in more turbulent air flow through the heat exchanger, increasing the air-side heat-transfer coefficient. Similar to increasing fin density, as described above, adjusting fin design may result in water retention in the evaporator or fouling due to dirt and dust collection. To improve refrigerant-side heat-transfer coefficients, manufacturers may incorporate refrigerant tubes with a grooved interior surface. This significantly increases the refrigerant-side heat-transfer coefficient compared to a typical smooth-surface refrigerant tube. Manufacturers may also improve the condenser heat-transfer coefficient by spraying or dripping condensate from the evaporator over the condenser. The condensate evaporating off of the warm condenser surface enhances the heat transfer compared to a condenser rejecting heat only to an air stream.

Microchannel heat exchangers may also increase heat transfer coefficients compared to typical tube-and-fin heat exchangers. Microchannel heat exchangers use many small rectangular channels with aluminum fins brazed between the rectangular tubes to increase heat transfer while reducing pressure drop compared to conventional coils. However, DOE is not aware of any portable ACs that incorporate microchannel heat exchangers, likely due to the much higher investment cost required for the equipment needed to fabricate these heat exchangers (*i.e.*, brazing ovens) as compared with equipment used for fabrication of conventional heat exchangers.

Research has compared the performance of a window-mounted room air conditioner with microchannel condensers to a baseline system with a conventional tube-and-fin condenser. The results showed the heat transfer rates per unit core volume of the microchannel heat exchangers were 14 to 331 percent higher than the conventional heat exchangers. However, the overall efficiencies of two systems using the microchannel condenser heat exchanger were 1 to 3-percent lower than the baseline system. The lower efficiencies attained by this work were believed to be due, in part, to the un-optimized condensate slinger ring and decreased subcooling of the microchannel systems. The results did show reductions in refrigerant charge, condenser core volume, and weight of 35, 55, and 35 percent, respectively, using microchannel condensers.[15]

More recent research performed in 2006 indicated that a microchannel condenser with the same area as a fin-and-tube configuration requires 49-percent less internal refrigerant flow volume and 10-percent lower refrigerant charge, and results in a 6 to 10-percent increase in the steady-state coefficient of performance (COP), defined as the cooling capacity divided by the power consumption. This COP increase is due to a decrease in the compressor power consumption rather than an increase in the cooling capacity. The research also indicated that a microchannel condenser system with the same frontal area as a traditional fin-and-tube configuration results in a greater than 7-percent increase in seasonal efficiency.[16]

Additional research performed in 2009 for mobile air conditioning indicated that microchannel heat exchangers provide volume benefits (17.2-percent and 15.1- percent volume reduction for evaporator and condenser, respectively) and weight benefits (2.8-percent and 14.9-percent weight reduction for evaporator and condenser, respectively) when compared with fin-and-tube heat exchangers. The overall cooling capacity and COP of the microchannel heat exchanger system were increased by about 5 percent and 8 percent, respectively, under ideal conditions.[17]

Improved Compressor Efficiency

Portable ACs typically use rotary R-410A compressors. Rotary R-410A compressors are available in a range of efficiencies, from an EER of 9 Btu per watt-hour (Btu/Wh) up to roughly 11.1 Btu/Wh, where EER represents the cooling capacity of the compressor divided by its power input.

"Inertia" compressors and scroll compressors have higher efficiencies than the traditional rotary compressors. However, manufacturer interviews and DOE's market research indicated that finding a suitable high-efficiency compressor at the capacities and price points needed for a portable AC is a challenge.

The inertia compressor is a technology that allows reciprocating compressors to approach an EER of 12.0 Btu/Wh. "Inertia" compressors utilize lightweight, responsive valve technology and an innovative refrigerant flow path to reduce losses and improve cylinder volumetric efficiency.

Scroll compressors require high precision to produce their internal components and are typically found in higher-efficiency central air-conditioning systems. Scroll compressors compress gas in a fundamentally different manner from traditional compressors – between two spirals, one fixed and one nutating. Scroll compression is inherently more efficient than traditional compression methods.

Both inertia and scroll compressors are, however, substantially larger, heavier, and sometimes noisier than their rotary counterparts, and, as such, are not well-suited for use in portable ACs.

Improved Blower/Fan Efficiency

The air-circulation system of a portable AC usually consists of permanent split capacitor (PSC) fan motors that drive the evaporator and condenser blowers.

Fans and blowers for portable ACs are generally molded plastic parts with fairly advanced geometries. The housings for the fans and heat exchangers are also molded plastic parts designed for each particular unit. Air system efficiency could possibly be improved through more advanced fan and blower design; however, this would likely be a relatively costly design option for a manufacturer in relation to the minimal efficiency benefit. The air system efficiency could also be improved by reducing restrictions to air flow; however, improving the efficiencies of the heat exchangers often corresponds to restricting air flow, as discussed in the sections addressing heat exchangers above.

Given the limited opportunity to improve air system efficiency, manufacturers would likely consider efficiency improvements to the fan motor only.

In a PSC motor, the start-up winding is electrically connected in parallel with the main winding and in series with a capacitor. At start-up, the interactions between the magnetic field generated by the start-up winding and that generated by the main winding induce rotation. As the capacitor charges, the current flowing through the start-up winding decreases and the start-up winding becomes an auxiliary winding after the motor reaches running speed. Consequently, the current to the start-up winding is cut off once the capacitor is fully charged and the motor reaches steady-state speed. Because of this, PSC motors are substantially more efficient than their shaded-pole counterparts, with motor efficiencies ranging from 60 to 65 percent. Like shaded-pole motors, PSC motors are produced in large quantities and are relatively inexpensive.[18]

Electric motors with even higher efficiencies can be implemented by switching to permanent-magnet motors, which come in many varieties. The most widely-known variety is the electronically-commutated motor (ECM), though DC motors can also be used. Permanent magnet motors are less noisy and substantially more efficient than either shaded-pole or PSC motors. ECM motors convert single-phase AC input power into three-phase power, and have motor efficiencies approaching 80 percent.[19] However, ECM motors can weigh twice as much as equivalent PSC motors, potentially necessitating a redesign of the portable AC chassis. In addition, ECM motors are complex, are not currently produced in large volumes, and can cost roughly twice as much as a PSC motor.[20]

Low-Standby-Power Electronic Controls

Electronic controls may consume power even when the portable AC is not performing its intended function. Depending on the implementation of the controller, standby power is required to enable the electronic controls to detect user input without the user first having to turn on a mechanical power switch or to enable displays, illuminate switches, *etc*. Reducing the standby power consumption of electronic controls will reduce the annual energy consumption of the portable AC, but will not impact the energy consumption of the unit during operation in cooling mode.

Ducting Insulation

The portable AC test procedure in appendix CC accounts for any heat lost to the conditioned space from the duct(s). Under the most stringent test conditions specified in appendix CC for cooling mode, DOE testing demonstrated that the condenser exhaust duct carries air that is on average 40 degrees Fahrenheit (°F) warmer than the 80 °F temperature of the indoor side test chamber. Accordingly, the warm exhaust duct transfers heat to the conditioned space. For dual-duct units, the condenser inlet duct also has a net heating effect, although not as significant because it carries air that is cooler than the condenser exhaust duct. Manufacturers may choose to insulate ducts to minimize heat lost to the conditioned space. However, DOE notes that it is not aware of any portable ACs that utilize insulated ducting. DOE observed that manufacturers use accordion-style plastic ducts that ship in a compacted state, and thus insulation opportunities would be limited.

Improved Duct Connections

DOE is aware that the duct connections at the window mounting bracket or portable AC are often not well sealed. Air leaking through these duct connections may be up to 40 °F warmer than the ambient temperature, and may leak from the condenser exhaust stream to the conditioned space. DOE, therefore, acknowledges the overall cooling performance benefit of tightly-sealed duct connections. However, DOE did not observe any units in the test sample that provided additional sealing in the duct connections. DOE also did not observe any significant gaps in any of the duct connections (either at the portable AC or the window mounting bracket) for units in its test sample. DOE lacks detailed information regarding the heat impacts of air leakage at the duct connections.

Case Insulation

Portable AC product cases house internal components that may operate at high temperatures, such as the compressor, which may result in locally high case surface temperatures and heat transferred to the conditioned space. Manufacturers could potentially limit this heat loss using insulated cases. Although DOE is aware that certain portable ACs incorporate insulation to seal the air flow between the heat exchanger compartments, DOE is not aware of any portable ACs that use additional insulation on the external product case to limit heat transfer to the room. Therefore, DOE does not have information regarding the performance and reliability effects of restricting the heat rejection from the internal components.

Variable-Speed Compressors

Variable-speed compressors are typically implemented through the use of an electronic control that varies the input frequency of the power supply for the compressor motor. Variable-speed compressors enable modulation of the refrigeration-system cooling power beyond simple on/off control, allowing the portable AC to better match the compressor power to the load, increasing compression efficiency. DOE expects that a variable-speed compressor in a portable AC could provide more precise control of the evaporator coil temperature to ensure more efficient heat removal, especially at low temperatures where ice buildup may occur. Additionally, DOE is aware that variable speed compressors available in the capacity range appropriate for portable ACs are able to achieve higher efficiencies than the typically used single-speed compressors, reaching nominal efficiencies of up to 13.7 Btu/Wh, thereby providing efficiency gains even when operating continuously at a single speed.

In addition to a higher single-speed operating efficiency, the greatest benefit of variable-speed systems is to save energy under varying operating conditions. The DOE test procedure in appendix CC includes two cooling mode tests with different outdoor conditions that are held constant throughout the test. DOE is not aware of units that currently utilize variable-speed compressors, so it was unable to test any units to quantify the efficiency improvements associated with variable-speed compressors when tested according to the DOE test procedure under part-load test conditions. However, DOE notes that in central air conditioning systems, research shows that variable-speed compressors may produce energy savings from 15 to 40 percent.[21, 22, 23]

Thermostatic or Electronic Expansion Valves

Nearly all portable ACs use capillary-tubes for flow control. The capillary tube is a pressure-reducing device that consists of a small-diameter line that connects the outlet of the condenser to the inlet of the evaporator. It is designed to provide optimum energy efficiency at one design point. If sized properly, the capillary-tube expansion valve compensates automatically for load and system variations and gives acceptable performance over a wide range of operating conditions. Because ambient temperature and humidity vary, however, portable ACs sometimes operate under conditions outside of the target conditions, leading to reduced efficiency.

The thermostatic expansion valve (TXV) — a flow-control alternative to the capillary tube — is commonly used in higher-efficiency central air-conditioning systems. TXVs regulate the flow of liquid refrigerant entering the evaporator in response to the superheat of the refrigerant leaving it. TXVs can adapt better to changes in operating conditions such as those due to variations in ambient temperature, which affect the condensing temperature. As a result, TXVs can lead to a somewhat increased seasonal operating efficiency.

Electronic expansion valves (EEVs) are similar to TXVs, but unlike TXVs, they can be actively controlled. While a TXV relies on a single temperature sensor for feedback, digital controllers can use multiple sensors for feedback control and respond using multiple approaches. For example, besides modulating the refrigerant flow, the controller may also vary the fan speed to optimize efficiency under varying conditions. As with TXVs, EEVs can use the superheat control method to regulate refrigerant flow. Other methods, such as controlling compressor discharge temperature, can also be used.

During the reverse-engineering analysis, DOE did not observe any units with either TXVs or EEVs. Given the cost of TXVs and EEVs, it is unlikely that manufacturers would implement them in portable ACs.

Alternative Refrigerants

DOE found that most of the portable ACs in its test sample and in the U.S. market use R-410A refrigerant as the refrigeration system working fluid. A Significant New Alternatives Policy (SNAP) final rule, published by the U.S. Environmental Protection Agency (EPA) on April 10, 2015, approved the use of propane (R-290) and R-32 for portable ACs. 80 FR 19453. DOE received comments in response to the February 2015 Preliminary Analysis that these refrigerants would result in capacity and efficiency improvements compared to the refrigerants commonly in use.

DOE observed that propane refrigerant is used for certain portable ACs manufactured and sold internationally, and that R-32 is being introduced in some markets outside the United States for portable and room ACs, primarily because it is has a low Global Warming Potential (GWP). Based on this product availability and discussions with manufacturers, DOE agrees that propane, R-32, and possibly other alternative refrigerants could improve portable AC efficiencies.

One manufacturer claims to have achieved a 10-percent portable AC efficiency improvement using propane. According to the manufacturer, refrigerant costs would decrease due to a lower required charge volume, and heat exchanger costs would decrease by over 25 percent due to reduced heat exchanger size. Further, the manufacturer claims that although the cost of the necessary electronic components would increase, the net cost of the unit would still be lower than a comparable R-410A model.[24]

An Emerson Climate Technology Report from 2012 noted that R-32 has a lower refrigerant cost, higher latent heat and thermal conductivity, and 8 percent higher critical temperature (*i.e.*, better performance at higher ambient conditions) when compared to R-410A, though requires a complete system redesign to take advantage of the lower refrigerant density and system refrigerant charge. That study found that switching to R-32 from R-410A resulted in a theoretical increased cooling capacity of 3 to 14 percent and -1 to 5 percent increase in EER. It further found that for a 3 ton heat pump, substituting R-32 in an existing R-410A system resulted in a 2.6 to 3.3 percent increase in cooling capacity (at outdoor test conditions of 82 °F and 95 °F, respectively) while decreasing EER by about 1.5 percent at both test conditions.[25] Another Emerson Climate Technology report from 2014 found that switching from R-410A to R-32 increased the capacity of chillers by 5 to 6 percent, while having a negligible impact on EER and increasing SEER by 2 to 3 percent.[26]

A 2015 Oak Ridge National Laboratory (ORNL) study based on mini-split AC testing with R-32 refrigerant in place of R-410A using the existing refrigeration system found consistently better performance, though the study noted that the compressor discharge temperature was significantly higher than for the R-410A system, which may impact compressor reliability. The ORNL study found that capacity and efficiency improved by 2 and 1 percent at an outdoor condition of 82 °F, respectively, and capacity and efficiency improved by 5 and 4 percent at an outdoor temperature of 95 °F, respectively.[27]

Reduced Infiltration Air

In developing the portable AC test procedure codified in appendix CC, DOE determined that air flow configuration and infiltration air may impact capacity and efficiency. DOE believes that optimizing airflow and subsequently reducing infiltration air may improve portable AC efficiencies, and therefore has included reduced infiltration air by way of optimizing airflow as a technology option in the technology assessment.

3.12.3 Energy Efficiency

In preparation for the screening and engineering analyses, DOE gathered data on the energy efficiency of portable ACs currently available in the marketplace. These data are taken from the CEC appliance efficiency database, which as discussed previously in section 3.7.1 comprise "spot air conditioners." While this section is not intended to provide a complete characterization of the energy efficiency of all portable ACs currently available and in use, it does provide a general overview of the energy efficiency of these products as measured by an existing industry test method. Figure 3.12.2 and Figure 3.12.3 display a scatter plot of the energy efficiency data and a distribution of the capacities, respectively, of "spot air conditioners" listed in the CEC product database as of September 8, 2016.

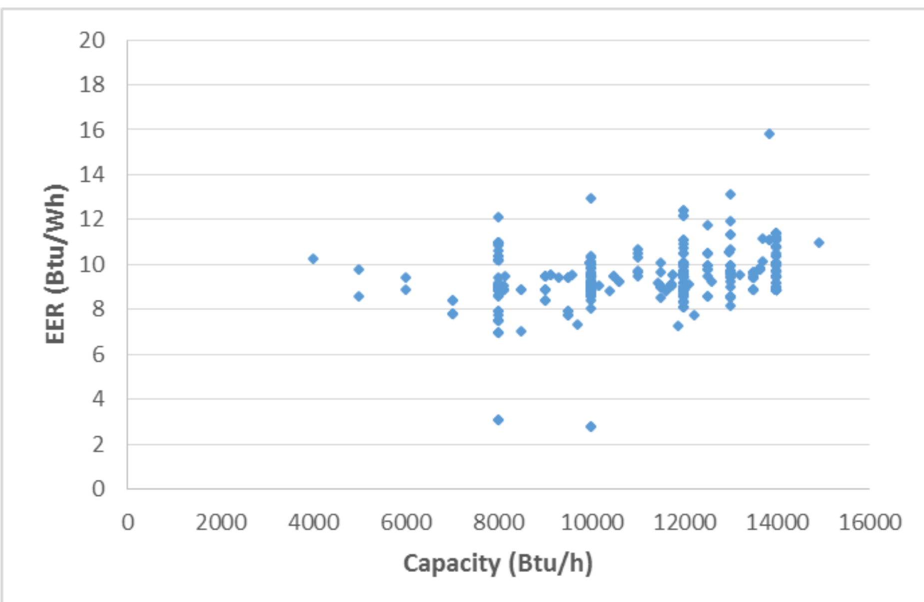


Figure 3.12.2 CEC Energy Efficiency and Capacity Data

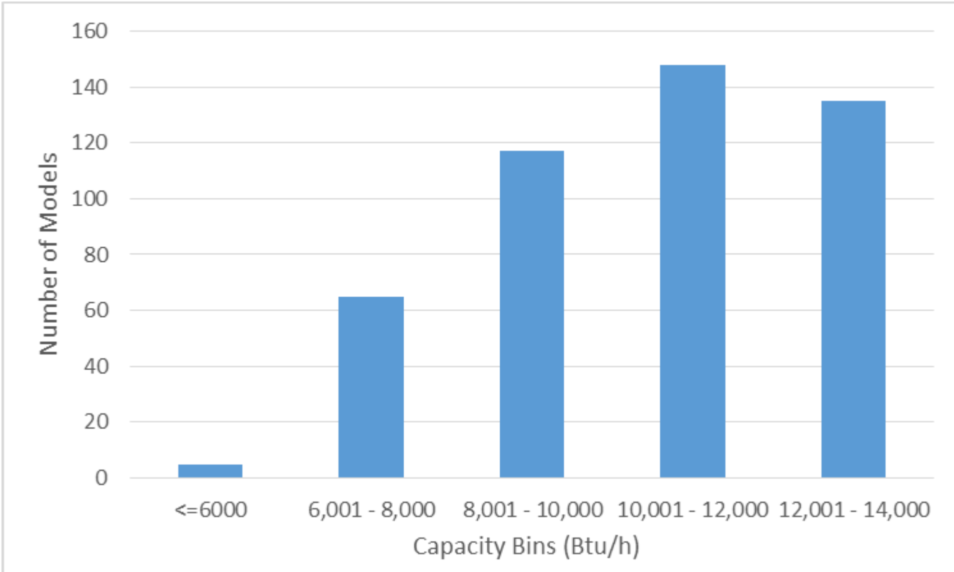


Figure 3.12.3 Distribution of the Capacities of Units in the CEC Database

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CHAPTER 4. SCREENING ANALYSIS

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CHAPTER 4. SCREENING ANALYSIS

4.1 INTRODUCTION

This chapter discusses the screening analysis conducted by the U.S. Department of Energy (DOE) of the technology options identified in the market and technology assessment for portable air conditioners (ACs) (chapter 3 of this final rule technical support document (TSD)). In the market and technology assessment, DOE presented an initial list of technologies that can be used to reduce energy consumption for portable ACs. The goal of the screening analysis is to identify any technology options that will be eliminated from further consideration in the rulemaking analyses.

The candidate technology options are assessed based on DOE's analysis as well as inputs from interested parties including manufacturers, trade organizations, and energy efficiency advocates. Technology options that are judged to be viable approaches for improving energy efficiency are retained as inputs to the subsequent engineering analysis. Technology options that are not incorporated in commercial products or in working prototypes, or that fail to meet certain criteria as to practicability to manufacture, install and service, as to impacts on product utility or availability, or as to health or safety will be eliminated from consideration in accordance with *Energy Conservation Program for Consumer Products: Procedures for Consideration of New or Revised Energy Conservation Standards for Consumer Products*. (61 FR 36974, section 4(a)(4) and 5(b)). The rationale for either screening out or retaining each technology option is detailed in the following sections.

4.2 DISCUSSION OF TECHNOLOGY OPTIONS

For portable ACs, the screening criteria specified in section 4.2.1 were applied to the technology options to either retain or eliminate each technology from the engineering analysis.

4.2.1 Screened-Out Technology Options

The technologies identified in the market and technology assessment were evaluated pursuant to the criteria set out in the Energy Policy and Conservation Act, as amended (EPCA or the Act). (42 U.S.C. 6291–6309) EPCA provides criteria for prescribing new or amended standards, which will achieve the maximum improvement in energy efficiency the Secretary of Energy determines is technologically feasible. (42 U.S.C. 6295(o)(2)(A)) It also establishes guidelines for determining whether a standard is economically justified. (42 U.S.C. 6295(o)(2)(B)) In view of the EPCA requirements for determining whether a standard is technologically feasible and economically justified, appendix A to subpart C of Title 10 Code of Federal Regulations part 430 (10 CFR part 430), *Procedures, Interpretations and Policies for Consideration of New or Revised Energy Conservation Standards for Consumer Products* (the

“Process Rule”), sets forth procedures to guide DOE in the consideration and promulgation of new or revised product efficiency standards under EPCA. These procedures elaborate on the statutory criteria provided in 42 U.S.C. 6295 and in part eliminate problematic technologies early in the process of revising an energy efficiency standard. Under the guidelines, DOE eliminates from consideration technologies that present unacceptable problems with respect to the following four factors:

(1) Technological feasibility. If it is determined that a technology has not been incorporated in commercial products or in working prototypes, then that technology will not be considered further.

(2) Practicability to manufacture, install, and service. If it is determined that mass production of a technology in commercial products and reliable installation and servicing of the technology could not be achieved on the scale necessary to serve the relevant market at the time of the effective date of the standard, then that technology will not be considered further.

(3) Impacts on product utility to consumers. If a technology is determined to have significant adverse impact on the utility of the product to significant subgroups of consumers, or results in the unavailability of any covered product type with performance characteristics (including reliability), features, size, capacities, and volumes that are substantially the same as products generally available in the United States at the time, it will not be considered further.

(4) Safety of technologies. If it is determined that a technology will have significant adverse impacts on health or safety, it will not be considered further.

The following sections detail the technology options that were screened out for this rulemaking, and the reasons why they were eliminated.

Ducting Insulation

In the market and technology assessment, chapter 3 of this final rule TSD, DOE identified duct insulation as a potential means for improving portable AC efficiency. Heat lost from ducts to the conditioned space offsets a significant amount of cooling capacity provided by the portable AC. If manufacturers insulate the product ducting, more heat will be exhausted outside of the conditioned space rather than transferred to the conditioned space through the duct walls.

During interviews, manufacturers indicated that they have considered insulated ducts to improve performance but have not identified any insulated ducts that are collapsible for packaging and shipping. No portable ACs in DOE’s teardown sample for the engineering analysis included insulated ducts. DOE is not aware of collapsible insulated ducts in any commercially available products or working prototypes. In the absence of a collapsible design, such an insulated duct would need to be packaged for shipment in its fully expanded configuration, significantly increasing the package size. Because of this significantly increased packaging size for non-collapsible insulated ducts and unavailability on the market of collapsible designs, DOE determined that insulated ducts are not technologically feasible, are impractical to manufacture and install, and would impact consumer utility. Therefore, DOE has screened out insulated ducting as a design option for portable ACs.

Alternative Refrigerants

The Significant New Alternatives Policy (SNAP) final rule, published by the Environmental Protection Agency (EPA) on April 10, 2015, limits the maximum allowable charge of alternative refrigerants in portable ACs to 300 grams for R-290 (propane), 2.45 kilograms for R-32, and 330 grams for R-441A. (Apr. 10, 2015) 80 FR 19453. The SNAP rule limits were consistent with those included for portable ACs in Underwriters Laboratories (UL) Standard 484, "Standard for Room Air Conditioners" (UL 484), eighth edition. However, the most recent version of UL 484, the ninth edition, reduces the allowable amount of flammable refrigerant (*e.g.*, propane and R-441A) to less than 40 percent of the SNAP limits. Manufacturers informed DOE that the new UL propane charge limits for portable ACs are not feasible for providing the necessary minimum cooling capacity, and therefore it would not be feasible to manufacture a portable AC with propane refrigerant for the U.S. market while complying with the UL safety standard. DOE reviewed propane refrigerant charges for portable ACs available internationally and found a typical charge of 300 grams. Therefore, DOE screened out propane as a design option for portable ACs as they are not practicable to manufacture at this time while meeting all relevant safety standards.

DOE is aware that certain room ACs are commercially available on the U.S. market that utilize the mildly flammable R-32, and is aware of no portable ACs available on the U.S. market and few available portable ACs in other markets that incorporate R-32. However, unlike propane and other flammable refrigerants, the UL 484 charge limit for R-32 is about 1 kilogram, which is well above the amount necessary for typical portable AC cooling, and would therefore be a viable option to improve efficiency. One commenter noted that there may be other safety concerns with having a high-pressure R-32-based refrigeration system inside of the home, though DOE has not found further information indicating there are safety issues with R-32.

For this final rule, DOE therefore screened out propane as a design option for portable ACs as it is not practicable to manufacture a portable AC with propane refrigerant at this time while meeting all relevant safety standards. However, because R-32 is a viable refrigerant based on the UL safety requirements and because the information provided by interested parties and described in various studies consistently indicate performance improvements through the use of this refrigerant, in this final rule DOE maintained R-32 as a potential design option for improving portable AC efficiency.

4.2.2 Retained Design Options

Table 4.2.1 lists the design options for portable ACs that were retained by DOE. After publishing a notice of proposed rulemaking in the *Federal* Register on June 13, 2016 (81 FR 38398), in which DOE discussed the screening of design options, DOE received feedback that it should screen out certain of these design options that were not considered further in the engineering analysis. However, DOE only screens out technology options based on the four screening criteria. Each of these technologies will be evaluated further in the subsequent engineering analysis. Chapter 5 of this final rule TSD includes discussion of these retained design options and DOE's basis for whether it incorporated each of them in the cost-efficiency relationship developed in the engineering analysis.

Table 4.2.1 Retained Design Options for Portable ACs

Increased Heat-Transfer Surface Area
1. Increased frontal coil area
2. Increased depth of coil (add tube rows)
3. Increased fin density
4. Add subcooler to condenser coil
Increased Heat-Transfer Coefficients
5. Improved fin design
6. Improved tube design
7. Spray condensate onto condenser coil
8. Microchannel heat exchangers
Component Improvements
9. Improved compressor efficiency
10. Improved blower/fan efficiency
11. Low-standby-power electronic controls
12. Improved duct connections
13. Case insulation
Part-Load Technology Improvements
14. Variable-speed compressors
15. Thermostatic or electronic expansion valves
Reduced Infiltration Air
16. Airflow Optimization
Alternative Refrigerants
17. R-32

CHAPTER 5. ENGINEERING ANALYSIS

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CHAPTER 5. ENGINEERING ANALYSIS

5.1 INTRODUCTION

After conducting the screening analysis, the U.S. Department of Energy (DOE) performed an engineering analysis based on the remaining design options. The engineering analysis consists of estimating the energy consumption and costs of portable air conditioners (ACs) at various levels of increased efficiency. This section provides an overview of the engineering analysis (section 5.1), discusses product classes (section 5.2), establishes baseline and incremental efficiency levels (section 5.3), explains the methodology used during data gathering (section 5.4), and discusses the analysis and results (section 5.5).

The primary inputs to the engineering analysis are baseline information from the market and technology assessment (chapter 3 of this final rule technical support document (TSD)) and technology options from the screening analysis (chapter 4). Additional inputs were determined through teardown analysis and manufacturer interviews. The primary output of the engineering analysis is a cost-efficiency curve. In the subsequent markups analysis (chapter 6), DOE determined customer (*i.e.*, product purchaser) prices by applying distribution markups, sales tax and contractor markups. After applying these markups, the cost-efficiency curve serves as the input to the building energy-use and end-use load characterization (chapter 7), and the life-cycle cost (LCC) and payback period (PBP) analyses (chapter 8).

DOE typically structures its engineering analysis around one of three methodologies. These are: (1) the design-option approach, which calculates the incremental costs of adding specific design options to a baseline model; (2) the efficiency-level approach, which calculates the relative costs of achieving increases in energy efficiency levels, without regard to the particular design options used to achieve such increases; and/or (3) the reverse-engineering or cost-assessment approach, which involves a "bottom-up" manufacturing cost assessment based on a detailed bill of materials (BOM) derived from teardowns of the product or equipment being analyzed. Deciding which methodology to use for the engineering analysis depends on the covered product, the design options under study, and any historical data that DOE can draw on.

In the preliminary analysis announced in a notice of public meeting published in the *Federal Register* on February 27, 2015 (February 2015 Preliminary Analysis, 80 FR 10628), DOE used a hybrid approach of the design-option and reverse-engineering approaches. This approach involved physically disassembling commercially available products, reviewing publicly available cost information, and modeling equipment cost. From this information, DOE estimated the manufacturer production costs (MPCs) for a range of products available on the market. DOE then considered the steps manufacturers would likely take to improve product efficiencies. In its analysis, DOE determined that manufacturers would likely rely on certain design options to reach higher efficiencies. From that information, DOE estimated the cost and efficiency impacts of incorporating specific design options at each efficiency level.

In the notice of proposed rulemaking (NOPR) published on June 13, 2016 (June 2016 NOPR), DOE followed the same general approach as for the February 2015 Preliminary Analysis, but modified the analysis based on comments from interested parties and to reflect the most current available information, including the portable AC test procedure that DOE established at 10 CFR part 430, subpart B, appendix CC (appendix CC). 81 FR 38397.

For this final rule engineering analysis, DOE followed the same general approach as for the June 2016 NOPR and the February 2015 Preliminary Analysis, but modified the analysis to include new test data provided by interested parties, updates related to fan operation during off-cycle mode for some of DOE's test units, and other adjustments, including updating the MPCs to reflect the latest dollar year available at the time of this final rule analysis. This TSD chapter further describes the process DOE followed to establish its cost-efficiency relationship for portable ACs.

5.2 PRODUCT CLASSES ANALYZED

Because portable ACs were not previously covered by the Energy Policy and Conservation Act (ECPA) of 1975, Pub. L. 94-163 (42 United States Code (U.S.C.) 6291–6309), there are no existing product classes for these products. DOE may divide covered products into product classes by the type of energy used or by capacity or other performance-related features that affect efficiency. Different energy conservation standards may apply to different product classes. (42 U.S.C. 6295(q))

DOE considered two product characteristics for potentially establishing multiple portable AC product classes: duct configuration and capacity. As discussed in chapter 3 of this final rule TSD, DOE only conducted this final rule analysis on single-duct and dual-duct portable ACs because it did not observe a correlation between duct configuration (*i.e.*, the presence of a condenser inlet air duct from the unconditioned space) and portable AC efficiency. Additionally, DOE is not aware of any unique consumer utility associated with duct configuration. DOE determined that duct configuration, therefore, does not require separate product classes.

Portable AC efficiencies also typically increase for products with higher capacities. From its test and modeled data, as well as test data submitted by interested parties, DOE observed a consistent trend relating efficiency to capacity across the range of analyzed capacities. DOE relied on this trend to determine appropriate efficiencies for its analysis instead of separating portable ACs into different product classes by capacity. Therefore, for this final rule analysis, DOE analyzed and subsequently establishes a single portable AC product class.

5.3 EFFICIENCY LEVELS

DOE developed representative efficiency levels using a combination of test and modeled portable AC performance data. Each efficiency level represents efficiency as a function of cooling capacity relative to a nominal efficiency based on DOE's test sample.

5.3.1 Baseline Efficiency Levels

Typically, a baseline unit is a unit that just meets current energy conservation standards and provides basic consumer utility. Because there are no existing energy conservation standards for portable ACs, DOE analyzed the performance of its test units and observed whether units tested with lower efficiencies incorporated similar design options or features. DOE considered the range of data collected during testing when defining baseline performance.

As discussed further in section 5.5.2, based on testing conducted in support of DOE's recent test procedure rulemaking[a] and as discussed in the preliminary TSD, DOE observed that the air flow pattern through a portable AC has a significant effect on measured cooling capacity and efficiency when tested according to the test procedure proposed in the DOE test procedure proposed on February 25, 2015 (February 2015 Test Procedure NOPR, 80 FR 10211).

In the February 2015 Preliminary Analysis, DOE considered the energy efficiency ratio in cooling mode (EER_{cm}) in accordance with the test procedure proposed at the time in the February 2015 Test Procedure NOPR. For the June 2016 NOPR analysis, DOE updated the analyses and efficiency levels to reflect the DOE test procedure for portable ACs in appendix CC, which was modified from the test procedure proposal that was the basis of the February 2015 Preliminary Analysis. Appendix CC includes a second cooling mode outdoor test condition for dual-duct units and infiltration air condition for both single-duct and dual-duct units, modifying the combined energy efficiency ratio (CEER) metric for both single-duct and dual-duct units to address performance at the two cooling mode test conditions. Other changes to the initially proposed test procedure that were adopted in appendix CC that affected the June 2016 NOPR analysis include the elimination of provisions for measuring case heat transfer and heating mode performance. Similar to the June 2016 NOPR analysis, DOE based this final rule analysis on the test procedures in appendix CC.

As discussed in the February 2015 Preliminary Analysis, DOE used EER_{cm} as the basis for analyzing potential energy conservation standards instead of CEER because cooling is the primary function for portable ACs, and DOE expected that manufacturers would likely focus on improving efficiency in this mode to achieve higher CEERs. Because appendix CC does not include a heating mode test and includes a second cooling mode test condition, the CEER metric as codified combines the performance at both cooling mode test conditions with energy use in the low-power modes. Accordingly, DOE utilized CEER as the basis for the proposed portable

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[a] Further information on the recent test procedure rulemaking is available at: http://www1.eere.energy.gov/buildings/appliance_standards/product.aspx/productid/79.

AC energy conservation standards in the June 2016 NOPR, and the energy conservation standards established in this final rule. DOE also based the June 2016 NOPR and this final rule analysis on the seasonally adjusted cooling capacity (SACC) measured in appendix CC, a weighted combination of the cooling capacities at the two cooling mode test conditions.

For units that draw air from the conditioned space over the condenser and then exhaust it outside of the conditioned space, an equivalent amount of infiltration air must enter the conditioned space due to the net negative pressure differential that is created between the conditioned and unconditioned spaces. Because the outdoor test conditions proposed at the time of the February 2015 Preliminary Analysis were significantly higher (a difference of 15 °F) than the indoor air, the infiltration air offset a portion or all of the cooling capacity for each tested portable AC. DOE found that the greater the amount of infiltration air, the lower the cooling capacity would be. Based on the measured condenser exhaust air flow rates and the corresponding calculated magnitudes of the infiltration air heating effect, DOE concluded in the February 2015 Preliminary Analysis, that single-duct units (*i.e.*, units that draw all of the condenser intake air from within the conditioned space and exhaust to the unconditioned space via a duct) would represent the baseline efficiency level for portable ACs.

After the February 2015 Preliminary Analysis, DOE established the portable AC test procedure in appendix CC, which incorporates two cooling mode test conditions and weighting factors to determine overall performance. Because the additional test condition is at a lower outdoor temperature and has a significantly larger weighting factor than the original test condition, the impact of infiltration air on overall performance is greatly reduced. Therefore, the approach of considering a baseline unit to be a single-duct portable AC with typical system components was no longer valid for the June 2016 NOPR.

For the June 2016 NOPR, DOE instead conducted an alternate analysis in which it analyzed the performance of all test units in its test sample to develop a relationship between SACC and CEER that provides nominal portable AC performance. Because CEER is a function of both cooling mode power and SACC, DOE isolated the power component of CEER to develop a relationship for CEER in terms of SACC alone. DOE plotted the average power during the cooling mode rating test period, in Watts, and SACC, in British thermal units per hour (Btu/h), for each test unit and fit a power curve (the best-fit trend) to the data to represent cooling mode power as a function of SACC, shown in Figure 5.3.1.1.

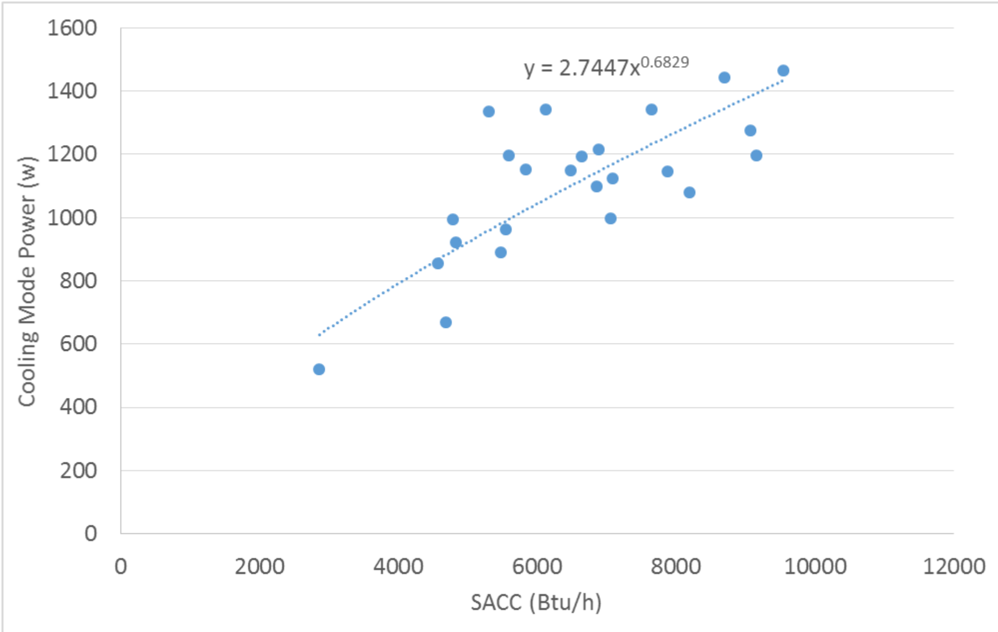

Figure 5.3.1.1 Test Unit Performance – Cooling Mode Power and SACC – June 2016 NOPR

DOE then used this relationship to develop an equation to determine the expected or nominal CEER for a given SACC based on DOE's test results according to the test procedure in appendix CC, shown below.

$$Nominal\ CEER = \frac{SACC}{(2.7447 \times SACC^{0.6829})}$$

DOE then assessed the relative efficiency of each unit in the test sample by comparing the measured CEER from testing to the nominal CEER as defined by the equation above (DOE will refer to this ratio of actual CEER to nominal CEER as performance ratio (PR) for a given unit). As discussed above, DOE found that efficiency typically increased with capacity, so this approach allowed for performance comparison among all units regardless of capacity.

Based on the minimum PR observed for units in the test sample, DOE defined the June 2016 NOPR baseline performance as a PR of 0.72. To determine if a unit meets the baseline efficiency level, the baseline CEER for a particular unit is calculated by multiplying the nominal CEER by a PR of 0.72, as shown below.

$$NOPR\ Baseline\ CEER = 0.72 \times \frac{SACC}{(2.7447 \times SACC^{0.6829})}$$

Following publication of the June 2016 NOPR, the Association of Home Appliance Manufacturers (AHAM) compiled and provided DOE with additional test data from its members for 22 portable ACs. DOE included those data provided by AHAM in conducting this final rule engineering analysis and also reassessed its own test data and performance modeling. DOE corrected minor errors in its test data and more accurately represented the modeled performance of dual-duct units operating at the lower 83 °F test condition.

In the June 2016 NOPR analysis, the CEER for each test sample, and resulting PRs, were representative of units that cycled the indoor fan off during off-cycle mode, or within the first 5 minutes of off-cycle mode, thereby equating off-cycle and inactive mode power consumption for purposes of the test procedure in appendix CC. However, following additional investigation of typical portable AC cycling, DOE determined that some portable ACs on the market continuously operate the fan during off-cycle mode and, therefore, considered the power draw associated with fan operation as the power draw in off-cycle mode for those units.

The new and updated test data resulted in a new relationship between cooling mode power and SACC that slightly differed from that developed in the June 2016 NOPR, shown in Figure 5.3.1.2.

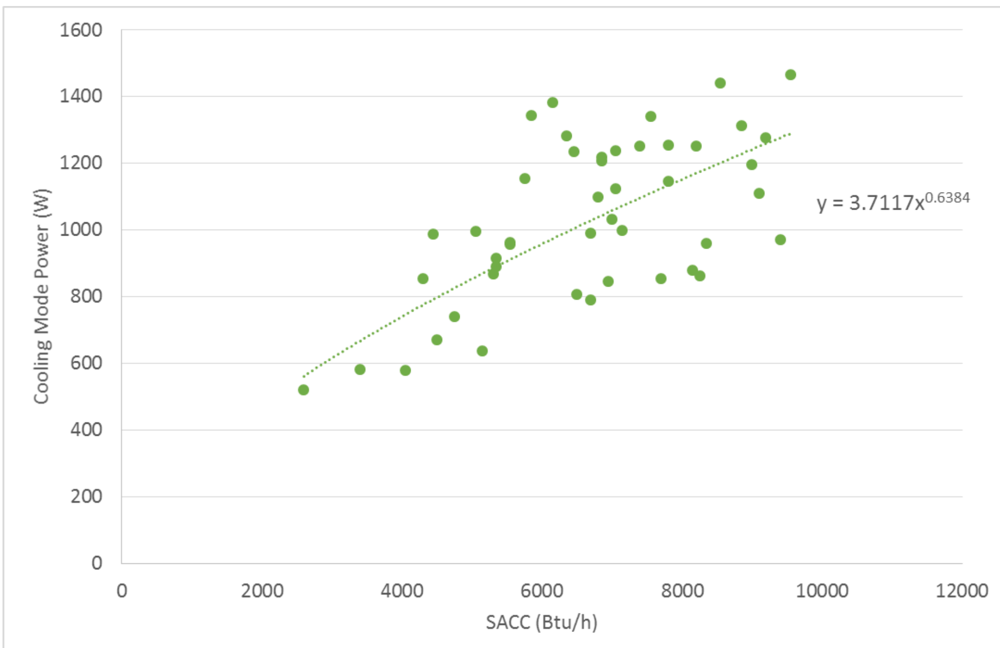

Figure 5.3.1.2 Test Unit Performance – Cooling Mode Power and SACC – Final Rule

DOE then used this relationship between cooling mode power and SACC to develop an equation to determine the expected or nominal CEER for a given SACC, shown below.

$$Nominal\ CEER = \frac{SACC}{(3.7117 \times SACC^{0.6384})}$$

For this final rule, DOE reassessed the relative efficiency of the units in the combined data sample by comparing the measured CEER to the nominal CEER as defined by the equation above. As with the June 2016 NOPR results, DOE found that efficiency typically increased with capacity.

The relative efficiency for each of DOE's test units and the AHAM-provided test data are shown below in Table 5.3.1.2.

Table 5.3.1.1 Test Unit Performance Ratio – Final Rule

DOE Test Units		AHAM-Provided Data	
Test Unit	**Performance Ratio**	**Test Unit**	**Performance Ratio**
SD1	0.96	A	0.90
SD2	1.07	B	1.04
SD3	0.93	C	0.84
SD4	0.86	D	0.87
SD5	1.26	E	0.89
SD6	1.01	F	1.06
SD7	0.90	G	0.93
SD8	0.72	H	0.78
SD9	0.92	J	0.97
SD10	1.17	K	0.80
SD11	0.84	L	1.07
SD12	1.03	M	0.83
SD13	1.15	N	0.78
SD14	1.08	O	0.87
SD15	1.03	P	0.88
SD16	0.94	Q	0.75
SD17	N/A[1]	R	0.75
SD18	0.76	S	0.92
DD1	1.25	T	0.94
DD2	0.93	U	0.87
DD3	0.88	W	0.96
DD4	0.77	Z	0.88
DD5	0.97		
DD6	0.93		
DD7	0.96		

[1]SD17 was excluded from the analysis due to an incomplete data set.

Based on the minimum PR observed for units in the test sample, DOE defined the final rule baseline performance as a PR of 0.67. To determine if a unit meets the baseline efficiency level, the baseline CEER for a particular unit is calculated by multiplying the nominal CEER by a PR of 0.67, as shown below.

$$Baseline\ CEER = 0.67 \times \frac{SACC}{(3.7117 \times SACC^{0.6384})}$$

Although the final rule baseline PR value is lower than the value of 0.72 presented in the June 2016 NOPR, applying the new value to the updated nominal CEER curve results in a baseline efficiency level curve for this final rule that closely matches the baseline efficiency level analyzed in the June 2016 NOPR. The similarity in baseline efficiency levels is shown below in Figure 5.3.1.3.

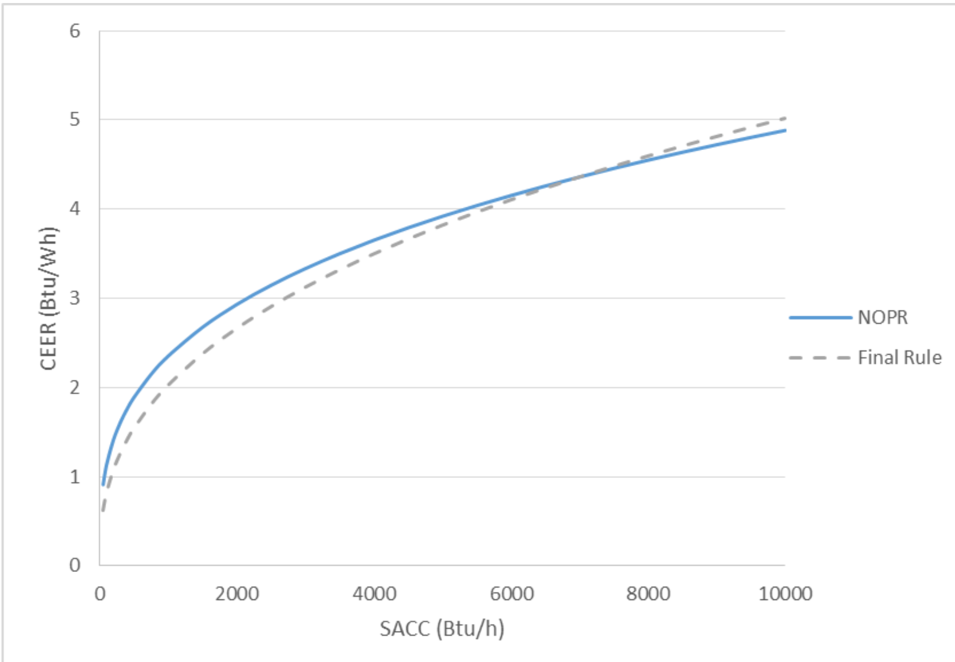

Figure 5.3.1.3 Baseline Efficiency Levels – NOPR and Final Rule

5.3.2 Incremental Efficiency Levels

For the February 2015 Preliminary Analysis, DOE developed incremental efficiency levels based on the design options manufacturers would likely use to improve portable AC efficiency. The proposed test procedure at that time led DOE to conclude that the presence of infiltration air had a large impact on unit performance, and therefore, DOE expected that when improving efficiencies beyond the baseline, manufacturers would first make improvements to incrementally reduce the amount of infiltration air.

In the June 2016 NOPR analysis, DOE modified its efficiency level approach, moving from an airflow optimization approach to a component efficiency improvement approach. DOE utilized its test sample to determine three additional efficiency levels beyond the baseline and one additional level representing the maximum technology available. The baseline efficiency level was based on the minimum observed PR; Efficiency Level 3 (EL 3) reflected the single highest PR observed in its test sample; Efficiency Level 2 (EL 2) corresponded to the maximum available efficiency across a full range of capacities; and Efficiency Level 1 (EL 1) was an intermediate level selected between the baseline and EL 2. Efficiency Level 4 (EL 4, the "max-tech" level) was developed as a theoretical level based on modeling the most efficient available components for each test unit, discussed further in section 5.5.4.

For this final rule, DOE reassessed the baseline efficiency level, as discussed above, to include the AHAM-provided test data and additional updates to the test data from DOE's test sample. DOE then considered three incremental efficiency levels beyond the baseline based on the larger test sample performance, and one additional level representing the maximum technology available. The incremental efficiency levels were based on the same criteria used in the June 2016 NOPR analysis. The baseline efficiency level corresponds with the minimum observed PR; EL1 is an intermediate efficiency level between the baseline and EL2; EL2 corresponds with the maximum available efficiency across a full range of capacities; EL3 corresponds with the single highest PR observed in the combined test sample; and EL4 is the max-tech modeled level.

Section 5.5.5 provides additional detail describing the basis and application of the efficiency levels.

5.4 METHODOLOGY OVERVIEW

DOE relied on multiple sources of information for this engineering analysis. These sources include manufacturer interviews, internal product testing, and product teardowns.

5.4.1 Manufacturer Interviews

DOE understands that there is variability among manufacturers in product offerings, design strategies, and cost structures. To better understand and explain these variances, DOE conducted manufacturer interviews as part of this analysis. These confidential interviews provided a deeper understanding of the various combinations of technologies used to increase portable AC efficiency, and their associated manufacturing costs. DOE conducted interviews prior to the preliminary analysis stage of this rulemaking, and conducted an additional round of interviews in advance of the June 2016 NOPR analysis. This allowed DOE an opportunity to receive confidential manufacturer feedback in response to the February 2015 Preliminary Analysis. Sample questions from the NOPR analysis interviews are contained in appendix 12A of this final rule TSD.

During the interviews, DOE also gathered information about the capital expenditures required to increase the efficiency of the baseline units to various efficiency levels (*i.e.*, capital conversion expenditures by efficiency or energy-use level). The interviews provided information about the size and the nature of the capital investments. DOE also requested information about the depreciation method used to expense the conversion capital. The manufacturer impact analysis in chapter 12 of this final rule TSD includes a discussion of this information obtained during manufacturer interviews.

5.4.2 Product Testing

Although manufacturers did not have an opportunity to submit performance data according to the DOE test procedure prior to the June 2016 NOPR analysis due to the test procedure's recent publication, following the June 2016 NOPR publication, AHAM provided DOE with test results for 22 portable ACs according to the test procedures in appendix CC. DOE utilized these data in conducting this final rule engineering analysis. There was little other publicly available data on portable AC performance, and where data is publically available, the test basis is unknown or not directly applicable to this analysis (*e.g.*, the California Energy Commission requires reporting of spot cooler performance based on American National Standards Institute (ANSI)/American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) Standard 128-2001 "Method of Rating Unitary Spot Air Conditioners" (ANSI/ASHRAE 128-2001); however, more recent industry standards, including ANSI/AHAM PAC-1-2015 "Portable Air Conditioners"[b] (AHAM PAC-1-2015), Canadian Standards Association (CSA) C370-2013 "Cooling Performance of Portable Air Conditioners" (CSA 370-13)[c], and the 2011 updated version of ANSI/ASHRAE Standard 128, ANSI/ASHRAE Standard 128-2011 "Method of Rating Unitary Spot Air Conditioners" (ANSI/ASHRAE Standard 128-2011) all require a substantially lower indoor ambient testing temperature).

To address this general lack of portable AC performance data, DOE conducted its own investigative testing in preparing the February 2015 Preliminary Analysis and utilized those data for the June 2016 NOPR and this final rule. As discussed in the February 2015 Test Procedure NOPR, DOE conducted testing according to an air enthalpy method (similar to current industry test methods) and a calorimeter method (similar to the method used for room ACs). Specifically, DOE conducted the testing to:

- Investigate and determine the most representative test methodology for portable ACs;
- Establish efficiency trends for products over a range of capacities;
- Develop a better understanding of the design options and product features currently available on the market; and
- Develop a better understanding of the operational characteristics of portable ACs.

5.4.3 Product Teardowns

Other than obtaining detailed manufacturing costs directly from a manufacturer, the most accurate method for determining the production cost of a product is to disassemble representative units piece-by-piece and estimate the material, labor, and overhead costs associated with each

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[b] ANSI/AHAM test procedures are available for purchase online at: www.aham.org.

[c] CSA standards are available for purchase online at: http://shop.csa.ca/.

component using a process commonly called a physical teardown. DOE performed physical teardown analysis on portable ACs from a range of manufacturers. The teardown methodology is explained in the following sections.

5.4.3.1 Selection of Units

DOE generally adopts the following criteria for selecting units for teardown analysis:

- The selected products should span the full range of efficiency levels for each product class under consideration;
- Within each product class, the selected products should, if possible, come from the same manufacturer and belong to the same product platform;
- The selected products should, if possible, come from manufacturers with large market shares in that product class, although the highest efficiency products are chosen irrespective of manufacturer; and
- The selected products should have non-efficiency-related features that are the same as, or similar to, features of other products in the same class and at the same efficiency level.

5.4.3.2 Generation of Bill of Materials

The end result of each teardown is a structured BOM, which describes each product part and its relationship to the other parts, in the estimated order of assembly. The BOMs describe each fabrication and assembly operation in detail, including the type of value—added equipment needed (*e.g.*, stamping presses, injection molding machines, spot-welders, *etc.*) and the estimated cycle times associated with each conversion step. The result is a thorough and explicit model of the production process.

Materials in the BOM are divided between raw materials that require conversion steps to be made ready for assembly, while purchased parts are typically delivered ready for installation. The classification into raw materials or purchased parts is based on DOE's previous industry experience, recent information in trade publications, and discussions with original equipment manufacturers (OEMs). For purchased parts, the purchase price is based on volume-variable price quotations and detailed discussions with suppliers.

For parts fabricated in-house, the prices of the underlying "raw" metals (*e.g.*, tube, sheet metal) are estimated on the basis of 5-year averages to smooth out spikes in demand. Other "raw" materials such as plastic resins, insulation materials, *etc.* are estimated on a current-market basis. The costs of raw materials are based on manufacturer interviews, quotes from suppliers, secondary research, and by subscriptions to publications including the American Metals Market[d] (AMM). Past price quotes are indexed using applicable Bureau of Labor Statistics producer price index tables as well as AMM monthly data.

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[d] For information on American Metals Market, please visit: www.amm.com.

5.4.3.3 Cost Structure of the Spreadsheet Models

The manufacturing cost assessment methodology used is a detailed, component-focused technique for rigorously calculating the manufacturing cost of a product (direct materials, direct labor and some overhead costs). Figure 5.4.3.1 shows the three major steps in generating the manufacturing cost.

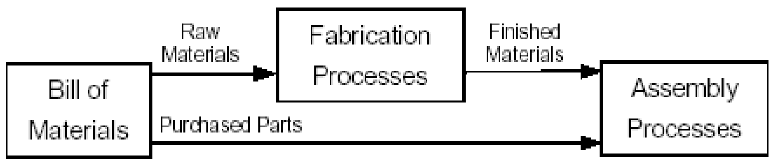

Figure 5.4.3.1 Manufacturing Cost Assessment Stages

The first step in the manufacturing cost assessment was the creation of a complete and structured BOM from the disassembly of the units selected for teardown. The units were dismantled, and each part was characterized according to weight, manufacturing processes used, dimensions, material, and quantity. The BOM incorporates all materials, components, and fasteners with estimates of raw material costs and purchased part costs. Assumptions on the sourcing of parts and in-house fabrication were based on industry experience, information in trade publications, and discussions with manufacturers. Interviews and plant visits were conducted with manufacturers to ensure accuracy on methodology and pricing.

Following the development of a detailed BOM, the major manufacturing processes were identified and developed for the spreadsheet model. Some of these processes are listed in Table 5.4.3.1.

Table 5.4.3.1 Major Manufacturing Processes

Fabrication	Finishing	Assembly/Joining	Quality Control
Fixturing Stamping/Pressing Brake Forming Cutting and Shearing Insulating Turret Punch Tube Forming Enameling	Washing Powder Coating De-burring Polishing Refrigerant Charging	Adhesive Bonding Spot Welding Seam Welding Packaging	Inspecting & Testing

Fabrication process cycle times for each part made in-house were estimated and entered into the BOM. Based on estimated assembly and fabrication time requirements, the labor content of each appliance could be estimated. For this analysis, DOE estimated labor costs based on typical annual wages and benefits of industry employees.

Cycle requirements for fabrication steps were similarly aggregated by fabrication machine type while accounting for dedicated vs. non-dedicated machinery and/or change-over times (die swaps in a press, for example). Once the cost estimate for each teardown unit was finalized, a detailed summary was prepared for relevant components, subassemblies and processes. The BOM thus details all aspects of unit costs: material, labor, and overhead.

Design options used in units subject to teardown are noted in the summary sheet of each cost model and are cost-estimated individually. Thus, various implementations of design options can be accommodated, ranging from assemblies that are entirely purchased to units that are made entirely from raw materials. Hybrid assemblies, consisting of purchased parts and parts made on site are thus also accommodated.

5.4.3.4 Cost Model and Definitions

The cost model is based on production activities and divides factory costs into the following categories:

- Materials: Purchased parts (*i.e.*, motors, valves, *etc*.), raw materials, (*i.e.*, cold rolled steel, copper tube, *etc*.), and indirect materials that are used for processing and fabrication.
- Labor: Fabrication, assembly, indirect, and supervisor labor. Fabrication and assembly labor cost are burdened with benefits and supervisory costs.
- Overhead: Equipment, tooling, and building depreciation, as well as utilities, equipment and tooling maintenance, insurance, and property taxes.

Cost Definitions

Because there are many different accounting systems and methods to monitor costs, DOE defined the above terms as follows:

- Direct material: Purchased parts (out-sourced) plus manufactured parts (made in-house from raw materials).
- Indirect material: Material used during manufacturing (*e.g.*, welding rods, adhesives).
- Fabrication labor: Labor associated with in-house piece manufacturing.
- Assembly labor: Labor associated with final assembly.
- Supervisory labor: Labor associated with fabrication and assembly basis. Assigned on a span basis (x number of employees per supervisor) that depends on the industry.
- Indirect labor: Labor costs that scale with fabrication and assembly labor. These included the cost of technicians, manufacturing engineering support, stocking, *etc*. that are proportional to all other labor.
- Equipment depreciation: Money allocated to pay for initial equipment installation and replacement as the production equipment is amortized. All depreciation is assigned in a linear fashion and affected equipment life depends on the type of equipment.

- Tooling depreciation: Cost for initial tooling (including non-recurring engineering and debugging of the tools) and tooling replacement as it wears out or is rendered obsolete.
- Building depreciation: Money allocated to pay for the building space and the conveyors that feed and/or make up the assembly line.
- Utilities: Electricity, gas, telephones, *etc.*
- Maintenance: Annual money spent on maintaining tooling and equipment.
- Insurance: Appropriated as a function of unit cost.
- Property Tax: Appropriated as a function of unit cost.

5.4.3.5 Cost Model Assumptions

As discussed in the previous section, assumptions about manufacturer practices and cost structure played an important role in estimating the final product cost. In converting physical information about the product into cost information, DOE reconstructed manufacturing processes for each component using internal expertise and knowledge of the methods used by the industry. Site visits allowed DOE to confirm its cost model assumptions through direct observation of the manufacturing plant, as well as through manufacturer interviews, reviews of current Bureau of Labor Statistics data, *etc*.

5.5 ANALYSIS AND RESULTS

5.5.1 Manufacturer Interviews

DOE conducted interviews with portable AC manufacturers to develop a better understanding of current product features and the technologies used to improve energy efficiency. The manufacturers interviewed represent a wide range of U.S. market share and included both domestic and international companies that sell portable ACs in the United States. During these interviews, DOE asked manufacturers questions about the following topics related to the engineering analysis:

- Product classes and mix of product offerings
- Design features of current baseline products
- Proposed incremental efficiency levels
- Design options required to meet each efficiency level
- Performance at reduced ambient temperatures
- Impacts on consumer utility

The discussion helped DOE understand what design options have already been implemented and what additional design options DOE should consider. Discussion representing a consolidation of the manufacturer responses provided during confidential interviews for this rulemaking, can be found in chapter 5 of the preliminary analysis TSD and NOPR TSD.

5.5.2 Product Testing

Prior to the February 2015 Preliminary Analysis, DOE conducted investigative testing on portable ACs in support of determining the appropriate methodology for the DOE portable AC test procedure, codified in appendix CC. DOE utilized the results of this investigative testing to support the preliminary engineering analysis and to determine efficiency levels and the design changes necessary to achieve those levels.

The test data used in support of the February 2015 Preliminary Analysis remained applicable for the NOPR analysis with relevant numerical adjustments to align with the DOE test procedure in appendix CC, namely the additional cooling mode test condition. Those same data were also applicable for this final rule, with updates as described in section 5.3.1. The following sections detail the testing process, from product selection through data analysis.

5.5.2.1 Product Selection

DOE's test sample included 24 portable ACs. DOE selected units covering a range of manufacturer-rated cooling capacities (5,000 to 14,000 Btu/h) and energy efficiency ratios (EERs, 7.0 to 12.0 Btu/Wh) from a range of manufacturers. Because DOE does not currently regulate portable ACs, the rated capacities and EERs do not necessarily reflect performance under the DOE test procedure in appendix CC; however, they provided a basis for DOE to differentiate between units available on the market. DOE's test sample also covered the two major product configurations: 17 single-duct units and 7 dual-duct units. DOE notes that one of the dual-duct units shipped with a conversion kit to enable testing in single-duct configuration. DOE tested this unit in both single-duct and dual-duct configurations.

5.5.2.2 Test Approach and Results

DOE first performed testing in accordance with AHAM PAC-1-2009[e] to determine baseline performance according to industry standards. This baseline performance was then used to evaluate the suitability of the current industry standards through comparisons with modified or alternate test approaches.

As discussed and presented in a notice of data availability (NODA) published on May 9, 2014 (May 2014 NODA), DOE further investigated heat transfer effects not currently captured in available portable AC test procedures through additional testing according to a room calorimeter approach adapted from ANSI/ASHRAE Standard 16-1983 (RA 99), "Method of Testing for Rating Room Air Conditioners and Packaged Terminal Air Conditioners" (ANSI/ASHRAE Standard 16-1983). DOE conducted that testing on a representative sample of four single-duct and two dual-duct units. DOE also conducted similar calorimeter testing on an additional 18 test

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[e] AHAM PAC-1-2009 was the applicable AHAM portable AC test standard at the time that the testing was conducted.

units not covered by the May 2014 NODA in preparation for the February 2015 Preliminary Analysis. The calorimeter testing used two test chambers, one maintained at the indoor conditions, 80 degrees Fahrenheit (°F) dry-bulb temperature and 67 °F wet-bulb temperature, and the other maintained at the outdoor conditions, 95 °F dry-bulb temperature and 75 °F wet-bulb temperature, specified in AHAM PAC-1-2009. Rather than installing the test unit in the wall between the indoor and outdoor test rooms, as for a room AC, the portable AC under test was located within the indoor test room with the condenser duct(s) interfacing with the outdoor test room by means of the manufacturer-supplied or manufacturer-recommended mounting fixture.

DOE then considered a modified test approach that followed the procedure outlined in AHAM PAC-1-2009, but included calculations to account for any heat transfer due to infiltration air. DOE found that infiltration air heat input caused a significant reduction in cooling capacity and efficiency when compared with the results from the nominal AHAM PAC-1-2009 test procedure.

In the February 2015 Test Procedure NOPR, DOE concluded that the AHAM PAC-1 test approach should be the basis of a DOE test procedure for portable ACs to ensure representative test results, minimize additional test burden, and align with current industry practices. Therefore, DOE proposed referencing the newly-released version of the PAC-1 standard, AHAM PAC-1-2014[f] with additional provisions and clarifications to determine representative performance. Figure 5.5.2.1 presents the measured cooling capacity and EER_{cm} of its test sample consistent with the approach proposed in the February 2015 Test Procedure NOPR. The inclusion of infiltration air heating results in a significant reduction in net cooling compared to manufacturer-rated values.

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[f] As noted in the February 2015 Test Procedure NOPR, DOE's testing and analysis in support of the test procedure rulemaking was completed prior to the publication of AHAM PAC-1-2014. After careful examination, DOE concluded that the differences between the 2009 and 2014 versions of the test standard would not significantly affect testing results, and, therefore, DOE proposed a test procedure that would reference certain provisions of the then-current version of the standard (AHAM PAC-1-2014). AHAM PAC-1-2015 contains identical testing provisions as AHAM PAC-1-2014.

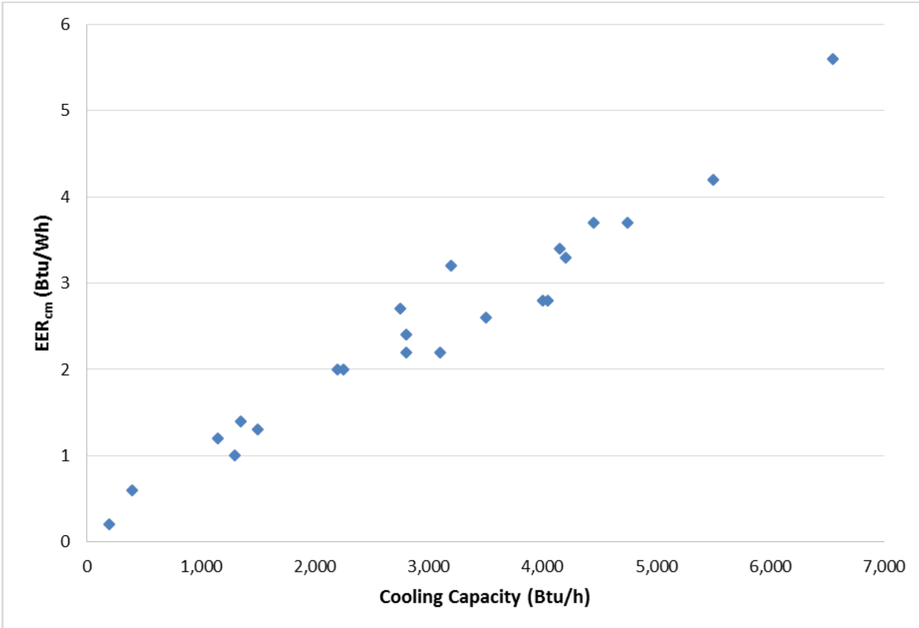

Figure 5.5.2.1 Measured Cooling Capacity and EER_{cm} – Preliminary Analysis

In the February 2015 Test Procedure NOPR, DOE also proposed test procedures to determine heating capacity and efficiency, energy consumption in off-cycle mode, and energy consumption in various standby modes and off mode. In addition, DOE proposed an overall combined EER (CEER), which combines unit performance in each of these available modes. However, because cooling is the primary function of portable ACs, DOE expected that manufacturers would likely focus on improving efficiency in that mode to achieve higher CEERs. Accordingly, DOE focused on performance in cooling mode for the engineering analysis in the February 2015 Preliminary Analysis.

After publishing the February 2015 Preliminary Analysis, DOE established the test procedure in appendix CC. As discussed previously, DOE maintained the overall approach from the February 2015 Test Procedure NOPR with the following changes: added a second cooling mode test condition, removed measurements associated with heating mode and case heat transfer, and incorporated other technical corrections. With the removal of heating mode and addition of the second set of testing conditions in cooling mode, DOE revised the CEER metric to use a weighted average of the two cooling mode test conditions and include low power mode energy consumption, all based on the annual cooling mode hours. Figure 5.5.2.2 and Table 5.5.2.1 present the numerically calculated SACC and CEER for the units in DOE's test sample as analyzed in the June 2016 NOPR.

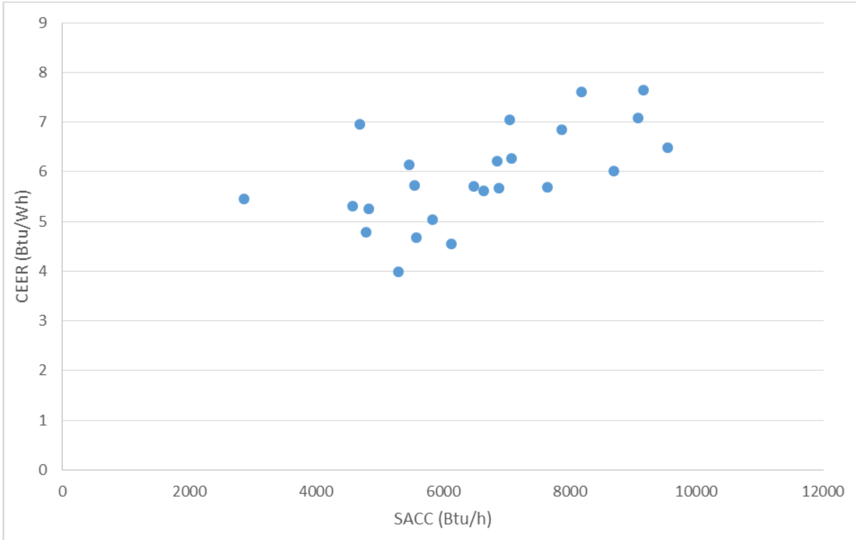

Figure 5.5.2.2 Test Sample SACC and CEER – June 2016 NOPR

Table 5.5.2.1 Test Sample SACC and CEER – NOPR

Test Sample	**Configuration**	**SACC** *(Btu/h)*	**CEER** *(Btu/Wh)*
SD1	Single-Duct	4,550	5.3
SD2	Single-Duct	5,450	6.1
SD3	Single-Duct	9,550	6.5
SD4	Single-Duct	8,700	6.0
SD5	Single-Duct	4,700	7.0
SD6	Single-Duct	9,100	7.1
SD7	Single-Duct	7,650	5.7
SD8	Single-Duct	5,850	5.0
SD9	Single-Duct	5,550	5.7
SD10	Single-Duct	7,050	7.1
SD11	Single-Duct	4,800	4.8
SD12	Single-Duct	6,850	6.2
SD13	Single-Duct	9,150	7.6
SD14	Single-Duct	7,900	6.9
SD15	Single-Duct	2,850	5.4
SD16	Single-Duct	7,100	6.3
SD17	Single-Duct	4,150	4.9
SD18	Single-Duct	6,150	4.5
DD1	Dual-Duct	8,200	7.6
DD2	Dual-Duct	6,900	5.7
DD3	Dual-Duct	5,600	4.7
DD4	Dual-Duct	5,300	4.0
DD5	Dual-Duct	4,850	5.3
DD6	Dual-Duct	6,500	5.7
DD7	Dual-Duct	6,650	5.6

Following publication of the June 2016 NOPR analysis, DOE reassessed the test data and performance modeling for each unit in its test sample. As discussed in section 5.3.1, DOE found that some of the data used in support of the June 2016 NOPR contained minor errors, which DOE has corrected in this final rule. DOE also improved the performance modeling for dual-duct units operating at the lower 83 °F test condition, and DOE updated the off-cycle mode power for those units with product documentation clearly stating that the fan operates continuously during off-cycle mode. Figure 5.5.2.3 and Table 5.5.2.2 present the SACC and CEER for the units in DOE's test sample in this final rule analysis, consistent with the test requirements in appendix CC.

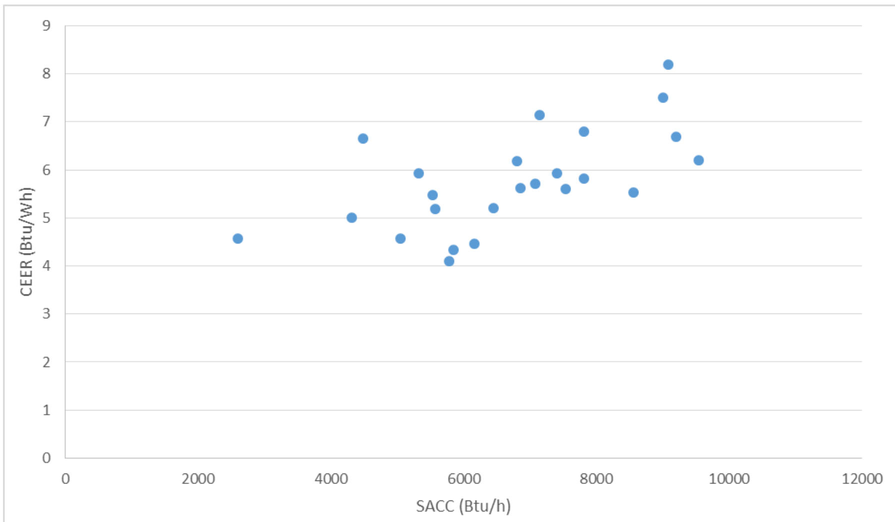

Figure 5.5.2.3 Test Sample SACC and CEER – Final Rule

Table 5.5.2.2 Test Sample SACC and CEER – Final Rule

Test Sample	**Configuration**	**SACC** *(Btu/h)*	**CEER** *(Btu/Wh)*
SD1	Single-Duct	4,300	5.0
SD2	Single-Duct	5,350	5.9
SD3	Single-Duct	9,550	6.2
SD4	Single-Duct	8,550	5.5
SD5	Single-Duct	4,500	6.7
SD6	Single-Duct	9,200	6.7
SD7	Single-Duct	7,550	5.6
SD8	Single-Duct	5,750	4.1
SD9	Single-Duct	5,550	5.2
SD10	Single-Duct	7,150	7.1
SD11	Single-Duct	5,050	4.6
SD12	Single-Duct	6,800	6.2
SD13	Single-Duct	9,000	7.5
SD14	Single-Duct	7,800	6.8
SD15	Single-Duct	2,600	4.6
SD16	Single-Duct	7,050	5.7
SD17	Single-Duct	4,700	5.5
SD18	Single-Duct	5,850	4.3
DD1	Dual-Duct	9,100	8.2
DD2	Dual-Duct	7,800	5.8
DD3	Dual-Duct	6,450	5.2
DD4	Dual-Duct	6,150	4.5
DD5	Dual-Duct	5,550	5.5
DD6	Dual-Duct	6,850	5.6
DD7	Dual-Duct	7,400	5.9

As detailed in the following sections, in this final rule DOE utilized test data when conducting teardowns and modeling to correlate efficiency gains with certain design options for the units in the test sample.

5.5.3 Product Teardowns

After completing the investigative testing described in the previous section, DOE conducted teardowns on 23 units in its sample that were available at the end of the test series. The teardown units spanned the range of product efficiencies and features available on the market from multiple manufacturers. DOE relied on the portable AC teardowns to supplement the information gained through manufacturer interviews and to investigate how product construction related to performance observed during testing. Specifically, the teardowns allowed DOE to identify design features for improving efficiency and to develop corresponding manufacturing costs for products at different efficiency levels.

DOE observed that all portable ACs in the teardown sample had similar construction. All units were housed in a plastic case with either a plastic or metal internal structure. The units typically featured distinct upper and lower internal sections to separate the evaporator and condenser and their associated components. The top section included the evaporator, evaporator blower, and air filter, while the bottom section included the condenser, compressor, and condenser blower assembly, including an air filter. For the single-duct units, the duct was connected at one end to the condenser exhaust port on the back of the case and at the other end to the window mounting bracket for exhausting the air outside of the conditioned space. Dual-duct units similarly attached a duct to the back of the case at the condenser exhaust, but also included a second duct attached at the condenser air inlet. Both ducts were connected to the window mounting bracket. For all units, the accordion-style collapsible plastic coil ducts were almost identical, with slight variations in diameter and construction (*i.e.*, some ducts included a wire support while others were entirely plastic).

The units were constructed such that any condensate formed on the evaporator in the upper chamber would drip over the condenser, allowing some or all condensate to evaporate before the remainder is collected in a small internal reservoir at the bottom of the unit. All units either implemented a slinger wheel or pump in the internal reservoir to circulate any collected condensate back on to the condenser where it would be evaporated and removed from the case in the condenser exhaust air stream. All units included a condensate drain outlet to allow manual draining of any condensate collected in the internal reservoir that exceeds the amount that could be re-evaporated.

All units featured rotary R-410A compressors secured to the base of the unit's internal case platform. DOE observed that all blowers used permanent split capacitor (PSC) motors. The evaporator and condenser within each unit had similar dimensions and number of tube passes, and were connected via capillary tubes. The copper tubing exiting the evaporator and entering the compressor was typically insulated, though the thickness and length of insulation varied among units. All of the units in DOE's test and teardown sample featured electronic controls, although DOE believes other units available on the market may use electromechanical controls.

5.5.4 Modeled Performance

Although DOE tested and tore down a large sample of units from different manufacturers at varying capacities and efficiencies, the sample did not cover the entire range of efficiency levels and design options that are technically feasible. To fill in the gaps in the teardown sample and to estimate the maximum efficiencies possible as measured by DOE's test procedure in appendix CC, DOE numerically modeled unit performance with various design option configurations.

5.5.4.1 Component Efficiency Improvements

Unlike the February 2015 Preliminary Analysis, for which DOE relied upon airflow optimization for the majority of efficiency levels, the analyses in the June 2016 NOPR and this final rule considered the impacts of component efficiency improvements to improve overall performance. These component improvements included increasing heat exchanger area, improving compressor and fan motor efficiencies, and reducing standby power with more efficient controls. DOE incorporated these changes to estimate performance improvements for each test unit to determine the changes necessary to reach higher efficiency levels.

Increased Heat Exchanger Area

Increasing the heat transfer area of the evaporator and condenser coils can improve portable AC performance. DOE considered the efficiency improvements that would be associated with incrementally larger coils for each test unit. During manufacturer interviews, concern was expressed that portable AC case sizes and weights are already approaching the limits of acceptable portability for consumers, and that significantly larger case sizes or greater weights may limit the ability for consumers to move units from room to room or to carry the unit up or down stairs.

However, DOE observed in its test sample that heat exchanger areas varied significantly from unit to unit. DOE first determined the overall relationship between SACC and heat exchanger area. Figure 5.5.4.1 shows the overall trend in evaporator and condenser cross-sectional areas for a range of SACCs. The solid lines represent the average trends and the dotted lines represent plus or minus 20 percent from the average trend. As shown in the figure, the heat exchanger areas for units in the test sample typically ranged from approximately 20 percent below to 20 percent above the average trend.

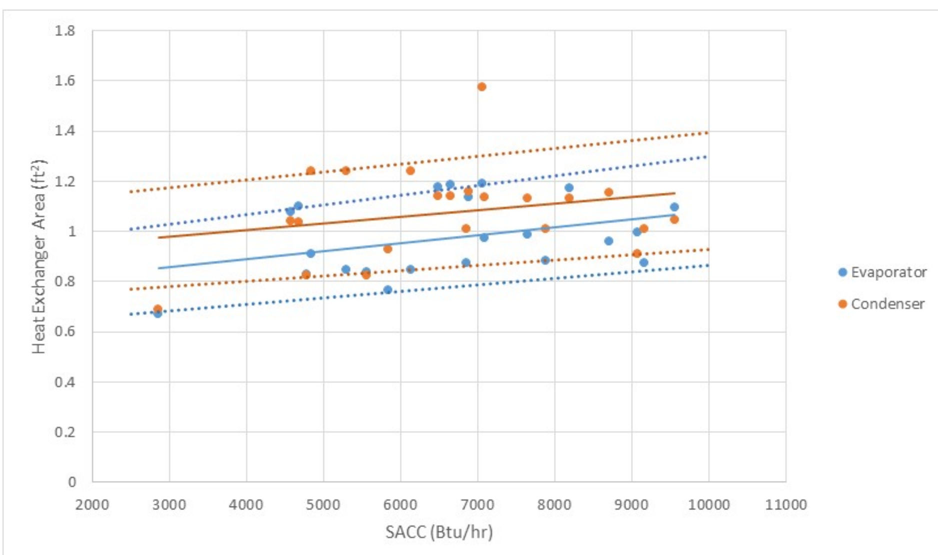

Figure 5.5.4.1 Test Unit Heat Exchanger Areas and Cooling Capacities

The range in observed heat exchanger areas suggests that manufacturers have an opportunity to increase heat exchanger areas beyond what DOE had estimated for the February 2015 Preliminary Analysis. Based on the range of observed heat exchanger areas in its test sample, DOE determined that a 20-percent increase in heat exchanger area is an appropriate limit. While certain units in DOE's test sample already incorporate larger-than-average heat exchangers at their tested capacity, these units did not always test with correspondingly high CEERs. To avoid limiting the potential design improvements that could be applied to these units, DOE assumed that all units in the test sample would be capable of incorporating a 20-percent increase in heat exchanger area.

DOE does not expect this increase in heat exchanger size, and the resulting increases in case size and weight, to impact product portability, in part because all single-duct and dual-duct portable ACs that DOE identified incorporate wheels. For this final rule, DOE further investigated the weight increases, and based on teardowns, DOE estimated that the overall unit weight would typically increase by about 6 percent with a 20-percent heat exchanger cross-sectional area increase, which includes the weights of the heat exchangers as well as all other components that must be adjusted to incorporate the larger heat exchangers. Applying this typical percent weight increase to DOE's full test sample resulted in an increase from 45 to 48 pounds for the lightest unit in the test sample, which is less than the maximum recommended lifting weight of 51 pounds for one person according to the National Institute for Occupational Safety and Health (NIOSH).[g] For the heaviest unit in DOE's test sample, the weight would increase from 86 to 92 pounds, which is within a reasonable lifting weight for two people. All other units in DOE's test sample weighed above 50 pounds and therefore would already require two people to lift based on NIOSH recommendations before implementing any design options, so the heat exchanger size and subsequent weight increases would not require additional lifting manpower. Therefore, DOE concludes that the minimal weight increase associated with increased heat exchanger area and the presence of wheels ensures that consumer utility is not significantly impacted by this design option.

To estimate the effect of larger heat exchangers on efficiency, DOE modeled unit performance using the MarkN model.[h] DOE adjusted the heat exchanger parameters of a calibrated model to include 10-percent, 15-percent, and 20-percent larger cross-sectional areas and developed a curve that related heat exchanger cross-sectional area to performance. This curve was used to estimate performance gains associated with increased heat exchanger area. DOE further modeled the other potential heat exchanger design options, increasing coil depth and increasing fin density, and confirmed that increasing cross-sectional area resulted in the largest efficiency gains.

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[g] NIOSH developed a mathematical model that helps predict the risk of injury based on the weight being lifted and other criteria. The NIOSH model, which identifies 51 pounds as the maximum recommended lifting weight for one person to avoid injury, is based on medical research and can be found on the NIOSH website (http://www.cdc.gov/niosh/docs/94-110/).

[h] See chapter 5 of the preliminary TSD for a description of the MarkN model development.

Improved Compressor Efficiency

To determine an appropriate range of compressor efficiencies, DOE utilized information gathered in the preliminary engineering analysis for dehumidifiers.[i] 79 FR 29380 (May 22, 2014). At the time of the February 2015 Preliminary Analysis, DOE was aware of compressors available with rated EERs ranging from approximately 8.5 to 10.5 Btu/Wh. For the June 2016 NOPR analysis, DOE conducted further research and determined that the maximum single-speed compressor EER rating was approximately 11.1 Btu/Wh. DOE notes that this range represents a limited number of compressors based on a survey of the market, not necessarily those observed during teardowns.

DOE numerically modeled each test unit with increased compressor EER of 10.5 Btu/Wh, the maximum available efficiency in the February 2015 Preliminary Analysis, and 11.1 Btu/Wh, the current maximum efficiency for single-speed rotary R-410A compressors. DOE further modeled each test unit with a variable-speed compressor with an EER of 13.7 Btu/Wh, representative of the maximum available compressor efficiency for the capacity range appropriate for portable ACs. Although DOE is not aware of any portable ACs that incorporate a variable-speed compressor, the potential efficiency improvements associated with these compressors may make them a more attractive option for manufacturers.

The efficiency improvement associated with this design change varied from unit to unit depending on the efficiency of the compressor currently used. The overall average compressor efficiency observed for units in DOE's teardown sample was 9.8 Btu/Wh.

Improved Blower Motor Efficiency

DOE is aware that efficiency gains may be possible through improvements to portable AC blower motors. All units in DOE's teardown sample used PSC fan motors. Permanent-magnet (PM) or electronically commutated motors (ECM) would provide slightly higher motor efficiencies compared to PSC motors (DOE estimates them to be 80-percent efficient compared to 60 percent for PSC motors), but the improvements to overall efficiency would be relatively small due to the smaller portion of energy consumed by the blower motor compared to the compressor. In interviews, manufacturers stated that they likely would not rely on changes to the blower to improve product efficiency due to the small efficiency gains and high cost. However, to consider the maximum efficiency possible for portable ACs, DOE considered this blower motor efficiency improvement (*i.e.*, substituting a PSC motor with an ECM) when modeling each test unit at its maximum efficiency.

Low-Standby-Power Electronic Controls

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[i] The preliminary engineering analysis for dehumidifiers is available in the preliminary TSD for this rulemaking, found at http://www.regulations.gov/#!documentDetail;D=EERE-2012-BT-STD-0027-0015.

As discussed above, for this final rule engineering analysis, DOE considered portable AC performance in terms of CEER and SACC, based on the test procedure in appendix CC. The CEER metric includes consideration for energy consumed in low-power modes. For the component change representing the maximum unit efficiency, DOE assumed all products would improve standby efficiency and have a standby power of 0.46 Watts, the lowest observed in DOE's test sample.

5.5.4.2 Design Options Not Specifically Considered

DOE observed that manufacturers typically implement the design options discussed above to improve portable AC efficiency. While many of the technology options identified in chapter 3 of this final rule TSD may produce energy savings in certain real-world situations, DOE did not further consider them in this analysis because there was not sufficient information available on the specific efficiency gains, or because the DOE test procedure would not capture those potential improvements. DOE considered the following design options in this engineering analysis, but does not expect manufacturers to rely on these features to meet higher efficiency levels.

Add Subcooler to Condenser Coil

DOE is aware that subcooling the refrigerant exiting the condenser may improve product efficiencies by increasing the amount of heat rejected by the condenser. However, based on product testing, DOE expects that any beneficial refrigerant subcooling already occurs within existing condensers. DOE observed that refrigerant temperatures exiting the condenser were well below the refrigerant condensing temperature. DOE expects that the use of condensate spray on the condenser contributes to the subcooling without the need for an additional heat exchanger.

Increased Heat-Transfer Coefficients

In the market and technology assessment, chapter 3 of this final rule TSD, DOE identified technologies that would improve heat transfer coefficients in portable AC heat exchangers. In its teardown sample, DOE observed that units already incorporate many of the design options that would improve heat transfer coefficients, such as slit fins, grooved refrigerant tubes, and condensate spray over the condenser. DOE also identified microchannel heat exchangers as a potential means to improve heat-transfer coefficients. As discussed in chapter 3, DOE expects the efficiency gains to be limited with a microchannel heat exchanger, but they may reduce the necessary refrigerant charge and condenser size.

Because portable ACs already include many design options to improve heat transfer in the evaporator and condenser, and because it lacks information on the potential efficiency gains with microchannel heat exchangers, DOE did not specifically consider these design options in further improving portable AC efficiencies. As discussed earlier in this section, DOE determined that manufacturers would likely rely on increased heat exchanger cross-sectional areas to improve heat transfer and increase efficiencies.

Improved Duct Connections

In the market and technology assessment, DOE identified improved duct connections to the portable AC case and mounting bracket as a technology option to potentially improve portable AC performance by reducing air leakage. DOE did not observe any units in the test sample that provided additional sealing in the duct connections. DOE also lacks information regarding leakage rates and potential savings associated with reducing condenser air leakage to the room. Therefore, DOE did not further consider the improvements associated with improved duct connections in this final rule.

Improved Product Case Insulation

In the market and technology assessment, DOE identified insulation as a component to potentially improve portable AC performance, and DOE found that the cases in its test sample had little or no insulation. However, DOE observed that the average case surface temperature for products in its test sample was 82 °F, which is only 2 °F higher than the indoor room test condition in appendix CC. Therefore, DOE expects that adding insulation to the product case would result in little or no improvement compared to existing product cases. Additionally, the test procedure adopted in appendix CC does not include case heat transfer in SACC.

Part-Load Technology Improvements

In the market and technology assessment, DOE identified variable-speed compressors and thermostatic or electronic expansion valves to potentially improve portable AC performance. DOE notes that these design options would typically improve portable AC performance under varying conditions by optimizing and adjusting the refrigeration system performance to the specific indoor and outdoor conditions. DOE was unable to consider variable-speed compressors and other part-load technology improvements when developing its portable AC test procedure because it was unaware of any portable ACs on the market which incorporate such a component. However, DOE notes that variable-speed compressors available in the capacity range appropriate for portable ACs are able to reach higher efficiencies than the typically used single-speed compressors. For this reason, DOE included variable-speed compressors in this final rule as a design option to achieve the max-tech efficiency level, though the efficiency gains associated with this technology are based on continuous operation at constant test conditions. The test procedure does not account for the efficiency impacts of compressor cycling for single-speed compressors.

R-32 Refrigerant

In the market and technology assessment, DOE identified potential efficiency gains associated with substituting R-32 refrigerant for the commonly used R-410A. However, DOE notes that some of those efficiency gains were theoretical and others were determined based on testing experimental products in laboratories. Further, the studies DOE found were not based on portable ACs, but rather heat pumps, chillers, and mini-split air conditioners. Although these products are similar to portable ACs in operating components, and studies do indicate efficiency gains associated with R-32, DOE is unaware of studies that investigate potential efficiency gains for portable ACs. DOE also notes that no portable ACs that implement R-32 were available to for testing to validate any efficiency gains. Therefore, DOE did not further consider the improvements associated with switching to R-32 refrigerant in this final rule.

5.5.5 Efficiency Levels

As described above, DOE assessed individual unit performance relative to the nominal CEER relationship based on the performance of the combined test data sample and identified a baseline efficiency level at PR = 0.67. For EL 2, DOE determined the PR that corresponded to the maximum available efficiency across a full range of capacities (1.04), and then selected an intermediate efficiency level for EL 1 based on a PR between the baseline and EL 2 (0.85). For EL 3, DOE identified the PR for the single highest efficiency unit observed in its test sample (1.18).

Due to the variations in performance among units in DOE's test sample, DOE conducted additional performance modeling to augment its test data when estimating efficiency and manufacturing costs at each efficiency level. DOE numerically modeled component improvements for each of the 23 out of 24 test units for which detailed component information were available to estimate potential efficiency improvements to existing product configurations.[j] The component improvements were performed in three steps for each unit.

The first incremental improvement for each unit included a 10-percent increase in heat exchanger frontal area and raising the compressor EER to 10.5 Btu/Wh.

The second incremental component efficiency improvement step for each unit included a 15-percent increase in heat exchanger frontal area from the original test unit and an improvement in compressor efficiency to an EER of 11.1 Btu/Wh, which DOE identified as the maximum efficiency for currently available single-speed R-410A rotary compressors of the type typically found in portable ACs and other similar products. As with the 10-percent heat exchanger area increase, DOE expects that a chassis size and weight increase would be necessary to fit a 15-percent increased heat exchanger, but believes portability and consumer utility would not be significantly impacted.

DOE included all available design options in the third efficiency improvement step for each unit, including a 20-percent increase in heat exchanger frontal area from the original test unit, more efficient ECM blower motor(s), and a variable-speed compressor with an EER of 13.7 Btu/Wh. DOE believes that a 20-percent increase in heat exchanger size is the maximum allowable increase for consumer utility and portability to be retained, though would require a

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[j] For the final rule analysis, DOE numerically modeled component improvements for two test units from its test sample that were not previously modeled in the preliminary analysis or June 2016 NOPR. Detailed component information for these two test units become available after the June 2016 NOPR publication.

more significant chassis redesign than the previous heat exchanger size increases. DOE also improved the standby power of controls in this final step, adjusting the standby power for each test unit to the minimum observed 0.46 W in the test sample. With these design options modeled for units in its test sample, DOE found that the single, theoretical maximum-achievable efficiency among all modeled units corresponded to a PR of 1.62.

Table 5.5.5.1 summarizes the specific improvements DOE made to each test unit.

Table 5.5.5.1 Component Improvements Summary

Heat Exchanger Area *(% increase)*	**Compressor EER** *(Btu/Wh)*	**Blower Motor** *(Type)*	**Standby** *(Watts)*
10%	10.5 (single-speed)	-[1]	-
15%	11.1 (single-speed)	-	-
20%	13.7 (variable-speed)	ECM (variable-speed)	0.46

[1] No blower motor or standby power changes were applied to the first two incremental steps

DOE notes that the design improvements listed in Table 5.5.5.1 do not necessarily represent the design options associated with each efficiency level beyond the baseline. Baseline through EL 3 are defined by the range of test data, while EL 4 is defined by the maximum theoretical PR after modeling all design options listed in Table 5.5.5.1.

In this final rule, DOE analyzed efficiency levels based on test data and modeled performance according to the following equation and the PR values listed in Table 5.5.5.2:

$$Minimuim\ CEER = PR \times \frac{SACC}{(3.7117 \times SACC^{0.6384})}$$

Table 5.5.5.2 Efficiency Levels and PRs

Efficiency Level	Efficiency Level Description	Performance Ratio (PR)
Baseline	Minimum Observed	0.67
EL 1	Gap Fill 1	0.85
EL 2	Maximum Available for All Capacities	1.04
EL 3	Maximum Observed	1.18
EL 4	Max-Tech (Maximum of Modeled Component Improvements)	1.62

Figure 5.5.5.1 plots each efficiency level curve for SACCs from 50 to 10,000 Btu/h, based on the nominal CEER curve scaled by the PR assigned to each efficiency level.

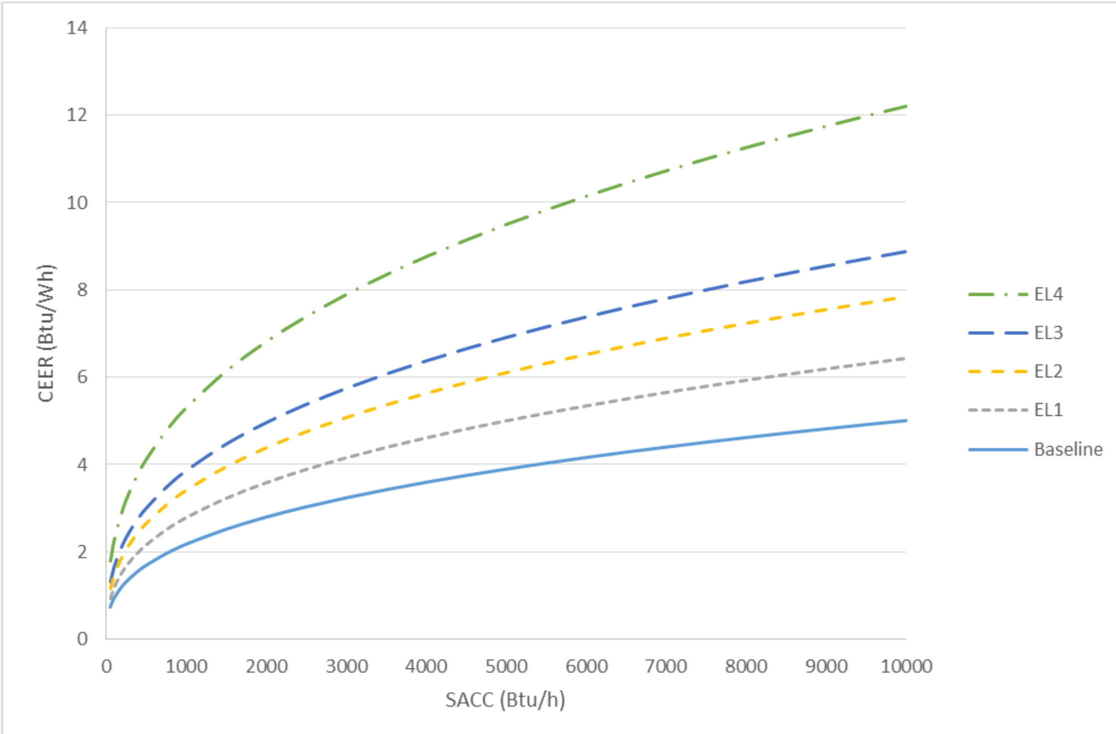

Figure 5.5.5.1 Portable Air Conditioner Efficiency Level Curves – Final Rule

5.5.6 Cost Estimates

As described in section 5.4.3, DOE developed estimates of MPCs for each unit in the teardown sample. When assigning costs to efficiency levels in this analysis, DOE considered all units with tested or modeled performance between two efficiency levels as representative of the lower of the two efficiency levels. DOE determined an average baseline MPC based on the units in DOE's test sample with a CEER below EL 1 (PR = 0.85). Ten units in DOE's test sample and seven in AHAM's data tested below EL 1. DOE expects the average MPCs from these units to reflect the baseline for the overall portable AC market because the average capacity of these units was within approximately 20 Btu/h of the overall average capacity for the entire combined test sample.

DOE subsequently determined the costs for all torn-down and modeled units, and determined the average costs associated with each incremental component efficiency improvements when moving between efficiency levels. In addition to the costs associated with the improved components themselves, DOE also considered the increased costs associated with other related product changes, such as increasing case sizes to accommodate larger heat exchangers.

Although DOE's test and modeled data resulted in a range of PRs from 0.67 to 1.62, DOE observed that not all units in its test sample were capable of reaching higher PRs with the identified design option changes. For example, the modeled max-tech PR represents a unit in the test sample that had a high PR as a starting point (near EL 3). Modeling increased heat exchanger sizes and a more efficient compressor in this unit resulted in a higher modeled PR than could be achieved theoretically by applying the same design options to baseline units. For these units that start at lower PRs, DOE expects that manufacturers would have to undertake a complete product redesign and optimization to reach higher PRs, rather than just applying the identified design options. As a result, manufacturers of these units would incur higher MPCs to reach the higher efficiency levels and also significant conversion costs associated with updating their product lines. These conversion costs are discussed further in sections IV.J and V.B.2 of the final rule notice and chapter 12 of this final rule TSD.

With this approach, DOE found that four units in the teardown sample would be capable of reaching EL 3 without significant product redesign (i.e., the one unit that tested at EL 3 and three units that could theoretically achieve EL 3 with highest efficiency single-speed compressors and increasing the heat exchanger area no more than 15 percent). At EL 4 (max-tech), DOE expects all products to require redesigns. EL 4 represents the maximum modeled efficiency with a 20-percent increase in heat exchanger area and the most efficient variable-speed compressor. DOE expects that manufacturers would undertake a product redesign when switching from a single-speed to a variable-speed compressor. Additionally, DOE notes that the ability of a product to reach EL 3 or EL 4 would be dependent on the availability of the most efficient components. However, compressor availability for portable ACs is largely driven by the room AC industry, so the most efficient single-speed and variable-speed compressors may not be available over the entire range of capacities necessary for all portable AC product capacities. As a result, moving to EL 3 or EL 4 may necessitate manufacturers to remove certain portable AC cooling capacities from the market.

Products that would require a redesign to reach a certain efficiency level with the identified design options would subsequently incur additional incremental MPCs to achieve any improvement beyond that efficiency. Although DOE does not expect manufacturers to actually implement the associated design changes for the reasons discussed below, DOE included them for completeness to estimate MPCs representative of the full capacity range at all efficiency levels. To estimate increased material costs after manufacturers undertake a product redesign, DOE allowed the heat exchanger areas to increase beyond the 20-percent limit where necessary, resulting in higher costs for the heat exchangers and associated case changes.

As described earlier, DOE observed that all products would require redesigns at EL 4 and all but four would require product redesigns at EL 3. However, based on its modeling, certain products would also require redesigns at EL 1 and EL 2. Table 5.5.6.1 presents DOE's estimates on the portion of products requiring redesigns at each of the analyzed efficiency levels. In addition to developing the MPCs, these product redesign estimates were used to determine the conversion costs necessary at each efficiency level, as discussed in the manufacturer impact analysis in chapter 12 of this final rule TSD.

Table 5.5.6.1 Estimated Product Redesigns by Efficiency Level

Efficiency Level	Portion of Test Sample Requiring Redesign
Baseline	0%
EL 1	25%
EL 2	82%
EL 3	95%
EL 4	100%

Based on the method described above, DOE determined the incremental changes needed for products to move to each higher efficiency level. Table 5.5.6.2 presents the average design change necessary for products moving to each analyzed efficiency level.

Table 5.5.6.2 Estimated Average Heat Exchanger and Compressor Design Changes

Efficiency Level	HX Area Increase	Compressor EER Increase[2]
Baseline	0%	0%
EL 1	8%	6%
EL 2	19%	17%
EL 3	24%[1]	33%
EL 4	35%[1]	37%

[1] Represents a design change intended to reflect the costs associated with a product redesign rather than the actual changes manufacturers would make.
[2] For this final rule, the compressor EER was not modeled beyond the max-tech efficiency of 13.7 Btu/Wh.

DOE calculated all MPCs associated with these design changes and the design changes mentioned earlier in this chapter (improved fan motor efficiencies, low-standby-power controls) in 2015 dollars (2015$), the most recent year for which full-year data were available. Table 5.5.6.3 presents the updated MPC estimates DOE developed for this final rule.

Table 5.5.6.3 Incremental Portable AC Manufacturer Production Costs

Efficiency Level	Incremental MPC *(2015$)*
Baseline	$ -
EL 1	$ 18.95
EL 2	$ 50.57
EL 3	$ 93.84
EL 4	$ 115.53

CHAPTER 6. MARKUPS ANALYSIS

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CHAPTER 6. MARKUPS ANALYSIS

6.1 INTRODUCTION

To perform the life-cycle cost (LCC) calculations described in chapter 8 of this technical support document (TSD), the U.S. Department of Energy (DOE) determined the cost consumers will pay for portable air conditioners (ACs). The cost is determined for both baseline products and more efficient products that consumers would purchase following the promulgation of any new or amended energy conservation standards for portable ACs. The manufacturer selling price (MSP) for both baseline and more efficient products is determined in the engineering analysis (chapter 5 of this TSD). By applying a multiplier called a markup to the MSP, DOE can estimate the purchase price of the product after it travels through its distribution channel to the retailer. This chapter describes how DOE derived markups for both manufacturers and retailers.

6.1.1 Distribution Channels

The appropriate markups for determining consumer product prices depend on the type of distribution channel through which the product moves from manufacturer to consumer. At each point in the distribution channel, companies mark up the price of the product to cover their business costs and profit margin. Almost all portable ACs are purchased for residential use, although DOE estimates that perhaps one percent are used in a commercial setting.

Data from the Association of Home Appliance Manufacturers (AHAM)[1] indicate that an overwhelming majority of residential appliances are sold through retail outlets. Available data indicate no other distribution channel that plays a significant role for portable ACs; therefore, DOE assumed that consumers purchase all portable ACs, whether destined for residential or commercial settings, from retail outlets. DOE considered portable ACs purchased for the replacement market and by first-time owners or owners who purchase an additional unit, but did not consider the new construction market, because DOE found no information to indicate the extent, if any, to which builders install the products in new construction.

6.1.2 Procedure for Calculating Markups

As noted above, companies at each point in the distribution channel mark up the price of a product to cover their business costs and profit margin. In financial statements, gross margin (GM) is the difference between a company's revenue and its cost of sales, or cost of goods sold (CGS). The GM of companies throughout the distribution channel includes expenses such as overhead (sales, general, and administration); research and development (R&D) and interest expenses; depreciation; taxes—and company profits. To cover costs and to contribute positively to company cash flow, the price of a product must include a markup. Products command lower or higher markups depending on company expenses associated with the product and the degree of market competition. In developing markups for manufacturers and retailers, DOE obtained data about the revenue, CGS, and expenses of firms that produce and sell portable ACs.

6.2 MANUFACTURER MARKUPS

DOE uses manufacturer markups to transform a manufacturer's production costs into an MSP. Applying the CGS and GM, DOE calculated the manufacturer markup using the following equation.

$$MU_{MFG} = \frac{SALES_{MFG}}{CGS_{MFG}} = \frac{CGS_{MFG} + GM_{MFG}}{CGS_{MFG}} = 1 + \frac{GM_{MFG}}{CGS_{MFG}}$$

Where:

MU_{MFG} = manufacturer markup multiplier,
CGS_{MFG} = manufacturer's cost of goods sold or manufacturer production cost (MPC), and
GM_{MFG} = manufacturer's gross margin.

The manufacturer's CGS (or MPC*)* plus its GM equals the manufacturer selling price (MSP). DOE developed an average manufacturer markup by examining publicly available financial information, including Securities and Exchange Commission (SEC)[2] 10-K reports for manufacturers of major household appliances having product offerings that include portable ACs. DOE determined the weighted-average manufacturer markup for portable ACs to be 1.42. The method for deriving manufacturer markups is described in more detail in the engineering analysis (chapter 5).

6.3 RETAILER MARKUPS

If a change in energy efficiency standards increases the manufacturer selling price paid by retailers, then the way in which retailers adjust the retail price paid by consumers must be accounted for in the markups. Prior to 2000, DOE used the same markup multiplier to estimate the prices of both the baseline and more efficient products. However, given the nature of the appliance retail market, applying the same markup on higher manufacturer selling prices of more efficient products would imply an increase in the dollar margin earned by retailers, and an increase in per-unit profit.

Based on microeconomic theory, the degree to which firms can pass along a cost increase to consumers depends on the level of market competition and market structure on both the supply and demand side (e.g., supply and demand elasticity). DOE examined industry data from IBISWorld and the results suggest the industry groups involved in appliance retail exhibit a strong degree of competition (Table 6.3.1).[a] In addition, consumer demand for household appliances is relatively inelastic (*i.e.*, demand is not expected to decrease substantially with an

[a] IBISWorld, US Industry Reports (NAICS): http://clients.ibisworld.com/reports/us/industry/home.aspx (Last accessed August, 2015.)

increase in the price of equipment). In such a relatively competitive markets with inelastic demands, it may be tenable for retailers to maintain a fixed markup for a short period of time after an product cost increase, but the market competition would eventually force them to readjust their markups to reach a medium-term equilibrium in which per-unit profit is relatively unchanged before and after standards are implemented.

Table 6.3.1 Competitive Environment of Appliance Retailers

Sector	Industry Concentration	Competition	Barriers to Entry
TV & appliance retailers	low	high and steady	medium and steady
Consumer electronics stores	medium	medium and increasing	medium and steady
Department stores	medium	high and increasing	medium and steady
Home improvement clubs	high	medium and steady	medium and steady

* Note that there is competition between the four types of appliance retailers listed in this table, as well as within each individual retailing type.

Thus, DOE concluded that applying fixed markups for both baseline products and higher-priced products meeting a new standard is not viable in the medium to long term considering the nature of the appliance retail market. DOE developed the incremental markup approach based on the widely accepted economic view that firms are not able to sustain a persistently higher dollar profit in a competitive market in the medium to long term. If the wholesale price of the product increases under standards, the only way to maintain the same dollar profit as before is for the markup (and percent gross margin) to decline.

To estimate the markup under standards, DOE derived an incremental markup that is applied to the incremental equipment costs of higher efficiency products. The overall markup on the products meeting standards is an average of the markup on the component of the cost that is equal to the baseline product (baseline markup) and the markup on the incremental cost (incremental markup), weighted by the share of each in the total cost of the standards-compliant product.

DOE's incremental markup approach allows the part of the cost that is thought to be affected by the standard to scale with the change in manufacturer price. The income statements DOE used to develop retailer markups itemize firm costs into a number of expense categories, including direct costs to purchase or install the equipment, operating labor and occupancy costs, and other operating costs and profit. Although retailers tend to handle multiple commodity lines, DOE contends that these aggregated data provide the most accurate available indication of the cost structure of distribution channel participants.

DOE uses these income statements to divide retailer costs between those that are not likely to scale with the manufacturer price of equipment (labor and occupancy expenses, or "invariant" costs) and those that are (operating expenses and profit, or "variant" costs). For example, when the manufacturer selling price of equipment increases, only a fraction of a retailer's expenses increase (operating expenses and profit), while the remainder can be expected to stay relatively constant (labor and occupancy expenses). For example, if the unit price of a portable AC increases by 20 percent under standards, it is unlikely that the cost of secretarial support in an administrative office or office rental expenses will increase proportionally.

6.3.1 Methodology for Retailer Markups

DOE based the retailer markups for portable ACs on financial data for electronics and appliance stores from the 2012 U.S. Census *Annual Retail Trade Survey* (ARTS)[3], which is the most recent survey that includes industry-wide detailed operating expenses for that economic sector.[3]

The baseline markup converts the MSP of baseline products to the retailer sales price. DOE considers baseline models to be products sold under current market conditions (*i.e.*, without amended energy conservation standards). DOE used the following equation to calculate an average baseline markup (MU_{BASE}) for retailers.

$$MU_{BASE} = \frac{SALES_{RTL}}{CGS_{RTL}} = \frac{CGS_{RTL} + GM_{RTL}}{CGS_{RTL}} = 1 + \frac{GM_{RTL}}{CGS_{RTL}}$$

Where:

MU_{BASE} = retailer's baseline markup multiplier,
$SALES_{RTL}$ = retailer's sales revenue,
CGS_{RTL} = retailer's cost of goods sold (CGS), and
GM_{RTL} = retailer's gross margin (GM).

To estimate incremental retailer markups, DOE divides retailers' operating expenses into invariant and variant cost categories, as described in previous section. DOE used the following equation to calculate the incremental markup (MU_{INCR}) for retailers.

$$MU_{INCR} = \frac{CGS_{RTL} + VA_{RTL}}{CGS_{RTL}} = 1 + \frac{VA_{RTL}}{CGS_{RTL}}$$

Where:

MU_{INCR} = retailer's incremental markup multiplier,
CGS_{RTL} = retailer's cost of goods sold, and
VC_{RTL} = retailer's variant costs.

6.3.2 Derivation of Retailer Markups

The 2012 ARTS data for electronics and appliance stores provide total sales data and detailed operating expenses. To construct a complete data set for estimating markups, DOE needed to estimate CGS and GM. The most recent 2012 ARTS publishes a separate document containing historical sales and gross margin from 1993 to 2012 for household appliance stores.

DOE took the GM as a percent of sales reported for 2012 and combined that percent with detailed operating expenses data from 2012 ARTS to construct a complete income statement for electronics and appliance stores to estimate both baseline and incremental markups. Table 6.3.2 shows the calculation of the baseline retailer markup.

Table 6.3.2 Data for Calculating Baseline Markup: Electronics and Appliance Stores

Business Item	Amount ($1,000,000)
Sales	102,998
Cost of goods sold (CGS)	73,946
Gross margin (GM)	29,052
Baseline markup = (CGS+GM)/CGS	1.39

Source: U.S. Census, *2012 Annual Retail Trade Survey*.

Table 6.3.3 shows the breakdown of operating expenses for electronics and appliance stores based on the 2012 ARTS data. The incremental markup is calculated as 1.13.

Table 6.3.3 Data for Calculating Incremental Markup: Electronics and Appliance Stores

Business Item	Amount ($1,000,000)
Sales	102,998
Cost of goods sold (CGS)	*73,946*
Gross margin (GM)	*29,052*
Labor & Occupancy Expenses (invariant)	
Annual payroll	11,371
Employer costs for fringe benefit	2,023
Contract labor costs, including temporary help	209
Purchased utilities, total	529
Cost of purchased repair and maintenance services	386
Cost of purchased professional and technical services	1,117
Purchased communication services	362
Lease and rental payments	3,166
Taxes and license fees (mostly income taxes)	451
Subtotal:	19,617
Other Operating Expenses & Profit (variant)	
Expensed equipment	75
Cost of purchased packaging and containers	47
Other materials and supplies not for resale	463
Cost of purchased transportation, shipping, and warehousing services	567
Cost of purchased advertising and promotional services	1,961
Cost of purchased software	122
Cost of data processing and other purchased computer services, except communications + commissions paid	280
Depreciation and amortization charges	1,564
Other operating expenses	2,113
Net profit before tax (operating profit)	*2,243*
Subtotal:	9,435
Incremental markup = (CGS + Total Other Operating Expenses and Profit)/CGS	1.13

Source: U.S. Census. *2012 Annual Retail Trade Survey*.

DOE applied the same baseline and incremental retail markups for both residential and commercial applications because the portable ACs for both applications go through the same distribution channel.

6.4 SALES TAXES

The sales tax represents state and local taxes that are applied to the price a consumer pays for a product. The sales tax is a multiplicative factor that increases the consumer product price. DOE derived state and local taxes from data provided by the Sales Tax Clearinghouse.[4] DOE then derived population-weighted average tax values for each region identified for the Residential Energy Consumption Survey (RECS)[5] and the Commercial Buildings Energy Consumption Survey (CBECS)[6]. DOE applied those population-weighted average tax values to residential and commercial applications, respectively, as shown in Table 6.4.1 and Table 6.4.2.

Table 6.4.1 Average Sales Tax Rates by RECS Region

RECS Region	State(s)	U.S. Population in 2022	2015 Tax Rate (%)
1	Connecticut, Maine, New Hampshire, Rhode Island, Vermont	8,453,982	5.13
2	Massachusetts	6,855,546	6.25
3	New York	19,576,920	8.45
4	New Jersey	9,461,635	6.95
5	Pennsylvania	12,787,354	6.35
6	Illinois	13,236,720	8.00
7	Indiana, Ohio	18,271,066	7.10
8	Michigan	10,695,993	6.00
9	Wisconsin	6,004,954	5.45
10	Iowa, Minnesota, North Dakota, South Dakota	10,353,316	6.88
11	Kansas, Nebraska	4,693,244	7.19
12	Missouri	6,199,882	7.45
13	Virginia	8,917,395	4.00
14	Delaware, District of Columbia, Maryland	7,941,375	5.26
15	Georgia	10,843,753	7.00
16	North Carolina, South Carolina	15,531,866	6.99
17	Florida	23,406,525	6.65
18	Alabama, Kentucky, Mississippi	12,198,158	7.27
19	Tennessee	6,780,670	9.45
20	Arkansas, Louisiana, Oklahoma	11,515,069	8.73
21	Texas	28,634,896	7.95
22	Colorado	5,278,867	6.10
23	Idaho, Montana, Utah, Wyoming	6,285,110	5.31
24	Arizona	8,456,448	7.20
25	Nevada, New Mexico	5,536,624	7.48
26	California	42,206,743	8.45
27	Oregon, Washington	11,692,529	5.66
28	Alaska	774,421	1.30
29	Hawaii	1,412,373	4.35
30	West Virginia	1,801,112	6.05
Population-weighted average			7.116

Table 6.4.2 Average Sales Tax Rates by CBECS Region

Census Division/State	Population (2022)	Tax Rate (2015) %
New England	15,309,528	5.63
Middle Atlantic	41,825,909	7.47
East North Central	48,208,733	6.90
West North Central	21,246,442	7.12
South Atlantic	68,442,026	6.26
East South Central	18,978,828	8.05
West South Central	40,149,965	8.17
Mountain	25,557,049	6.57
Pacific	56,086,066	7.67
Population-Weighted Average		**7.12**

6.5 SUMMARY OF MARKUPS

Table 6.5.1 summarizes the markups at each stage in the distribution channel for portable ACs, starting with the manufacturer, and then applies the average sales tax to arrive at overall markups.

Table 6.5.1 Summary of Markups

	Residential Application		Commercial Application	
Markup	**Baseline**	**Incremental**	**Baseline**	**Incremental**
Manufacturer	1.42		1.42	
Retailer	1.39	1.13	1.39	1.13
Sales Tax	1.071		1.071	
Overall	2.11	1.72	2.11	1.72

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CHAPTER 7. ENERGY USE ANALYSIS

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CHAPTER 7. ENERGY USE ANALYSIS

7.1 INTRODUCTION

When the U.S. Department of Energy (DOE) carries out a life-cycle cost (LCC) and payback period (PBP) analysis, it must determine the operating cost savings consumers will derive from more efficient products. This chapter describes how DOE calculated the annual energy consumption of portable ACs for use in the LCC and PBP analysis, which is described in chapter 8 of this final rule TSD.

The engineering analysis summarized in chapter 5 of this final rule TSD reports portable air conditioner (AC) power consumption based on the DOE test procedure. The test procedure provides standardized results that help compare the performance of various units operating under the same conditions. A unit's usage in the field, however, will differ from the test procedure results depending on the conditions under which the appliance is operated. To establish a reasonable range of real-world energy consumption for portable ACs in residential applications, DOE relied largely on data from the Energy Information Administration's (EIA's) *2009 Residential Energy Consumption Survey* (RECS 2009).[1] The RECS survey is a national sample of housing units to collect statistical information on residential energy consumption and expenditures across the nation, along with data on energy-related characteristics of the housing units and occupants. The EIA constructed RECS 2009, which collected energy-related data for 12,083 housing units, to represent the household population of the United States.

Although a significant percentage of all portable ACs are used in residences, a smaller percentage are used in commercial settings. To calculate the energy use patterns of portable ACs in commercial applications, DOE relied largely on data from the EIA's 2012 *Commercial Building Energy Consumption Survey* (CBECS 2012).[2] The EIA constructed CBECS 2012, which collected energy-related data for 6,719 buildings, to represent the commercial building stock in the United States.

RECS 2009 and CBECS 2012 collected data on room air-conditioners that provide geographic location, building type, number of units, unit age, and use frequency. For this final rule analysis, DOE assumed that the subset of users who own and operate room ACs are representative of owners of portable AC units. The details of each survey sample are described in the following sections.

7.2 SURVEY SAMPLES

The following sections describe the data DOE examined to develop an understanding of portable AC usage and energy use in both residential and commercial applications. The data represent window- or wall-mounted room ACs, which DOE assumes are used in the same way as are portable ACs.

7.2.1 Sample for Residential Applications

DOE assumed that the ownership of a window- or wall- mounted AC in RECS 2009 could be used to approximate ownership of a portable AC. It selected the subset of RECS 2009 records that met the following criteria:

- At least one room AC was present in the household.
- The energy consumption of the room AC was greater than zero.
- The capacity of the room AC was less than 14,000 Btu/hr (a cooling capacity comparable to portable ACs as measured by industry test methods).
- The room being cooled measured no more than 1,000 square feet.

Table 7.2.1 provides details about the RECS 2009 records used to represent portable ACs. DOE used EIA's weightings for each RECS 2009 household in the sample. The weightings indicate how frequently each household configuration occurs in the general population. Although the total number of households and portable ACs presented in Table 7.2.1 correspond to room ACs in RECS 2009, DOE believes the weightings associated with each household represent the relative frequency of a household with a potential portable AC installation.

Table 7.2.1 Table 7.2.1 RECS 2009 Records Used for Residential Portable AC Sample

No. of Records	No. of U.S. Households Represented *million*	No. of Portable ACs Represented *million*
2,378	23.2	46.4

Sizing charts provided by vendors indicate that portable ACs are intended to cool rooms having an area as large as approximately 525 to 600 square feet.[3, 4] A review of retail websites, however, indicated portable ACs may be used in rooms as large as 1,000 square feet. DOE assumed 1,000 square feet to be the maximum room size a user would attempt to cool using a portable AC. In practice, only 60 records in the RECS 2009 sample (about 2 percent) represent rooms between 600 and 1,000 square feet. DOE determined the room size in RECS 2009 by dividing the total cooled square footage by the number of rooms and number of cooling units to determine the room square footage for a single portable AC.

As a sensitivity scenario, DOE also performed an analysis in which there was no room size threshold applied to the residential sample. The results of that scenario can be found in appendix 8F of this final rule TSD.

7.2.2 Sample for Commercial Applications

DOE assumed that the ownership of a window- or wall- mounted room AC in CBECS 2012 could be used to approximate ownership of a portable AC. DOE selected the subset of CBECS 2012 records that met all of the following criteria:

- A room AC served as a source of air conditioning.

- The room AC that the building has does not have a packaged terminal air conditioning type of heating system
- The building was not vacant.
- A room AC was used as the primary equipment to cool at least part of the building.

CBECS 2012 provides the total air conditioned square footage and the fraction of conditioning provided by a room AC for each building record, but it does not provide the number of room ACs in a given building. DOE therefore used the total conditioned square footage to determine its sample. Table 7.2.2 shows the number of CBECS 2012 records DOE used in its sample. DOE used EIA's weightings for each CBECS 2012 building in the sample. The weightings indicate how frequently each building configuration occurs throughout the United States.

Table 7.2.2 CBECS 2012 Records Used for Commercial Portable AC Sample

No. of Records	**No. of U.S. Buildings Represented** ***million***
580	0.53

7.3 ESTIMATES OF ENERGY USE

DOE calculated the annual energy consumption of a portable AC using the following equation:

$$PAC_{ENERGY} = \left(\frac{Total\ Hours\ of\ Use}{Year}\right) \times \left[\left(\frac{Capacity \times X_{COOL}}{EER}\right)\left(\frac{1}{1000}\right) + (X_{Fan} \times kW_{Fan}) + (X_{Stby} \times kW_{stby})\right]$$

Where:

PAC_{ENERGY} = annual energy consumption of portable AC (kWh/year),

$\frac{Total\ Hours\ of\ Use}{Year}$ = number of hours the portable AC is used per year (at > 0 W),

$Capacity$ = rated capacity in Btu/hr as measured by the test procedure for portable ACs,

EER = energy efficiency ratio (Btu/hr/W),

X_{Cool} = fraction of time in cooling mode,

X_{Fan} = fraction of time in fan-only mode,

kW_{Fan} = power consumption (in kW) of fan-only mode,

X_{Stby} = fraction of time in standby mode, and

kW_{Stby} = power consumption (in kW) of standby/off mode.

DOE estimated the energy consumption of residential portable ACs in both residential and commercial settings by using (1) variables specific to each building in the sample and (2) data on cooling degree-days (CDDs).[1] Furthermore, DOE made the following assumptions for its energy use analysis:

- The portable AC was installed according to manufacturer instructions (for example, a dual-duct unit would have both ducts properly installed and insulated).
- The number of operating hours spent in cooling mode for a window- or wall-mounted room AC in a RECS household or a CBECS enterprise could be used to approximate the hours a portable AC spends in cooling mode.
- The upper limit of total hours in either cooling or fan-only mode was estimated, assuming that a portable AC would be operated only in months having five or more CDDs that exceed 65 °F.
- The average capacity and EER at a given efficiency level can be used to represent the full range of capacities and EERs at that efficiency level.

Below, DOE describes in greater detail the method used to calculate annual energy consumption of portable ACs.

7.3.1 Weather Station Assignment

DOE began by assigning each RECS household or CBECS enterprise that used a room AC to one of the 321 weather stations operated by the National Oceanic and Atmospheric Administration (NOAA).[5] DOE identified the weather station that best matched the heating and cooling degree-days of the RECS 2009 household or the CBECS 2012 building (see appendix 7A for more details). The weather data were used to constrain the total hours of operation in all modes (i.e., cooling, fan, and standby). In addition, regional energy prices were weighted to summer months, when portable ACs likely would be used.

7.3.2 Operating Hours

This section describes DOE's estimate of operating hours for portable ACs used in both residential and commercial applications. For both sectors, DOE estimated the number of hours in cooling mode using the methodology established for room ACs. This assumes that a portable AC would be operated the same number of hours as a room AC. DOE adopts these hours of use as the reference scenario. As a sensitivity scenario, DOE also performs energy-use and LCC calculations, assuming that the hours of use in cooling mode for a portable AC is 50 percent of a room AC. These results can be found in appendix 8F of this final rule TSD.

7.3.2.1 Residential Applications

DOE estimated the number of hours a portable AC operates in cooling mode based on data for room ACs operating in cooling mode. DOE began with the data reported by RECS 2009 on the annual energy consumption (field energy consumption) for room air conditioning, referred

[1] DOE used the calculation methodology described in its Final Rule for Room ACs (2011).[1]

to as $FEC(all)_{RECS}$. The reported end-use quantities were not based on the metering of individual appliances; rather, EIA used a regression technique to estimate how much of each household's total annual electricity consumption was attributable to each end-use category.[2]

RECS 2009 reports the number of room ACs in each household. Of all homes that use a room AC, 32 percent have two room ACs, and 20 percent have three or more units. To estimate the energy consumption of a single room AC, referred to as $FEC_{RECS,}$ DOE divided $FEC(all)_{RECS}$ by the reported number of room ACs. For houses having both central air conditioning and room AC, DOE scaled $FEC(all)_{RECS}$ using a relative use factor. Although each portable AC in a home may be utilized for a different amount of time, DOE has no way to estimate such differences.

DOE calculated the annual cooling-mode operating hours for each portable AC in each residential sample using the following formula based on room AC methodology:

$$OH = \frac{FEC_{RECS} * EER_{RECS}}{Capacity} * BldgShellAdj * CDDAdj$$

Where:

OH =	operating hours per year,
FEC_{RECS} =	estimated field energy consumption for the room AC,
EER_{RECS} =	estimated EER of the room AC,
$Capacity$ =	capacity of the room AC in Btu/hr,
$BldgShellAdj$ =	adjustment for building shell efficiency in 2022 (%), and
$CDDAdj$ =	adjustment for cooling degree-days in 2022.

The derivation of FEC_{RECS} was discussed above. Households were assigned to the sub-samples based on the average adjusted capacity of the unit needed for the household. The average adjusted capacity was calculated based on ENERGY STAR sizing guidelines for room air conditioners combined with household characteristics such as shading, insulation, window and glass type, number of household members, and ceiling type.[6]

So that the estimated operating hours could represent future conditions, DOE used the 2022 building shell index factor of 0.97 for space cooling in all residences from the EIA's *Annual Energy Outlook 2016* (*AEO 2016*).[7] DOE applied a CDD adjustment to ensure the calculated operating hours reflect cooling needs in 2022. DOE first scaled the reported number of 2009 CDD for each *RECS* household by the the 10-year historical average CDD from 2005-2015. DOE then applied CDD trends using CDD projections by census division from *AEO 2016* to estimate the number of CDDs in 2022. Applying the building shell index factor decreased energy use by 3 percent; the overall CDD adjustment factor decreased energy use by 6 percent on average.

[2] The desire to use numerous independent variables without using a large number of interaction terms, and the desire to adapt the regression procedures to account for heteroscedastic error terms, led EIA to use a nonlinear regression technique. For more information, see: http://www.eia.gov/consumption/residential/methodology/2009/pdf/faqs-enduse-models022013.pdf.

DOE estimated the EER of the room AC in each sample household by matching the reported age of the unit with the average EER for the reported product class in the year of its vintage. DOE assumed a uniform distribution within each vintage bin, and assigned an age to the room AC in each RECS 2009 household. DOE calculated scalars for each year based on the ratio of the total shipments-weighted EER for that year to the calculated EER, then applied those scalars to the minimum efficiency required in each year. DOE adopted these hours of use for a room AC as the cooling mode hours of use for a portable AC unit.

Hours of operation of portable ACs in fan-only mode were based on field-metering data of residential installations of portable ACs.[8] DOE derived a distribution of the ratio of fan-only mode hours to cooling-mode hours, and used this distribution to randomly assign a ratio to each sample household, which allows estimation of fan-only mode hours of operation.

DOE assumed portable ACs would only be plugged in during months with five or more CDDs. The annual hours in standby mode were derived by subtracting the cooling-mode and fan-only mode hours of operation from the total number of hours in a months with five or more CDDs.

The sum of the cooling-mode and fan-only mode hours of operation give the total hours a portable AC is in use. The estimated mean operating hours for a portable AC is 612 in cooling mode and 333 in fan-only mode.

7.3.2.2 Commercial Applications

DOE calculated annual operating hours for portable ACs in the commercial sector using the method presented in the Room AC Final Rule (2011). DOE calculated the annual operating hours for each commercial-sector portable AC in its sample by establishing a relationship between CDD and operating hours for various combinations of building types and building schedules. DOE assumed that a portable AC is operated when outdoor air conditions exceed the comfort zone described by ANSI/ASHRAE Standard 55-2004.[9] To estimate how often those outdoor conditions are exceeded, DOE used the following equation:

$$OH55 = (a * CDD) + b$$

Where:

OH55 = average annual hours when outdoor air conditions exceed the ASHRAE Standard 55 comfort zone,
CDD = number of annual cooling degree-days (in excess of 65 °F) for a given location, and
a and *b* = linear fit parameters.

DOE used data on CDDs from the National Solar Radiation Database (NSRDB) for 1991–2010.[10] This database is an hourly ground-based set of solar and meteorological fields for 1,454 stations (see appendix 7B for more details). There is a complete 15-year data record for 858 of the 1,454 stations. After removing the NSRDB sites in Hawaii, Guam, and the Caribbean islands, DOE performed regressions to estimate the hours per year that exceed ASHRAE

Standard 55 based on the number of CDDs for each year. The data points and regression lines are shown in Figure 7.3.1 for all hours of the year. Each data point represents 15 years of data for 842 NSRDB sites in the continental United States.

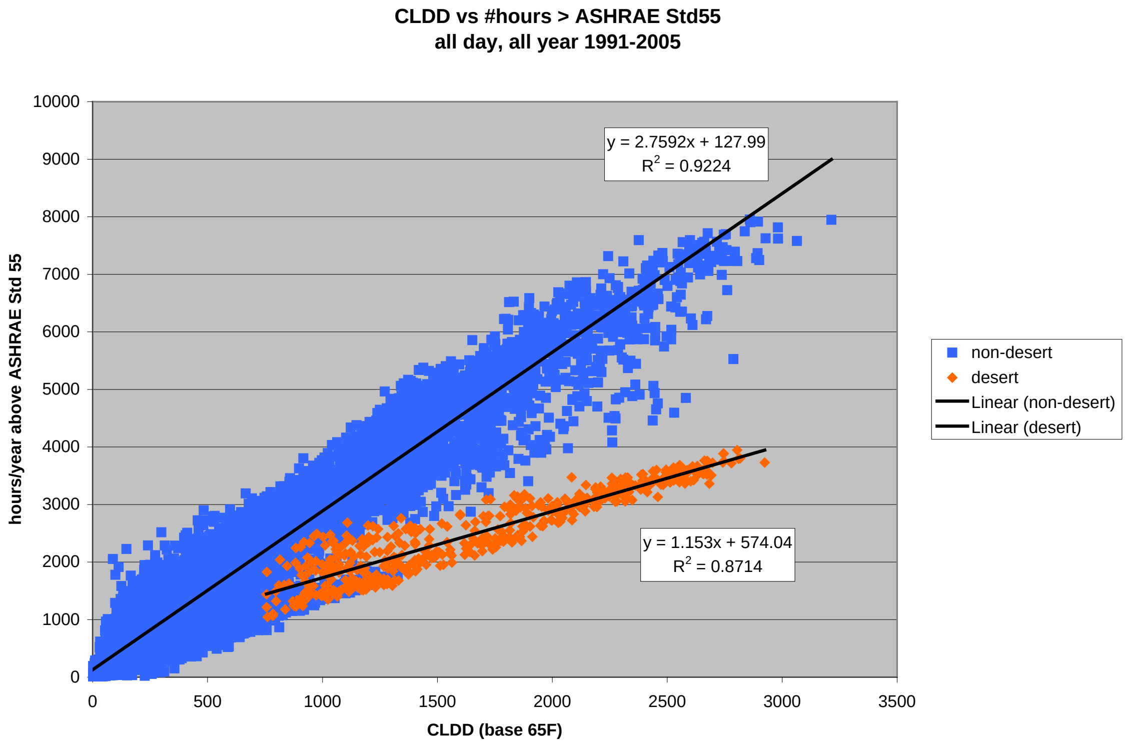

Figure 7.3.1 Number of Hours that Exceed ANSI/ASHRAE Standard 55 as a Function of Cooling Degree-Days

As Figure 7.3.1 illustrates, the data patterns differ for desert locations, where humidity does not affect comfort. The regression equations developed from the data are presented in Table 7.3.1.

Table 7.3.1 Regression Equations

Region	Equation	R^2	No. of Sites
Non-desert	OH55 = 2.759 x CDD + 127.99	0.9224	809
Desert	OH55 = 1.153 x CDD + 574.04	0.8714	33

For a given location, the annual number of hours that exceed the ASHRAE Standard 55 comfort zone varies by building schedule, which indicates the time that a building is open or in use. DOE performed the regression for many combinations of building type and schedule, yielding somewhat different equations for each combination. The building types included were assembly, education, food service, office, retail, and warehouse. For each building type, DOE estimated operating hours for the following schedules: (1) open 24 hours a day and 7 days a week; (2) open business hours Monday through Friday; (3) open business hours Monday through Saturday; (4) open business hours Monday through Friday and Sunday; (5) open business hours all week. Each schedule yielded a variation of the above equations.

To estimate the operating hours of room ACs for each building in the CBECS 2012 sample having a room AC, DOE identified the building type and schedule using information provided by CBECS, then used the appropriate equation (non-desert or desert) combined with the number of CDDs for the location of the building. DOE used a scaling factor to adjust the results to account for the difference between the number of building operating hours assumed for deriving the equations and the building operating hours reported by the CBECS 2012.

The above room AC approach provides the basis for determining the operating hours for the portable AC in a particular CBECS building. Operating hours are affected by some factors not included in the analysis, however, such as interior heat gains from equipment or people and solar gains. To develop a range for the number of operating hours for the portable AC in each sample building, DOE added an error band to the value derived using a regression equation. The error band includes values that are ± 10 percent from the regression line for the appropriate combination of building type and schedule. Operating hours for portable ACs in the commercial sector were estimated based on the cooling climate in 2012. To match the 10-year average CDD values from 2005-2015, DOE decreased the estimated operating hours in the commercial sector by 18 percent on average. DOE then used projected CDD trends from *AEO 2016* to adjust the number of CDDs projected in 2022.

Similar to the approach taken for the residential sector, hours of operation of portable ACs in fan-only mode were based on field-metering data of light commercial installations of portable ACs. DOE derived a distribution of the ratio of fan-only mode hours to cooling-mode hours, and used this distribution to randomly assign a ratio to each of the sample businesses, which allows estimation of fan-only mode hours of operation.

DOE assumed portable ACs would only be plugged in during months with five or more CDDs. The annual hours in standby mode were derived by subtracting the cooling-mode and fan-only mode hours of operation from the total number of hours in a months with five or more CDDs.

DOE calculated the mean number of operating hours as 1,561 in cooling mode and 592 in fan-mode only.

Figure 7.3.2 and Figure 7.3.3 show the range of average annual energy consumption by efficiency level for portable ACs within DOE's residential and commercial samples. For each efficiency level, the top and the bottom of the box indicate the 75th and 25th percentiles, respectively. The red line at the middle of the box indicates the median; 50 percent of households or establishments have energy-use values greater than this value. The "whiskers" at the bottom and the top of each box indicate the 5th and 95th percentiles with points outside the whisker reflecting all other values in the distribution. The yellow star shows the average energy use for each efficiency level. The figures illustrate the greater energy use of portable ACs in the commercial sector, although DOE estimates that commercial shipments represent 13 percent of total shipments.

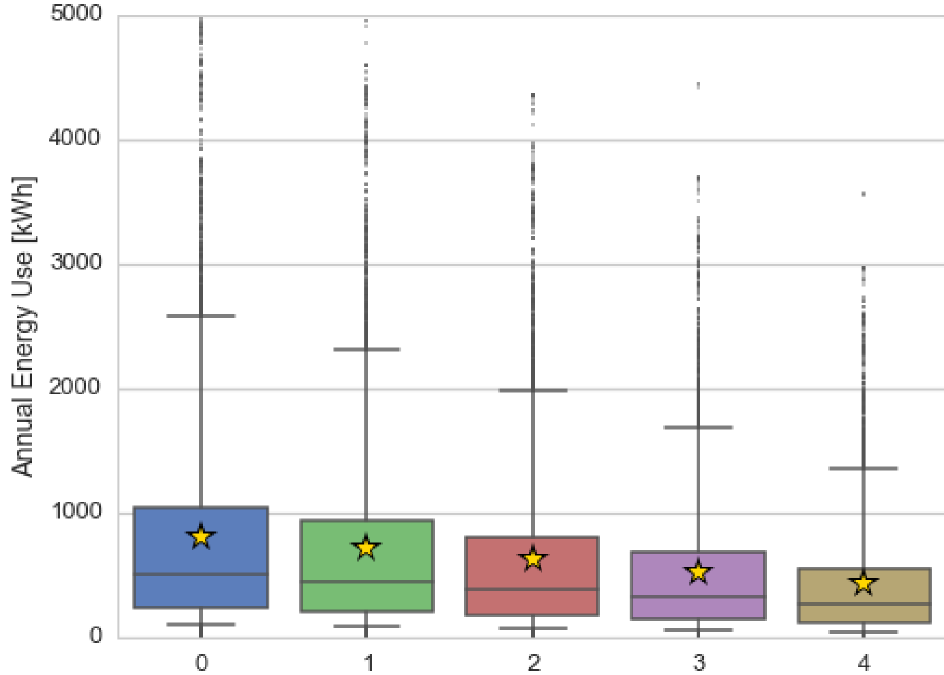

Figure 7.3.2 Range of Annual Energy Use for Portable Air Conditioners in the Residential Sector

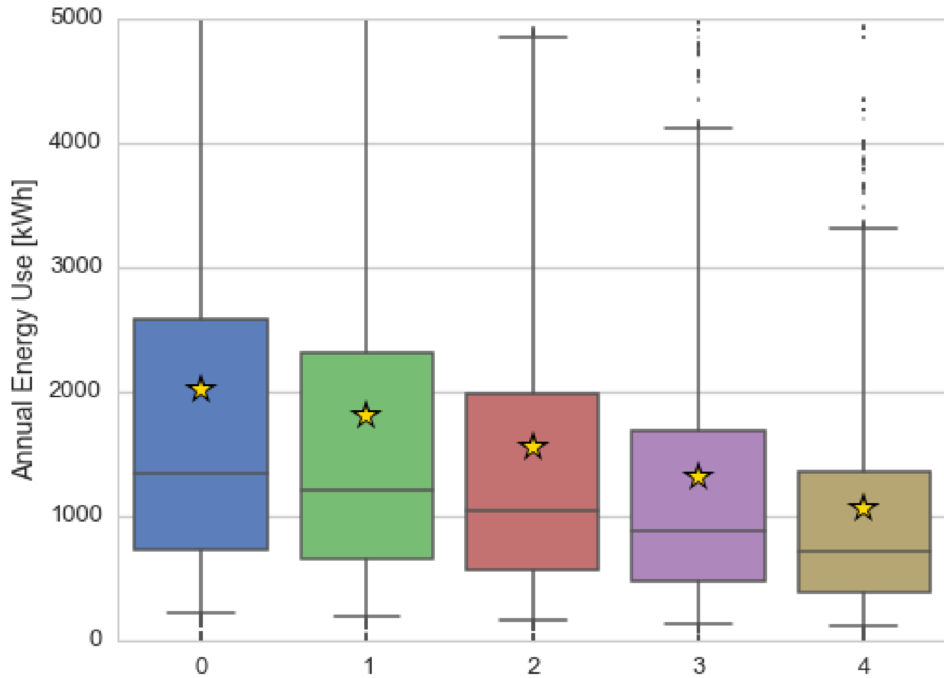

Figure 7.3.3 Range of Annual Energy Use for Portable Air Conditioners in the Commercial Sector

7.3.3 Average Annual Energy Consumption by Efficiency Level

Table 7.3.2 shows results for the baseline portable ACs and the levels DOE is considering for potential standards. Also shown is the overall average annual energy consumption calculated for combining energy use in both sectors, assuming that 87 percent of installations are in residential settings, and 13 percent are in commercial settings.

Table 7.3.2 Portable Air Conditioners: Average Annual Energy Use

Efficiency Level	Efficiency *EER*	Efficiency *CEER*	Residential Sector *kWh*	Commercial Sector *kWh*	Overall *kWh*
Baseline	5.35	5.08	804	2015	964
1	6.05	5.94	719	1801	862
2	7.15	7.13	618	1547	741
3	8.48	8.46	523	1312	627
4	10.75	10.73	422	1055	505

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CHAPTER 8. LIFE-CYCLE COST AND PAYBACK PERIOD ANALYSIS

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CHAPTER 8. LIFE-CYCLE COST AND PAYBACK PERIOD ANALYSIS

8.1 INTRODUCTION

This chapter describes the U.S. Department of Energy's (DOE's) method for analyzing the economic impacts of potential energy efficiency standards on individual consumers of portable air conditioners (ACs). The effects of standards on individual consumers include a change in operating expense (usually a decrease) and a change in purchase price (usually an increase). This chapter describes three metrics DOE used to determine the impact of standards on individual consumers:

- **Life-cycle cost** (LCC) is the total consumer expense during the lifetime of an appliance, including purchase expense and operating costs (including electricity expenditures). DOE discounts future operating costs to the time of purchase and sums them over the lifetime of the product.

- **Payback period** (PBP) measures the amount of time it takes a consumer to recover the assumed higher purchase price of a more energy efficient product through lower operating costs. DOE calculates a simple payback period which does not discount operating costs and average values for installed cost and first-year operating costs.

- **Rebuttable payback period** is a special case of the PBP. Whereas LCC is estimated for a range of inputs that reflect real-world conditions, rebuttable payback period is based on laboratory conditions, specifically the DOE test procedure.

Inputs to the LCC and PBP calculations are described in sections 8.2 and 8.3, respectively, of this chapter. Results of the analysis are presented in section 8.4. Key variables and calculations are presented for each metric. The calculations discussed here are illustrated with a Microsoft Excel spreadsheet available on the DOE's rulemaking website at (http://www.eere.energy.gov/buildings/appliance_standards/). Details and instructions for using the spreadsheets are provided in appendix 8A.

8.1.1 General Approach to Analysis

Because portable AC installations are not identical, DOE incorporates variability and uncertainty into the LCC calculations for a broad sample of purchasers. The results estimate the number of installations that experience various economic impacts. The LCC analysis employs Monte Carlo simulations and probability distributions to explicitly model both the uncertainty and the variability in the model's inputs (see appendix 8B). In addition to using probability distributions to characterize several of the inputs to the analysis, DOE developed a sample of individual households that use portable ACs. By developing household samples, DOE was able to perform the LCC calculations to account for the variability in energy consumption and/or energy price associated with each household. DOE also developed a sample of commercial buildings that use portable ACs.

As described in chapter 7 of this final rule TSD, DOE used the DOE Energy Information Administration (EIA)'s 2009 *Residential Energy Consumption Survey* (RECS 2009) to develop household samples for portable air conditioners based on households that use room ACs.[1] The EIA constructed RECS 2009, which consists of 12,083 housing units, to be representative of the household population of the United States. DOE was able to assign a unique annual energy use and/or energy price to each household in the sample. The large sample of households considered in the analysis provides wide ranges of annual energy use and energy prices. (The ranges in energy consumption are presented in chapter 7 of this final rule TSD.) The variability in annual energy use and/or energy pricing across households contributes to the range of LCCs calculated for any particular efficiency level. DOE also used the EIA's 2012 *Commercial Buildings Energy Consumption Survey* (CBECS 2012) to develop a sample of commercial buildings that use portable ACs, again based on buildings that use room ACs.[2] The EIA constructed the 2012 CBECS, which consists of 6,720 commercial buildings, to be representative of commercial buildings throughout the United States. DOE utilized CBECS 2012 as it did RECS 2009 to develop a broad sample of buildings that use portable ACs and to establish the variability of annual energy use and energy prices.

DOE displays the LCC savings results as distributions of impacts relative to the absence of a new energy conservation standard (hereafter referred to as the "no-new-standard case"). Results, presented in section 8.4, were derived from 10,000 samples for each Monte Carlo simulation run for the reference scenario. To illustrate the implications of the analysis, DOE generated frequency charts that depict the variation in LCC for each efficiency level considered for potential standards for portable ACs. In addition to the reference scenario, DOE performed sensitivity scenarios to investigate the impact of adopting different inputs. The results of the alternative LCC scenarios can be found in appendix 8F of this final rule TSD.

8.1.2 Overview of Inputs to Analysis

DOE categorizes inputs to the LCC and PBP analysis as: (1) inputs for establishing the purchase expense, otherwise known as *total installed cost,* and (2) inputs for calculating operating costs.

Following are the primary inputs for establishing the total installed cost:

- *Baseline manufacturer cost*: The costs incurred by the manufacturer to produce products that meet current minimum efficiency standards, if any.

- *Efficiency-level manufacturer cost increase*: The change in manufacturer cost associated with producing products to meet a particular efficiency level.

- *Markups and sales tax*: The markups and sales tax associated with converting the manufacturer cost to a consumer product cost.

- *Installation cost*: The cost to the consumer of installing the product. The installation cost represents all costs required to install the product other than the marked-up consumer product cost. The installation cost includes labor, overhead, and any miscellaneous materials and parts. Thus, the total installed cost equals the consumer product cost plus the installation cost.

Following are the primary inputs for calculating the operating cost.

- *Product energy consumption*: The product energy consumption is the site energy use associated with operating the product.

- *Product efficiency*: The product efficiency dictates the energy consumption associated with products that have efficiencies greater than the baseline efficiency.

- *Energy prices*: Energy prices are the prices paid by consumers for energy (e.g., electricity or gas).
- *Energy price trends*: DOE used the EIA *Annual Energy Outlook 2016,* reference case (hereafter, AEO 2016)[3] to forecast future energy prices for the results presented in this chapter of the final rule TSD. Electricity prices were escalated by the AEO 2016 no-CPP case forecasts to estimate future prices.

- *Repair and maintenance costs*: Repair costs are associated with repairing or replacing components that fail. Maintenance costs are associated with maintaining the operation of the product.

- *Lifetime*: The age at which the product is retired from service.

- *Discount rate*: The rate at which DOE discounts future expenditures to establish their present value.

The data inputs to the PBP are the average total installed cost (product cost and installation cost) to the consumer plus the average annual (first-year) operating costs for each efficiency level. The inputs to operating costs are the annual energy cost, the annual repair cost, and the annual maintenance cost. Because the PBP represents a simple payback, the energy price is required only for the year in which a potential energy conservation standard is estimated to take effect. The energy price DOE uses in the PBP calculation is the price projected for that year.

Figure 8.1.1 depicts the relationships among the inputs to installed cost and operating cost for calculating a product's LCC and PBP. In the figure, the yellow boxes indicate inputs, the green boxes indicate intermediate outputs, and the blue boxes indicate final outputs (the LCC and PBP).

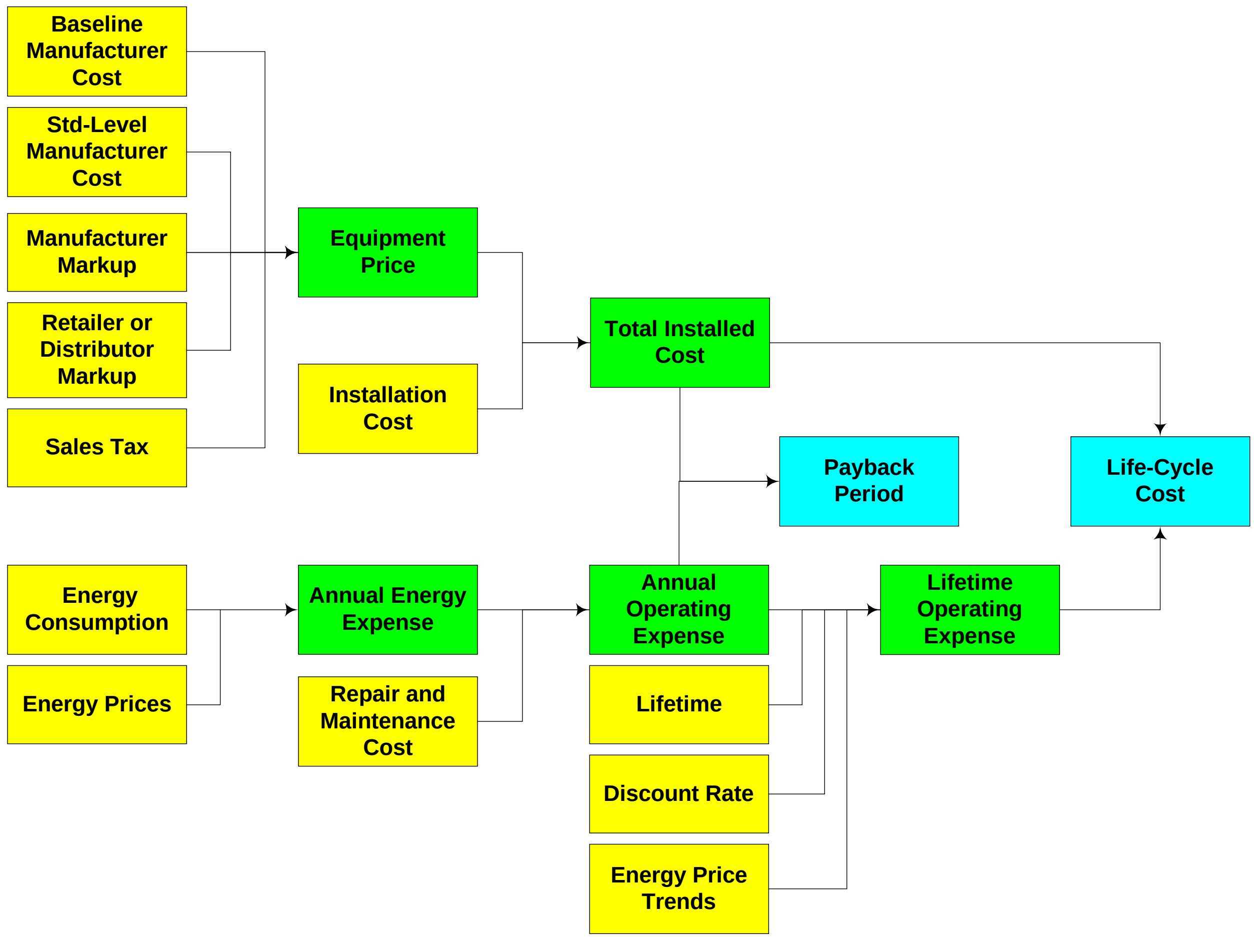

Figure 8.1.1 Flow Diagram of Inputs and Outputs for LCC and PBP

Table 8.1.1 summarizes the input values that DOE used to calculate the LCC and PBP for portable ACs. The table summarizes the inputs to total installed cost and operating costs, including the product lifetime, discount rate, and energy price trends. DOE used single-point values to characterize all the inputs to total cost, but characterized several inputs to operating cost using probability distributions that capture the input's uncertainty and/or variability. For those inputs characterized using probability distributions, the values provided in Table 8.1.1 are average or typical values.

Table 8.1.1 Summary of Inputs to LCC and PBP Analysis

Input	Average or Typical Value	Characterization
Baseline manufacturer production cost (2015$)	$316.02	Single-point value
Efficiency-level (EL) manufacturer cost increase (2015$)	EL 1 = $18.95 EL 2 = $50.57 EL 3 = $93.84 EL 4 = $115.53	Single-point value
Manufacturer markup	1.42	Single-point value
Retailer markup	Baseline = 1.39 Incremental = 1.13	Single-point value
Sales tax	7.1%	Variable based on region
Installation cost (2015$)	$0.00	Single-point value
Annual energy use	Baseline residential use = 804 kWh Baseline commercial use = 2014 kWh	Variable based on usage
2014 average energy prices (2015$)	Residential = $0.155 $/kWh Commercial = $0.127 $/kWh	Variable based on region
2014 marginal energy prices (2015$)	Residential = $0.156 $/kWh Commercial =$0.124 $/kWh	Variable based on region
Annual baseline maintenance costs	$0.00	Single-point value
Lifetime	10.5 years	Weibull distribution
Discount rate	Mean Residential = 4.4% Mean Commercial = 5.0%	Custom distribution based on purchaser sample
Energy price trend	AEO 2016, reference case	Time series

8.1.3 Distribution Channel

The LCC and PBP analysis uses separate values for replacement products and for products purchased by consumers who have not owned a portable AC previously (first-time owners) or are buying an additional unit. The type of application affects some variables, such as markups, installation costs, and discount rates. For portable ACs, DOE assumed that there would be no builder-installed products in newly constructed homes or commercial buildings. The derivation of the appropriate values for replacement applications is described in chapter 6 of this final rule TSD for markups, and in this chapter for installation costs and discount rates.

8.2 INPUTS TO LIFE-CYCLE COST

The LCC is the total consumer expense during the life of an appliance, including purchase expense and operating costs (including energy expenditures). DOE discounts future operating costs to the time of purchase and sums them over the lifetime of the product. DOE defines LCC by the following equation:

$$LCC = IC + \sum_{t=1}^{N} \frac{OC_t}{(1+r)^t}$$

Where:

LCC = life-cycle cost in dollars,
IC = total installed cost in dollars,
$\sum$ = sum over product lifetime, from year *1* to year *N*,
N = lifetime of appliance in years,
OC = operating cost in dollars,
r = discount rate, and
t = year for which operating cost is being determined.

DOE expresses dollar values in 2015$ for the LCC.

8.2.1 Inputs to Total Installed Cost

DOE defines the total installed cost using the following equation:

$$IC = CPC + INST$$

Where:

CPC = consumer product cost (i.e., consumer cost for the product only), and
INST = installation cost (the consumer cost to install the product).

The product cost depends on how the consumer purchases the product. As discussed in chapter 6 of this final rule TSD, DOE defines markups and sales taxes to convert manufacturing costs into consumer product costs. Table 8.2.1 summarizes the inputs for determining total installed cost.

Table 8.2.1 Inputs to Total Installed Cost

Baseline manufacturer cost
Efficiency-level manufacturer cost increase
Markups
Sales tax (part of markups)
Installation cost

The *baseline manufacturer cost* is the cost incurred by the manufacturer to produce products that meet current minimum efficiency standards, if any. *Efficiency-level manufacturer cost increase* is the change in manufacturer cost associated with producing products at a higher efficiency level. *Markups and sales tax* convert the manufacturer cost to a consumer product cost. The *installation cost* represents all costs to the consumer for installing the product, other than the marked-up consumer product cost. The installation cost includes labor, overhead, and any miscellaneous materials and parts. DOE calculated the total installed cost for baseline products using the following equation:

$$\begin{aligned} IC_{BASE} &= CPC_{BASE} + INST_{BASE} \\ &= COST_{MFG} \times MU_{OVERALL\_BASE} + INST_{BASE} \end{aligned}$$

Where:

IC_{BASE} = baseline total installed cost,
CPC_{BASE} = consumer product cost for baseline model,
$INST_{BASE}$ = baseline installation cost,
$COST_{MFG}$ = manufacturer cost for baseline model, and
$MU_{OVERALL\_BASE}$ = overall baseline markup (product of manufacturer markup, baseline retailer and/or distributor markup, and sales tax).

DOE calculated the total installed cost for products at higher efficiency levels using the following equation:

$$\begin{aligned} IC_{EL} &= CPC_{EL} + INST_{EL} \\ &= \left(CPC_{BASE} + \Delta CPC_{EL}\right) + \left(INST_{BASE} + \Delta INST_{EL}\right) \\ &= \left(CPC_{BASE} + INST_{BASE}\right) + \left(\Delta CPC_{EL} + \Delta INST_{EL}\right) \\ &= IC_{BASE} + \left(\Delta COST_{MFG} \times MU_{OVERALL\_INCR} + \Delta INST_{EL}\right) \end{aligned}$$

Where:

IC_{EL} = total installed cost for higher-efficiency product,
CPC_{EL} = consumer product cost for higher-efficiency product,

$INST_{EL}$ = installation cost for higher-efficiency product,
CPC_{BASE} = consumer product cost for baseline product,
ΔCPC_{EL} = change in product cost for higher-efficiency product,
$INST_{BASE}$ = baseline installation cost,
$\Delta INST_{EL}$ = change in installation cost for higher-efficiency product,
IC_{BASE} = baseline total installed cost,
$\Delta COST_{MFG}$ = change in manufacturer cost for higher-efficiency product, and
$MU_{OVERALL\_INCR}$ = incremental overall markup (product of manufacturer markup, incremental retailer or distributor markup, and sales tax for higher-efficiency product).

The rest of this section provides information about each of the above input variables that DOE used to calculate the total installed cost of portable ACs.

8.2.1.2 Baseline Manufacturer Cost

DOE developed the baseline manufacturer costs for portable ACs as described in chapter 5 of this final rule TSD. Table 8.2.2 shows the manufacturer cost for a baseline model that performs at an energy efficiency ratio (EER) of 5.35.

Table 8.2.2 Portable ACs: Baseline Manufacturer Cost

Baseline EER	Manufacturer Cost *2015$*
5.35	$316.02

8.2.1.3 Efficiency-Level Manufacturer Cost Increases

DOE used a reverse-engineering analysis to develop manufacturer cost increases associated with increases in efficiency levels for portable ACs. Refer to chapter 5 of this final rule TSD for details.

8.2.1.4 Overall Markup

The overall markup on a product is determined by multiplying the manufacturer and retailer markups and the sales tax together to arrive at a single markup value. Table 8.2.3 shows the overall baseline and incremental markups for portable ACs. Incremental markups are those that apply to products at higher efficiency levels manufactured under a potential energy efficiency standard. Refer to chapter 6 of this final rule TSD for details.

Table 8.2.3 Portable ACs: Overall Markups

Markup	Baseline Markup	Incremental Markup
Manufacturer	1.42	
Retailer	1.39	1.13
Sales Tax	1.071	
Overall	2.11	1.72

8.2.1.5 Installation Cost

The cost of installation covers all labor and material costs associated with installing a portable AC in a residence or business enterprise. DOE's research indicates that installation cost for a portable AC is independent of efficiency; therefore, DOE assumed an installation cost of $0 for all efficiency levels.

8.2.2 Forecasting Future Product Prices

Historical price data for certain appliances and equipment that have been subject to energy conservation standards indicate that the assumption of constant real prices and costs may overestimate long-term trends in appliance and equipment prices. Economic literature and historical data suggest that the real costs of products may trend downward over time based on "learning" or "experience" curves. According to the experience curve approach, the real cost of production is related to the cumulative production or "experience" with a product. An extensive literature describes the learning or experience curve phenomenon, which typically is based on observations in the manufacturing sector. Desroches et al. (2013)[4] and Weiss et al. (2010)[5] summarize the data and literature available to DOE that are relevant to forecasting prices for certain appliances and equipment.

Typically, DOE uses historical shipments data to estimate cumulative shipments (production). The historical shipments data for portable ACs are, however, too limited to use to construct robust cumulative production estimates for portable ACs. Therefore, DOE decided to use the most representative Producer Price Index (PPI) series for portable ACs to fit to an exponential model having *year* as the explanatory variable. In this case, the exponential function takes the form of:

$$Y = a \cdot e^{bX}$$

where *Y* is the proxy for portable AC price, *a* is the constant, *b* is the slope parameter of the time variable, and *X* is the time variable.

To derive the exponential parameters for portable ACs, DOE obtained historical PPI data for "small electric household appliances, except fans" from the Bureau of Labor Statistics for

1983 to 2015.[a, b] Although this PPI series encompass more than portable ACs, no PPI data specific to portable ACs were available. The PPI data reflect nominal prices, adjusted for changes in product quality. DOE calculated an inflation-adjusted (deflated) price index by dividing the PPI series by the Gross Domestic Product Chained Price Index. The deflated price index is presented in 2015 dollars. Figure 8.2.1 presents the nominal and inflation-adjusted PPI trends for portable ACs from 1983 to 2015.

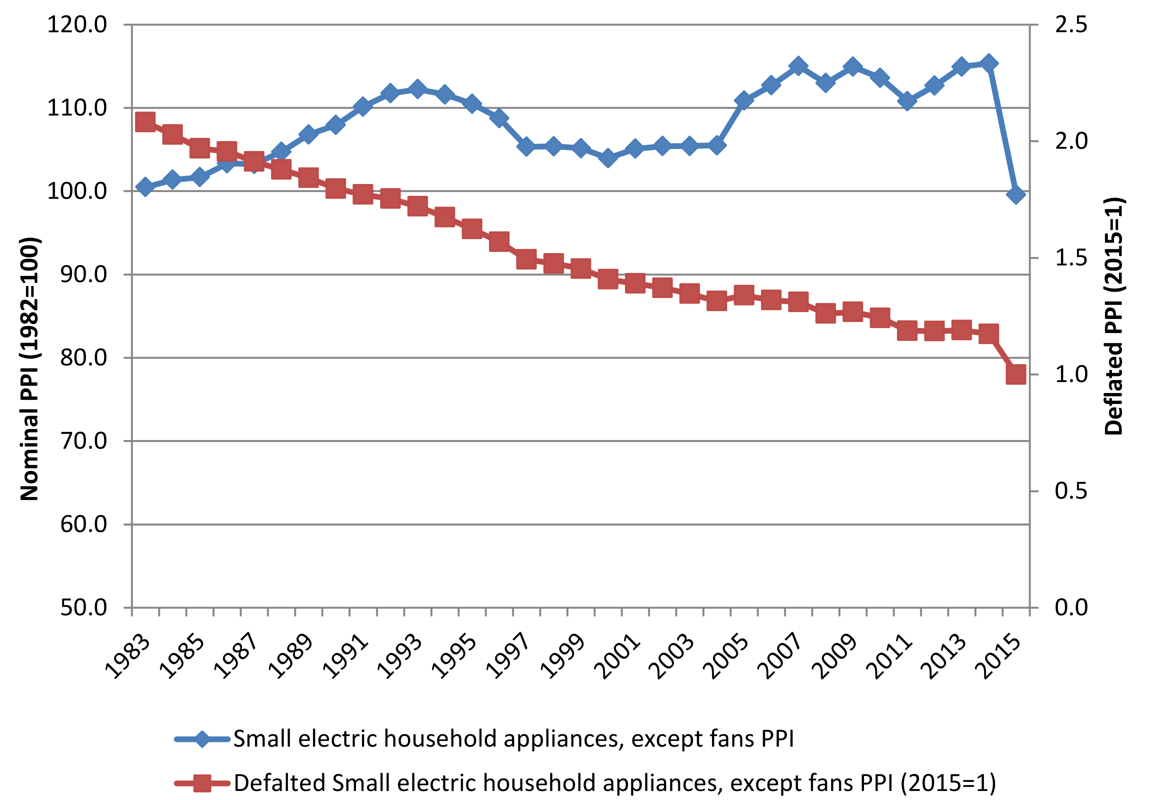

Figure 8.2.1 Nominal and Deflated PPI Series for Small Electric Household Appliances from 1983 to 2015

For portable ACs, the regression performed as an exponential trend line fit results in an R-square of 0.98, which indicates a superior fit to the data. The fit results in a 1.96-percent annual rate of price decline. The final estimated exponential function for portable ACs is:

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[a] Series ID PCU33521033521014; http://www.bls.gov/ppi/.

[b] DOE used a different PPI series to estimate the price trend of room ACs because the Bureau of Labor Statistics (BLS) publishes another PPI series, room air-conditioners and dehumidifiers, except portable dehumidifier (PCU3334153334156), that is more specific to room ACs. The PPI series used to estimate price trend of portable ACs is also used for portable dehumidifiers.

$$Y = 2.160 \times 10^{17} \cdot e^{(-0.019765)X}$$

Based on the fitted regressions, DOE derived a price factor index for portable ACs for each future year in the analysis period (2022–2051). For the LCC and PBP analysis, DOE renormalized the price factor index, 2013 (the year in which the engineering analysis of this final rule TSD was conducted) equal to 1, to estimate the price of portable ACs in 2022, the expected year of any new energy efficiency standard for portable ACs. In 2022, the price factor is 0.837, meaning that the projected price for portable ACs in 2022 is 0.837 relative to the 2013 price.

8.2.3 Total Installed Cost

The total installed cost is the sum of the consumer product cost and installation cost. Table 8.2.4 presents the total installed costs in 2022 for the portable ACs in the residential and commercial sectors, accounting for the effects of the learning curve. Costs are presented at the baseline level and each efficiency level identified in chapter 5 of this final rule TSD.

Table 8.2.4 Portable ACs: Total Installed Costs in 2022

Efficiency Level	Efficiency *EER*	Efficiency *CEER*	Installed Cost *2015$*
Baseline	5.35	5.08	559
1	6.05	5.94	588
2	7.15	7.13	635
3	8.48	8.46	700
4	10.75	10.73	733

8.2.4 Inputs to Operating Cost

DOE defines a product's operating cost (OC) using the following equation:

$$OC = EC + RC + MC$$

Where:

EC = energy expenditure associated with operating the product,
RC = repair cost associated with component failure, and
MC = cost for maintaining product operation.

Table 8.2.5 shows the inputs for determining the annual operating costs and their discounted value throughout a product's lifetime.

Table 8.2.5 Inputs to Operating Costs

Annual energy consumption
Energy prices and price trends
Repair and maintenance costs

The *annual energy consumption* is the site energy use associated with operating the product. The annual energy consumption changes with product efficiency. *Energy prices* are the prices paid by consumers for energy (e.g., electricity or gas). Multiplying the annual energy consumption by the energy price yields the annual energy cost. *Repair costs* are associated with repairing or replacing components that fail. *Maintenance costs* are associated with maintaining the operation of the product. DOE used energy price trends to forecast energy prices into the future and to establish the present value of lifetime energy costs.

DOE calculated the annual operating cost for baseline products using the following equation:

$$OC_{BASE} = (AEC_{BASE} \times PRICE_{ENERGY}) + RC_{BASE} + MC_{BASE}$$

Where:

OC_{BASE} = operating cost for baseline product,
AEC_{BASE} = annual energy consumption for baseline product,
$PRICE_{ENERGY}$ = energy price,
RC_{BASE} = repair cost associated with component failure for baseline product, and
MC_{BASE} = cost for maintaining baseline product.

DOE calculated the annual operating cost for higher-efficiency products using the following equation:

$$OC_{EL} = (AEC_{EL} \times PRICE_{ENERGY}) + RC_{EL} + MC_{EL}$$

Where:

OC_{EL} = operating cost for higher-efficiency product,
AEC_{EL} = annual energy consumption for higher-efficiency product,
$PRICE_{ENERGY}$ = energy price,
RC_{EL} = repair cost associated with component failure for higher-efficiency product, and
MC_{EL} = cost for maintaining higher-efficiency product.

The rest of this section provides information about each of the above input variables that DOE used to calculate the operating costs for portable ACs.

8.2.4.1 Annual Energy Consumption

As described in chapter 7 of this final rule TSD, and in section 8.1.1 of this chapter, DOE used data from RECS 2009 and CBECS 2012 to develop a sample of individual households and commercial buildings that have portable ACs. DOE performed the LCC calculation for each household and commercial enterprise in its samples to account for the variability in both energy use and energy price. Table 8.2.6 provides the average annual energy consumption by efficiency level for portable ACs in residential and commercial applications.

Table 8.2.6 Average Annual Energy Use by Efficiency Level for Residential and Commercial Applications

Efficiency Level	Efficiency *EER*	Efficiency *CEER*	Residential Sector *kWh*	Commercial Sector *kWh*	Overall *kWh*
Baseline	5.35	5.08	804	2015	964
1	6.05	5.94	719	1801	862
2	7.15	7.13	618	1547	741
3	8.48	8.46	523	1312	627
4	10.75	10.73	422	1055	505

8.2.4.2 Electricity Prices

DOE used average and marginal prices, which vary by region and baseline electricity consumption level. Average prices are used to calculate the operating cost savings of a baseline portable AC unit. Marginal prices are used to calculate the operating cost savings of more efficient portable AC units above the baseline level. That is, the marginal electricity prices are applied to the difference in annual operational electricity between a more efficient standard level product (efficiency levels 1, 2, etc.) and the baseline (efficiency level 0) product. DOE estimated these prices using data published with the Edison Electric Institute (EEI) Typical Bills and Average Rates reports for summer and winter 2014.[6] For the residential sector, the reports provide the total bill, assuming household consumption levels of 500, 750, and 1,000 kilowatt-hours (kWh) for the billing period for most of the major investor-owned utilities (IOUs) in the country. For the commercial sector, the reports provide typical bills for several combinations of monthly electricity peak demand and total consumption.

For both the residential and commercial sectors, DOE defined the average price as the ratio of the total bill to the total electricity consumption. For the residential sector, DOE used the EEI data also to define a marginal price as the ratio of the change in the bill to the change in energy consumption. For the commercial sector, marginal prices cannot be estimated directly from the EEI data. Commercial building marginal prices depend on both the change in electricity consumption and the change in monthly peak-coincident demand.

Regional weighted-average values for each type of price were calculated for the nine census divisions and four large states (California, Florida, New York, and Texas). Each EEI utility in a region was assigned a weight based on the number of consumers it serves; hence, the utility weight for the residential and commercial sectors may be slightly different. Consumer counts were taken from the most recent EIA Form 861 data (2012).[7] DOE adjusted these regional weighted-average prices to account for systematic differences between IOUs and publicly owned utilities (POUs), as the latter are not included in the EEI data set. For each region and sector, DOE estimated a correction factor based on the ratio of the average electricity price for IOUs to the average price charged by POUs (calculated using EIA form 861 data), and the percentage of consumers served by POUs.

DOE assigned average and marginal prices to each household or commercial building in the LCC sample based on its location and its baseline monthly electricity consumption. Average and marginal electricity prices by season are presented in Table 8.2.7 and Table 8.2.8 for the residential and commercial sector, respectively.

Table 8.2.7 Average Summer and Winter Residential Electricity Prices in 2014

RECS Region	Summer		Winter	
	Average 2015$/kWh	**Marginal 2015$/kWh**	**Average 2015$/kWh**	**Marginal 2015$/kWh**
Connecticut, Maine, New Hampshire, Rhode Island, Vermont	0.182	0.168	0.184	0.171
Massachusetts	0.183	0.168	0.185	0.171
New York	0.212	0.185	0.266	0.235
New Jersey	0.153	0.149	0.148	0.138
Pennsylvania	0.153	0.149	0.147	0.138
Illinois	0.136	0.126	0.128	0.114
Indiana, Ohio	0.136	0.126	0.127	0.113
Michigan	0.137	0.126	0.128	0.114
Wisconsin	0.137	0.126	0.128	0.114
Iowa, Minnesota, North Dakota, South Dakota	0.130	0.117	0.114	0.095
Kansas, Nebraska	0.129	0.117	0.114	0.095
Missouri	0.128	0.117	0.112	0.093
Virginia	0.122	0.116	0.116	0.102
Delaware, District of Columbia, Maryland	0.123	0.116	0.117	0.103
Georgia	0.122	0.117	0.116	0.103
North Carolina, South Carolina	0.122	0.116	0.116	0.102
Florida	0.112	0.101	0.111	0.100
Alabama, Kentucky, Mississippi	0.118	0.102	0.113	0.092
Tennessee	0.119	0.102	0.112	0.092
Arkansas, Louisiana, Oklahoma	0.108	0.100	0.096	0.080
Texas	0.119	0.111	0.107	0.098
Colorado	0.123	0.122	0.117	0.105
Idaho, Montana, Utah, Wyoming	0.123	0.122	0.115	0.105
Arizona	0.123	0.122	0.115	0.105
Nevada, New Mexico	0.123	0.122	0.117	0.105
California	0.211	0.345	0.196	0.324
Oregon, Washington	0.143	0.136	0.141	0.136
Alaska	0.215	0.344	0.222	0.331
Hawaii	0.214	0.346	0.205	0.326
West Virginia	0.122	0.116	0.115	0.102

Table 8.2.8 Average Summer and Winter Commercial Electricity Prices in 2014

	Summer		Winter	
Census Division	**Average 2015$/kWh**	**Marginal 2015$/kWh**	**Average 2015$/kWh**	**Marginal 2015$/kWh**
New England	0.156	0.171	0.162	0.168
Middle Atlantic	0.140	0.145	0.146	0.160
East North Central	0.114	0.127	0.106	0.115
West North Central	0.108	0.102	0.089	0.084
South Atlantic	0.103	0.098	0.100	0.093
East South Central	0.115	0.111	0.109	0.104
West South Central	0.097	0.090	0.084	0.076
Mountain	0.102	0.092	0.093	0.085
Pacific	0.179	0.142	0.123	0.106

Monthly Electricity Prices. Portable ACs are used during the warm months of the year. As described in chapter 7 of this final rule TSD, DOE assigned each household and commercial enterprise to a NOAA weather station. After matching the household or enterprise to a weather station, DOE utilized the monthly data for cooling degree-days from the corresponding weather station to estimate the relative fraction of cooling degree-days by month (see appendix 7A for more details). DOE divided the number of cooling degree-days in each month by the total number of cooling degree-days in the year for the corresponding weather station. DOE assumed the relative fraction of cooling degree-days by month reflects the appropriate weighting of electricity usage by month. DOE used these weighting factors in conjunction with the seasonal prices described above to determine the average annual electricity price for each household.

8.2.4.3 Electricity Price Trends

To estimate energy prices in future years, DOE multiplied the recent electricity prices by a projection of annual national-average residential and commercial electricity prices consistent with cases described on p. E-8 in *AEO 2016*. [c] To estimate the trend after 2040, DOE followed past guidelines provided by the EIA to the Federal Energy Management Program, applying the average rate of change during 2025–2040 to future prices. DOE calculated LCC and PBP using *AEO 2016*. Figure 8.2.1 and Figure 8.2.2 show residential and commercial electricity price trends.

c The standards finalized in this rulemaking will take effect a few years prior to the 2022 commencement of the Clean Power Plan compliance requirements. As DOE has not modeled the effect of CPP during the 30-year analysis period of this rulemaking, there is some uncertainty as to the magnitude and overall effect of the energy efficiency standards. These energy efficiency standards are expected to put downward pressure on energy prices relative to the projections in the AEO 2016 case that incorporates the CPP. Consequently, DOE used the electricity price projections found in the AEO 2016 No-CPP case as these electricity price projections are expected to be lower, yielding more conservative estimates for consumer savings due to the energy efficiency standards.

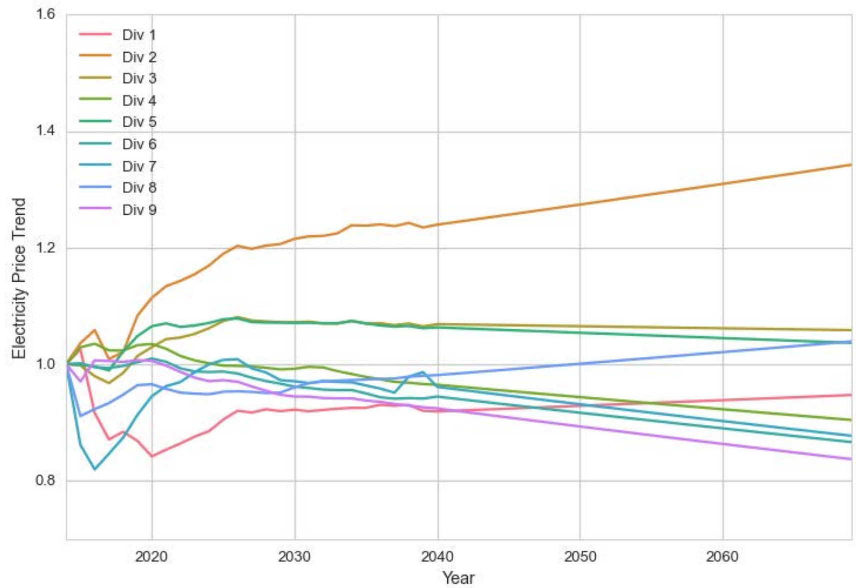

Figure 8.2.1 Residential Electricity Price Trend by Census Division from *AEO 2016*

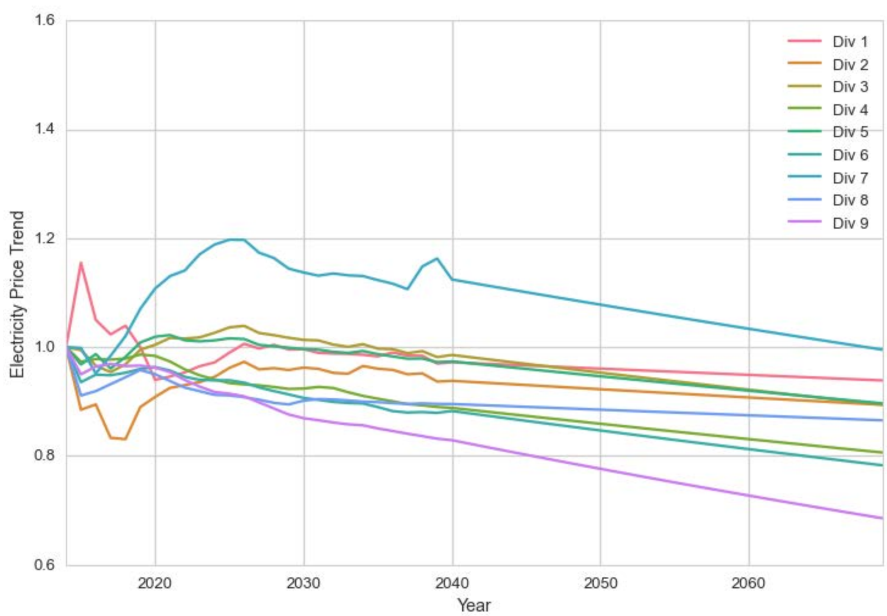

Figure 8.2.2 Commercial Electricity Price Trend by Census Division from *AEO 2016*

The maintenance cost is the cost of regular scheduled product maintenance. The repair cost is the cost to repair a product when it fails. Typically, small incremental changes in product efficiency incur no, or only very small, changes in repair and maintenance costs compared to baseline products. For portable ACs, available data showed that repair frequencies are low and do not increase for higher-capacity or higher-efficiency units. Because repair and maintenance costs do not increase with efficiency level, DOE assumed a cost of $0 for all efficiency levels.

8.2.5 Product Lifetime

The product lifetime is the age at which a product is retired from service. Rather than use a single average value for the lifetime of portable ACs, DOE developed a lifetime distribution to characterize the probability a portable AC will be retired from service at a given age. This section describes the survival function DOE developed for its analysis.

DOE assumed that the probability function for the annual survival of portable ACs would take the form of a Weibull distribution. A Weibull distribution is a probability distribution commonly used to measure failure rates.[d] Its form is similar to an exponential distribution, which models a fixed failure rate, except that a Weibull distribution allows for a failure rate that changes over time in a specific fashion. The cumulative Weibull distribution takes the form:

$$P(x) = e^{-\left(\frac{x-\theta}{\alpha}\right)^{\beta}} \text{ for } x > \theta \text{ and}$$

$$P(x) = 1 \text{ for } x \leq \theta$$

Where:

$P(x)$ = probability that the appliance is still in use at age x,
x = age of appliance in years,
θ = delay parameter, which allows for a delay before any failures occur,
α = scale parameter, which would be the decay length in an exponential distribution, and
β = shape parameter, which determines the way in which the failure rate changes through time.

When $\beta = 1$, the failure rate is constant over time, giving the distribution the form of a cumulative exponential distribution. In the case of appliances, β commonly is greater than 1, reflecting an increasing failure rate as appliances age. DOE estimated a delay parameter of $\theta = 1$ year, based on the typical manufacturer warranty period for portable ACs. Based on values for room ACs, DOE assumed a maximum lifetime of 20 years and an average lifetime of 10.47 years, then solved for the scale and shape parameters.[8] Table 8.2.9 shows the lifetime parameters

[d] For reference on the Weibull distribution, see sections 1.3.6.6.8 and 8.4.1.3 of the *NIST/SEMATECH e-Handbook of Statistical Methods*, <www.itl.nist.gov/div898/handbook/>.

for portable ACs, and Figure 8.2.3 displays the Weibull probability distribution. See appendix 8D of this final rule TSD for more details.

Table 8.2.9 Lifetime Parameters for Portable ACs

Value			Weibull Parameters	
Minimum (years)	Average (years)	Maximum (years)	Alpha (scale)	Beta (shape)
1	10.47	20	10.66	2.64

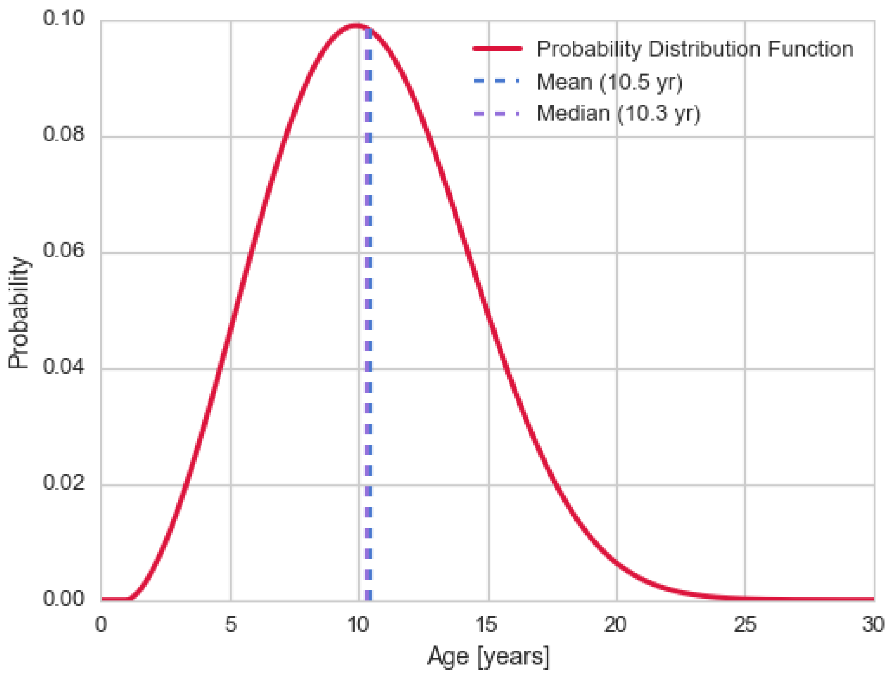

Figure 8.2.3 Weibull Probability Distribution for Portable AC Lifetime

8.2.6 Discount Rates

The discount rate is the rate at which future expenditures and savings are discounted to establish their present value. DOE estimated discount rates separately for residential and commercial end users. For residential end users, DOE calculated discount rates as the weighted average real interest rate across consumer debt and equity holdings. For commercial end users, DOE calculated commercial discount rates as the weighted average cost of capital (WACC), using the Capital Asset Pricing Model (CAPM).

8.2.6.1 Residential Purchases

DOE believes that few if any portable ACs are installed by builders in new homes. Therefore, DOE evaluated the costs associated with consumers purchasing portable ACs themselves. DOE used publicly available data (the Federal Reserve Board's *Survey of Consumer Finances*[9] [SCF]) to estimate a consumer's opportunity cost of funds related to appliance energy cost savings and maintenance costs. A discount rate is applied in the LCC to future energy cost savings and non-energy operations and maintenance costs in order to present the estimated net LCC savings. DOE notes that the discount rate used in the LCC analysis is distinct from an implicit discount rate, because it is not used to model consumer purchase decisions. The opportunity cost of funds in this case may include interest payments on debt and interest returns on assets.

DOE estimates separate distributions of discount rates for six income groups, divided based on income percentile as reported in the Federal Reserve Board's SCF.[9] This disaggregation reflects the fact that low and high income consumers tend to have substantially different shares of debt and asset types, as well as facing different rates on debts and assets. Summaries of shares and rates presented in this chapter are averages across the entire population. Table 8.2.10 lists the income groups DOE identified.

Table 8.2.10 Income Groups

Income Group	Percentile of Income
1	1st to 20th
2	21st to 40th
3	41st to 60th
4	61st to 80th
5	81st to 90th
6	91th to 99th

Sources: Federal Reserve Board. *SCF* for 1995, 1998, 2001, 2004, 2007, 2010, and 2013.

Debt and Asset Classes. DOE's approach involved identifying all relevant household debt or asset classes in order to approximate a consumer's opportunity cost of funds related to appliance energy cost savings and maintenance costs. The approach assumes that in the long term, consumers are likely to draw from or add to their collection of debt and asset holdings approximately in proportion to their current holdings when future expenditures are required or future savings accumulate. DOE has included several previously excluded debt types (*i.e.*, vehicle and education loans, mortgages, all forms of home equity loan) in order to better account for all of the options available to consumers.

DOE uses the average percentage of total debt plus equity and the associated interest rate of each asset and debt type to calculate a weighted-average discount rate for each SCF household. The household-level discount rates then are aggregated to develop distributions of discount rates for each of the six income groups. Note that in the past DOE aggregated asset and debt types among households by summing the dollar values across all households and then calculating percentages. Weighting by dollar value gave disproportionate influence to the percentages and rates of assets and debts of higher-income consumers. DOE has shifted to a household-level weighting, to more accurately reflect the average consumer in each income group.

DOE estimated the average percentages of each type of debt and equity, using data from the Federal Reserve Board's SCF for 1995, 1998, 2001, 2004, 2007, 2010, and 2013.[9, e] DOE derived the household-weighted mean percentages of each source of financing throughout the five years surveyed. Table 8.2.11 lists the percentages of each type of household debt and equity used by each of the six income groups identified. DOE posits that these long-term averages are the most appropriate for use in its analysis.

[e] Note that two older versions of the *SCF* are also available (1989 and 1992); these surveys are not used in this analysis because they do not provide all of the necessary types of data (*e.g.*, credit card interest rates, *etc.*). DOE feels that the 18-year span covered by the seven surveys included is sufficiently representative of recent debt and equity shares and interest rates.

Table 8.2.11 Types of Household Debt and Equity by Income Group

Type of Debt or Equity	Income Group					
	1	2	3	4	5	6
Debt %						
Mortgage	18.9	24.1	33.1	38.1	39.3	25.0
Home equity loan	3.1	3.3	2.6	3.6	4.5	7.2
Credit card	15.3	13.0	11.8	8.7	6.0	2.7
Other installment loan	25.1	20.6	17.3	13.2	9.6	4.7
Other residential loan	0.7	0.6	0.6	0.7	1.0	1.2
Other line of credit	1.6	1.5	1.3	1.5	2.1	1.8
Equity %						
Savings account	18.5	16.0	12.7	10.6	10.4	7.9
Money market account	3.6	4.5	4.0	4.5	5.0	8.6
Certificate of deposit	7.0	7.8	5.5	5.0	4.4	4.2
Savings bond	1.8	1.7	1.9	2.2	1.7	1.1
Bonds	0.2	0.4	0.5	0.7	0.8	3.8
Stocks	2.3	3.1	4.4	5.7	7.6	15.8
Mutual funds	2.1	3.5	4.3	5.7	7.6	15.9
Total	100.0	100.0	100.0	100.0	100.0	100.0

Sources: Federal Reserve Board. *Survey of Consumer Finances (SCF)* for 1995, 1998, 2001, 2004, 2007, 2010, and 2013.

Interest Rates for Types of Debt. DOE's source for interest rates for mortgages, loans, credit cards, and lines of credit was the Federal Reserve Board's SCF for 1995, 1998, 2001, 2004, 2007, 2010, and 2013,[9] which associates an interest rate with each type of debt for each household in the SCF. In calculating effective interest rates for home equity loans and mortgages, DOE accounted for the fact that interest on both is tax deductible. The effective rate corresponds to the interest rate after deduction of mortgage interest for income tax purposes and after adjusting for inflation (using the Fisher formula).[f] For example, a 6 percent nominal mortgage rate has an effective rate of 4.5 percent for a household paying taxes at a 25 percent marginal rate. When adjusted for an inflation rate of 2 percent, the effective real rate becomes 2.45 percent.[10]

Table 8.2.12 shows the household-weighted average effective real rates for various types of household debt. Because the interest rate for each type of debt reflects economic conditions

[f] The Fisher formula is given by: Real Interest Rate = [(1 + Nominal Interest Rate) / (1 + Inflation Rate)] – 1.

throughout numerous years and various phases of economic growth and recession, DOE expects them to be representative of rates in effect in 2022, the expected date of compliance for any new standard for portable ACs.

Table 8.2.12 Average Real Effective Interest Rates for Household Debt, %

Type of Debt	Income Group					
	1	**2**	**3**	**4**	**5**	**6**
Mortgage	3.36	3.26	3.13	2.93	2.78	2.59
Home equity loan	3.97	4.17	3.96	3.81	3.50	3.09
Credit card	11.82	11.95	11.12	10.61	10.07	9.87
Other installment loan	7.02	8.71	7.02	6.25	6.12	4.81
Other residential loan	4.87	4.71	4.55	4.79	4.54	3.90
Other line of credit	9.85	10.03	12.06	8.31	8.01	6.30

Sources: Federal Reserve Board. *Survey of Consumer Finances (SCF)* for 1995, 1998, 2001, 2004, 2007, 2010 and 2013.

Interest Rates for Types of Assets. No rate data are available from the SCF for classes of assets, so DOE derived interest rates from various sources of national historical data (1985–2014). The interest rates associated with certificates of deposit,[11] savings bonds,[12] and bonds (AAA corporate bonds)[13] were collected from Federal Reserve Board time-series data. Rates on money market accounts came from Cost of Savings Index data.[14] Rates on savings accounts were estimated as one-half the rate for money market accounts, based on recent differentials between the return on the two types of assets. The rates for stocks are the annual returns on the Standard and Poor's Index.[15] Rates for mutual funds are a weighted average of the stock rates (two-thirds weight) and bond rates (one-third weight) in each year. DOE assumed rates on checking accounts to be zero.

DOE adjusted the nominal rates to real rates using the annual inflation rate for each year. Average nominal and real interest rates for the classes of household assets are listed in Table 8.2.13. Because the interest and return rates for each type of asset reflect economic conditions throughout numerous years, DOE expects them to be representative of rates that may be in effect in 2022. For each asset type, DOE developed a distribution of rates, as shown in appendix 8E.

Table 8.2.13 Average Nominal and Real Rates of Return for Household Equity

Type of Equity	Average Real Rate %
Savings account	0.9
Money market account	1.7
Certificate of deposit	2.0
Savings and government bonds	3.2
State and local government bonds	2.7
Mortgage backed and Corporate bonds	4.0
Stocks	9.7
Mutual fund	7.5

Calculation and Summary of Consumer Discount Rates. Using the asset and debt data discussed above, DOE calculated distributions of discount rates for each income group. First, DOE calculated the discount rate for each consumer in each of the six years of the SCF, using the following formula:

$$DR_i = \sum_j Share_{i,j} \times Rate_{i,j}$$

Where:

DR_i = discount rate for consumer *i*,
$Share_{i,j}$ = percent of asset or debt type *j* for consumer *i*, and
$Rate_{i,j}$ = real interest rate or rate of return on asset or debt type *j* for consumer *i*.

After the real discount rate was estimated for each consumer, DOE compiled the distribution of discount rates in each SCF by income group by calculating the proportion of consumers whose discount rates fell into bins having 1 percent increments, ranging from 0 or 1 percent to more than 30 percent. Giving equal weight to each SCF, DOE compiled a six-survey distribution of discount rates.

Table 8.2.14 presents the average real effective discount rate and its standard deviation for each of the six income groups. To account for variations among households, DOE sampled a rate for each RECS household from the distributions for the appropriate income group. (RECS provides household income data.) Appendix 8E presents the full probability distributions for each income group that DOE considered in the LCC analysis.

Table 8.2.14 Average Real Effective Discount Rate

Income Group	Discount Rate %
1	4.88
2	5.08
3	4.67
4	3.95
5	3.68
6	3.49
Overall Average	4.43

8.2.6.2 Commercial Purchases

The commercial discount rate is the rate at which future operating costs are discounted to establish their present value in the LCC analysis. The discount rate value is applied in the LCC to future year energy costs and non-energy operations and maintenance costs to calculate the estimated net life-cycle cost of products of various efficiency levels and life-cycle cost savings as compared to the baseline for a representative sample of commercial end users.

DOE's method views the purchase of a higher-efficiency appliance as an investment that yields a stream of energy cost savings. DOE derives the discount rates for the LCC analysis by estimating the cost of capital for companies that purchase portable ACs. The weighted average cost of capital (WACC) is commonly used to estimate the present value of cash flows to be derived from a typical company project or investment. Most companies use both debt and equity capital to fund investments, so their cost of capital is the weighted average of the cost to the firm of equity and debt financing, as estimated from financial data for publicly traded firms in the sectors that purchase portable ACs.[16]

Damodaran Online, which is widely used as a source of information about debt and equity financing for most types of firms, was the primary source of data for this analysis.[15] Detailed sectors included in the Damodaran Online database are assigned to the aggregate categories of retail, property management, medical, industrial, lodging, office, and other.

DOE estimated the cost of equity using the capital asset pricing model (CAPM).[17] The CAPM assumes that the cost of equity (k_e) for a particular company is proportional to the systematic risk that company faces; whereby high risk is associated with a high cost of equity and low risk is associated with a low cost of equity. The systematic risk facing a firm is determined by several variables: the risk coefficient of the firm (β), the expected return on risk-free assets (R_f), and the equity risk premium (*ERP*). The risk coefficient of the firm indicates the risk associated with that firm relative to the price variability in the stock market. The expected return on risk-free assets is defined by the yield on long-term government bonds. The ERP represents the difference between the expected stock market return and the risk-free rate.

The cost of equity financing is estimated using the following equation, in which the variables are defined as above:

$$k_e = R_f + (\beta \times ERP)$$

Where:

k_e = cost of equity,
R_f = expected return on risk-free assets,
β = risk coefficient of the firm, and
ERP = equity risk premium.

Several parameters in the cost of capital equations can change substantially over time, so that the estimates can vary depending on: (1) the period for which data are selected, and (2) the details of the data-averaging method. DOE uses Federal Reserve methodologies for both the period and data to select for key parameters and for the averaging method. When applying the CAPM, the Federal Reserve uses a 40-year period for calculating discount rate averages, utilizes the gross domestic product price deflator for estimating inflation, and considers the best method for determining the risk-free rate as one where “the time horizon of the investor is matched with the term of the risk-free security.”[18]

By taking a 40-year average of Federal Reserve data on annual nominal returns for 10-year Treasury bills, DOE estimated the risk-free rates for 2011–2013 (see Table 8.2.15).[19] DOE also estimated the ERP by calculating the difference between the risk-free rate and stock market returns for the same period.[15]

Table 8.2.15 Risk-Free Rates and Equity Risk Premiums, 2004–2013

Year	Risk-Free Rate %	ERP %
2011	6.61	2.94
2012	6.41	3.99
2013	6.24	5.30

The cost of debt financing (k_d) is the interest rate paid on money borrowed by a company. The cost of debt is estimated by adding a risk adjustment factor (R_a) to the risk-free rate. This risk adjustment factor depends on the variability of stock returns represented by standard deviations in stock prices. For firm *i*, the cost of debt financing is calculated as:

$$k_{di} = R_f + R_{ai}$$

Where:

k_{di} = cost of debt financing for firm *i*,
R_f = expected return on risk-free assets, and
R_{ai} = risk adjustment factor for firm *i*.

DOE estimated the weighted-average cost of capital for a firm, using the following equation:

$$WACC = k_e \times w_e + k_d \times w_d$$

Where:

$WACC$ = weighted-average cost of capital,
w_e = proportion of equity financing, and
w_d = proportion of debt financing.

By adjusting for inflation, DOE estimated the real weighted-average cost of capital, or discount rate, for each company in its sample of companies that have portable ACs. DOE then aggregated each company's real WACC to estimate the discount rate for each type of ownership in the analysis of portable ACs in commercial settings. Table 8.2.16 shows the average WACC values for the major sectors that purchase portable ACs. Although WACC values for any sector may trend higher or lower over substantial periods, the values represent a cost of capital that is averaged over major business cycles.

Table 8.2.16 Weighted-Average Cost of Capital for Sectors that Purchase Portable ACs

Sector	Real Discount Rate *(%)*	Standard Deviation *(%)*
Retail	5.00	1.07
Medical	4.97	0.92
Hotels	5.96	1.65
Food service	4.90	0.95
Office	5.08	1.28
Education	3.42	2.15
Other	5.04	1.16

8.2.7 Effective Date of Potential Standard

The effective date is the future date when a potential energy efficiency standard becomes operative. Based on DOE's implementation report for energy conservation standards activities submitted pursuant to Section 141 of the Energy Policy Act of 2005, a final rule for the portable ACs being considered for this standards rulemaking is scheduled for completion in January 2017.[20] The effective date of any new energy efficiency standards for the products would be five years after the final rule is published, or January 2022. DOE calculated the LCC for all consumers as if each would purchase a new portable AC in the year potential standards would take effect.

8.2.8 Product Energy Efficiency in the No-New-Standard Case

To estimate the percentage of consumers who would be affected by a potential standard at any of the efficiency levels identified in chapter 5 of this final rule TSD, DOE's LCC analysis first considered the projected distribution of efficiencies for products that consumers purchase under the no-new-standard case (the case without new energy efficiency standards). DOE refers to this distribution of product energy efficiencies as the *no-new-standard case efficiency distribution.* Using the projected distribution of efficiencies for portable ACs, DOE randomly assigned a product efficiency to each household and a commercial user drawn from the RECS 2009 and CBECS 2012 data sets. If a consumer is assigned a product efficiency that is greater than or equal to the efficiency under consideration, the LCC savings calculation shows that the consumer would not be affected by that efficiency level. The energy efficiency distributions that DOE used in the LCC analysis are described below.

DOE estimated the no-new standards case based on portable AC units tested in development of the engineering analysis (chapter 5 of this final rule TSD). DOE assumed that the efficiency distribution of those units tested is representative of the market as a whole. Representative EER and CEER values for each EL were calculated by taking the average EER and CEER of units at each EL. DOE assumed this market distribution would be representative of the market in 2022. Table 8.2.17 shows the resulting no-new-standards case efficiency distribution. DOE assumed that the residential and commercial sectors have the same no-new-standard case efficiency distribution.

Table 8.2.17 Portable ACs: No-New-Standard Case Market Shares in 2022

Efficiency Level	Efficiency *EER*	Efficiency *CEER*	Market Share %
Baseline	5.35	5.08	37.0
1	6.05	5.94	47.8
2	7.15	7.13	13.0
3	8.48	8.46	2.2
4	10.75	10.73	0.0

8.3 INPUTS TO PAYBACK PERIOD

The payback period (PBP) is the amount of time, expressed in years, it takes a consumer to recover the assumed higher purchase price of a more energy-efficient product through lower operating costs. Payback periods can exceed the life of a product if the increased total installed cost of the more efficient product is not recovered quickly enough through reduced operating costs. Numerically, the PBP is the ratio of the increase in purchase cost (i.e., from a less-efficient to a more-efficient design) to the decrease in first-year annual operating expenditures. The equation for PBP is:

$$PBP = \frac{\Delta IC}{\Delta OC}$$

Where:

PBP = payback period in years,
ΔIC = difference in the total installed cost between the more efficient product (efficiency levels 1, 2, 3, etc.) and the baseline product, and
ΔOC = difference in first-year annual operating costs between the more efficient product and the baseline product.

The data inputs to PBP are the total installed cost of the product to the consumer for each efficiency level and the annual (first-year) operating costs for each efficiency level. As for the LCC, the inputs to the total installed cost are the product price and installation cost. The inputs to the operating costs are the annual energy and annual maintenance costs. The PBP uses the same inputs as does the LCC analysis, except that electricity price trends are not required. Because the PBP is a simple payback, the required electricity cost is only for the year in which a potential new efficiency standard would take effect—in this case, 2022.

DOE also calculates a rebuttable PBP, which is the time it takes the consumer to recover the assumed higher purchase cost of a more energy-efficient product through lower energy costs. Numerically, the rebuttable PBP is the ratio of the increase in purchase cost (from a less-efficient to a more-efficient design) to the decrease in annual energy expenditures, which is the decrease in first-year annual energy costs as calculated using the DOE test procedure. The calculation excludes repair and maintenance costs.

8.4 RESULTS OF LIFE-CYCLE COST AND PAYBACK PERIOD ANALYSIS

This section presents the LCC and PBP results for portable ACs. As discussed in section 8.1.1, DOE considered that room ACs were used similarly to portable ACs and conducted the LCC analysis on developing samples of consumers who use room ACs. DOE characterized the uncertainty of many of the inputs to the analysis with probability distributions. DOE used a Monte Carlo simulation technique to calculate the average LCC and LCC savings for the consumers in the sample. The calculation of payback period uses average values rather than distributions. PBP is calculated by dividing the change in average installed cost by the change in average first-year operating cost for the baseline efficiency level and each higher efficiency level considered.

In calculating LCC savings relative to the no-new-standard case, DOE first assigned portable ACs to consumers using the efficiency distribution in the no-new-standard case. In standards cases, DOE used a “roll-up” approach to estimate consumer purchasing decisions. In the roll-up approach, consumers that purchased products below the standard level in the no-standards case, purchase products that meet the minimum efficiency allowed by the standard. Purchasers that purchased products at or above the standard level in the no-standards case, choose the same product in the standards case efficiency. In addition, DOE calculated the LCC savings only for affected consumers. This means that consumers who would purchase the same product in the no-standard case and a particular EL were not included in the LCC savings calculation.

LCC calculations were performed 10,000 times on the sample of consumers established for residential and commercial applications. Each LCC calculation was performed on a single consumer who was selected from the sample. The selection of a consumer was based on its weight (i.e., how representative a particular consumer is of other consumers in the distribution). Each LCC calculation also sampled from the probability distributions that DOE developed to characterize many of the inputs to the analysis.

Based on the Monte Carlo simulations, DOE calculated the percent of consumers who would experience a net LCC cost for each efficiency level. DOE considered a consumer to receive no impact at a given efficiency level if DOE assigned it a baseline product that operates at the same or higher efficiency than the level under consideration. The tables and figures presented below illustrate the range of LCC impacts among sample consumers of portable ACs.

Table 8.4.1 shows the LCC and PBP results by efficiency level for portable ACs. The efficiency levels correspond to those identified in the engineering analysis (chapter 5 of this final rule TSD). Table 8.4.2 show the average LCC savings and the percentage of consumers that experience net cost relative to the no-new-standards case efficiency distribution. Both tables combine the results for residential and commercial users, which means that DOE had to assign an appropriate weight to the results for each type of user, assuming that 87 percent of shipments are to the residential sector and 13 percent to the commercial sector.

DOE performed an additional set of sensitivity analyses to gauge the impact of different inputs assumptions. DOE performed the following set of sensitivity analyses:

- A 50% reduction in cooling mode hours.
- A geographic distribution of consumers matching data provided by the Association of Home Appliance Manufacturers (AHAM) in comments to the NOPR.[g]
- Eliminating the room size threshold criteria of 1000 square feet used to define the residential consumer sample.
- *AEO 2016* electricity price trends for high economic growth.
- *AEO 2016* electricity price trend for low economic growth.

The full set of results for all sensitivity scenarios can be found in appendix 8F of this final rule TSD.

Table 8.4.1 Summary of LCC and PBP Results by Efficiency Level, All Sectors

EL	EER	CEER	Average Costs *2015$*				Simple Payback *years*	Average Lifetime *years*
			Installed Cost	First Year's Operating Cost	Lifetime Operating Cost	LCC		
0	5.35	5.08	559	135	1,103	1,663	--	10.5
1	6.05	5.94	588	122	990	1,578	2.2	10.5
2	7.15	7.13	635	105	855	1,490	2.6	10.5
3	8.48	8.46	700	89	729	1,429	3.2	10.5
4	10.75	10.73	733	73	594	1,327	2.9	10.5

Note: The average LCC and simple PBP for each efficiency level are calculated assuming that all consumers use products having that EL. This assumption allows the results for each efficiency level to be compared under the same conditions.

[g] AHAM comment to June 2016 NOPR, AHAM Comments_DOE NOPR PAC Standards_FINAL (00053556), September 26, 2016. https://www.regulations.gov/document?D=EERE-2013-BT-STD-0033-0043

Table 8.4.2 Average LCC Savings Relative to the No-New-Standards Case Efficiency Distribution, All Sectors

Efficiency Level	EER	CEER	Life-Cycle Cost Savings	
			% of Consumers Who Experience Net Cost	Average Savings* *2015$*
1	6.05	5.94	8	84
2	7.15	7.13	24	125
3	8.48	8.46	35	169
4	10.75	10.73	31	268

* The calculation excludes households with zero LCC savings (no impact).

8.4.1 No-New-Standards Case Distribution of Life-Cycle Cost

Figure 8.4.1 shows the no-new-standard case LCC distribution for portable ACs for residential consumers. The figure shows the full range of LCCs for the sample of residential portable ACs.

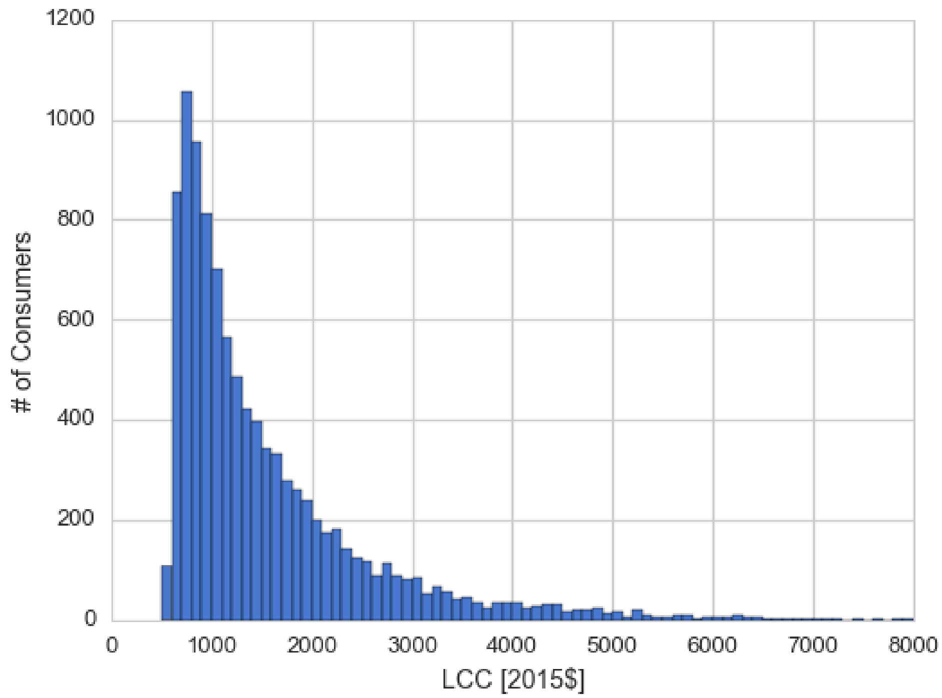

Figure 8.4.1 Distribution of LCCs at EL 0, Residential Settings

8.4.2 Distributions of Life-Cycle Costs at Higher Efficiency Levels

Figure 8.4.2 show the distributions of LCC savings at EL 2 for portable ACs used in the residential sector. DOE can generate frequency charts similar to those shown for every efficiency level.

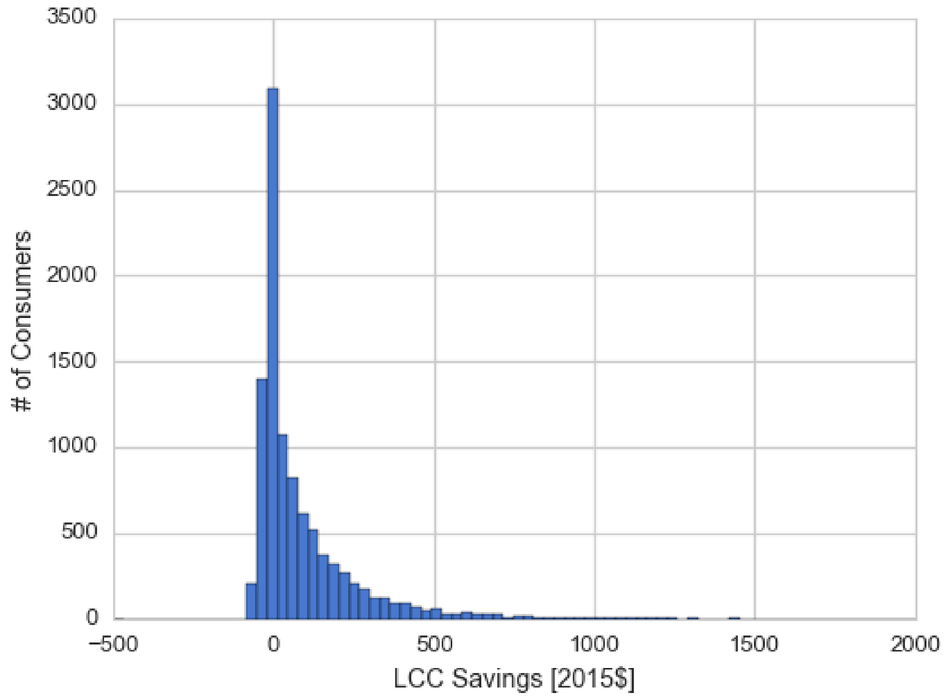

Figure 8.4.2 Distribution of LCC Savings for Efficiency Level 2, Residential Sector

Figure 8.4.3 shows the range of LCC savings for the efficiency levels considered for portable ACs in the residential sector, which comprises the majority of portable AC installations. For each efficiency level, the top and the bottom of the box indicate the 75th and 25th percentiles, respectively. The red line at the middle of the box indicates the median; 50 percent of households or establishments have life-cycle cost savings greater than this value. The "whiskers" at the bottom and the top of each box indicate the 5th and 95th percentiles, with points outside the whisker reflecting all other values in the distribution. The yellow star shows the average LCC savings for each efficiency level.

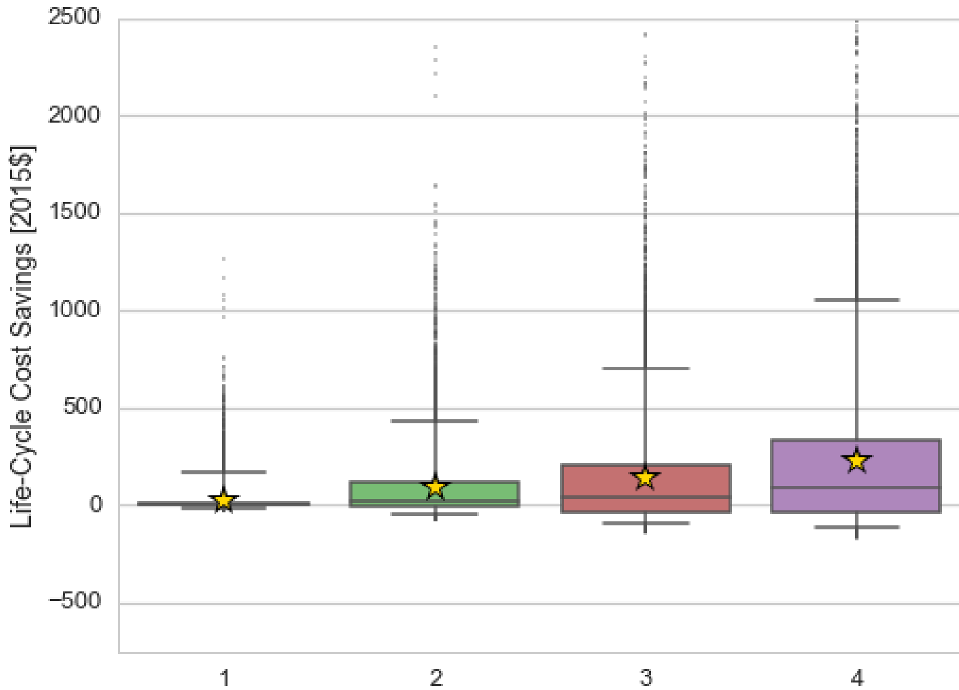

Figure 8.4.3 Range of Average LCC Savings at each TSL, Residential Sector

8.4.3 Rebuttable-Payback Period

EPCA establishes a rebuttable presumption that an energy conservation standard is economically justified if the increased purchase cost for a product that meets the standard is less than three times the value of the first year's energy savings resulting from the standard. DOE expresses this criterion as having a simple payback period of less than three years. In calculating a rebuttable-presumption payback period for each of the considered ELs, DOE based the energy use calculation on the DOE test procedures for portable ACs, as required by EPCA. Table 8.4.3 shows the results of this analysis for the considered ELs.

Table 8.4.3 Rebuttable PBP for Portable ACs

EL	Rebuttable PBP *years*
1	1.8
2	2.2
3	2.7
4	2.4

While DOE examined the rebuttable-presumption criterion, it considered whether the standard levels considered for this rule are economically justified through a more detailed analysis of the economic impacts of those levels, pursuant to 42 U.S.C. 6295(o)(2)(B)(i), that considers the full range of impacts to the consumer, manufacturer, nation, and environment. The results of that analysis serve as the basis for DOE to evaluate the economic justification for a potential standard level, thereby supporting or rebutting the results of any preliminary determination of economic justification.

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CHAPTER 9. SHIPMENTS ANALYSIS

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CHAPTER 9. SHIPMENTS ANALYSIS

9.1 INTRODUCTION

Estimates of future product shipments are a necessary input to calculations of the national energy savings (NES) and net present value (NPV) related to potential energy efficiency standards. Estimated shipments also are required for the manufacturer impact analysis. This chapter describes the data and methods the U.S. Department of Energy (DOE) used to project annual shipments of portable air conditioners (ACs) under no-new-standards case and standards-case efficiency levels.

DOE estimated shipments for portable ACs based on historical shipments data. The shipments model first estimates shipments for both of the residential and commercial sectors, and then disaggregates results to estimate the individual sector. To estimate the effect of potential standard levels on product shipments, the shipments model accounts for the effects of changes in both purchase price and annual operating cost on the consumer purchase decision. The shipments model was developed as a part of the spreadsheet for the national impacts analysis (NIA). Appendix 10A describes how to access the NIA workbook and provides basic instructions for its use.

The rest of this chapter explains the shipments model in more detail. Section 9.2 presents the approach to building the model; section 9.3 describes the data inputs; section 9.4 discusses impacts on shipments from changes in product purchase price and operating cost; section 9.5 discusses the affected stock of portable ACs; and section 9.6 presents the model results for various trial standard levels for product efficiency.

9.2 APPROACH TO SHIPMENTS MODEL

DOE has developed national stock models to estimate annual shipments of various products under potential new energy efficiency standards. The models consider market segments as distinct inputs to projected shipments. Typically, the primary market segments are new home installations, replacements, and first-time owners of existing households. The following is the general equation for calculating product shipments to the three market segments.

$$Ship_p(j) = Rpl_p(j) + NI_p(j) + FTO_p(j)$$

Where:

$Ship_p(j)$ = total shipments of product p in year j,
$Rpl_p(j)$ = units of product p retired and replaced in year j,
$NI_p(j)$ = number of new home installations of product p in year j, and
$FTO_p(j)$ = number of product p purchased by first-time owners in year j.

For portable ACs, in the preliminary analysis, DOE did not consider the new construction market because this product, unlike some household appliances, is not commonly installed in new homes (unlike central ACs). DOE included a market segment for purchases of portable ACs by first-time owners [or consumers who purchase an additional (rather than replacement) portable ACs]. However, this approach does not correctly characterize the stock and shipments of portable ACs based on historical shipments information that DOE received from manufacturer interviews during this Notice of Pubic Rulemaking (NOPR) analysis.

Therefore, in the NOPR and this final rule analysis, DOE estimated a saturation rate to project shipments of portable ACs. DOE assumed that the portable AC saturation rate would be no greater than half the current room AC saturation rate (based on the Residential Energy Consumption Survey (RECS) 2009) by the end of the analysis period, i.e., 2051.

This revised shipments model takes an accounting approach, tracking the vintage of units in the existing stock, and expected housing stock trends.

The stock accounting takes product shipments, a retirement function, and initial in-service product stock as inputs and develops an estimate of the age distribution of in-service product stocks for all years. The age distribution of in-service product stocks is a key input to calculations of both the NES and NPV, because the product operating cost for any year depends on the age distribution of the stock. The dependence of operating cost on the product age distribution occurs under a standards-case scenario that produces increasing efficiency over time, whereby older, less efficient units may have higher operating costs, while younger, more-efficient units have lower operating costs.

DOE calculates the total in-service stock of products by integrating historical shipments data starting from a specified year. The start year depends on the historical data available for each product. As units are added to the in-service stock, some older ones retire and exit the stock. To estimate future shipments, DOE developed a series of equations that define the dynamics and accounting of in-service stocks. For stock units, the equation is:

$$Stock(j, age = 1) = Ship(j - 1)$$

Where:

Stock(j, age) = the population of in-service units of a particular age,
j = year for which the in-service stock is being estimated, and
Ship (j) = number of units shipped in year *j*.

The above equation states that the number of one-year-old units is equal simply to the number of new units shipped the previous year. The following equation describes the accounting of the existing in-service stock of units.

$$Stock(j+1, age+1) = Stock(j, age) \times \left[1 - prob_{Rtr}(age)\right]$$

In the above equation, as the year is incremented from j to $j+1$, the age of units also is incremented from *age* to *age+1*. With time, a fraction of the in-service stock is removed, a fraction that is determined by a retirement probability function, $prob_{Rtr}(age)$, which is described in section 9.3. Over time, some units will be retired and removed from the stock, triggering the shipment of a new unit.

9.3 DATA INPUTS AND MARKET SEGMENTS

The following sections describe the data inputs and market segments considered for portable ACs. Those data inputs are used in the general equations presented in section 9.2 for estimation of shipments for portable ACs.

9.3.1 Historical Shipments

In the NOPR analysis, DOE revised its assumption that portable ACs account for approximately 10 percent of the total shipments of room ACs based on literature review.[1] DOE received historical portable AC shipments information reporting (1) total annual shipments (domestic shipments and imports) are approximately 1.32 million and (2) the average annual growth rate for the U.S. portable AC industry was 30 percent between the period 2004 and 2013. DOE used an exponential regression model to fit the historical shipments trend. DOE estimated historical shipments from 2014 back to 1985, the date that portable ACs were introduced to the retail market.[2] Figure 9.3.1 presents the estimated historical shipments of portable ACs.

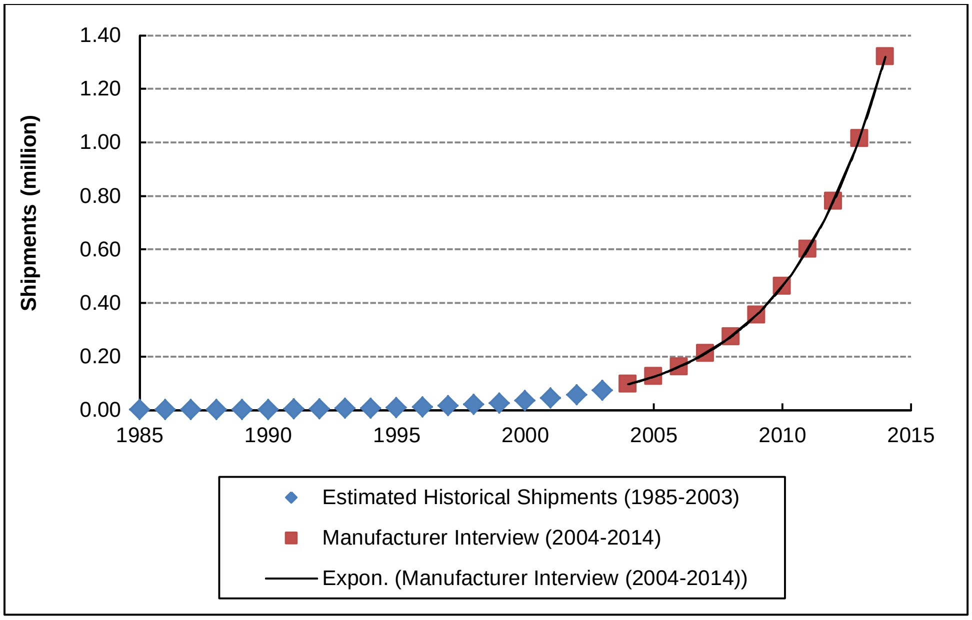

Figure 9.3.1 Historical Shipments of Portable ACs (1985 – 2014)

9.3.2 Product Saturation Rate

As described in section 9.2, DOE assumed that portable AC saturation rate would be no greater than half the current room AC saturation rate (based on RECS 2009) by the end of the analysis period, i.e., 2051[a]. The saturation rate of portable ACs was determined from a combination of the total stock of the product and total housing stock. The sections below discuss the two inputs in further detail.

9.3.2.1 Total Product Stock

DOE determined total product stock in each year of the projection period by tracking the vintage of units shipped to the market. To determine the useful service life of portable ACs to estimate how long the appliance is likely to remain in stock, DOE used a survival function based on a product lifetime distribution having an average value of 10.5 years. For a more complete discussion of DOE's estimated lifetime of portable ACs, refer to chapter 8. Figure 9.3.2 shows the survival and retirement functions that DOE used to estimate product stock.

[a] According to RECS 2009, the saturation rate of room ACs is approximately 23 percent in 2009.

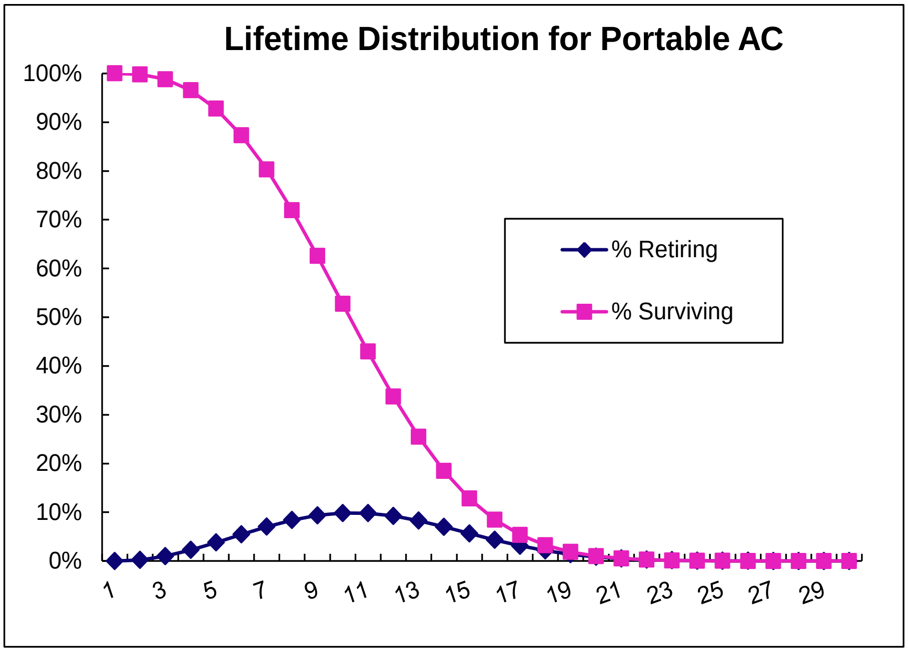

Figure 9.3.2 Portable ACs: Survival and Retirement Functions

9.3.2.2 Total Housing Stock

To forecast the product saturation rate for any given year during the analysis period, DOE divided the forecasted total product stock by the forecasted total housing stock. DOE used projections from the DOE's Energy Information Administration (EIA)'s *Annual Energy Outlook 2016* (*AEO 2016*) for 2014–2040.[3] *AEO 2016* provides three scenarios for total housing stock: a reference case, a high economic growth case, and a low economic growth case, as shown in Figure 9.3.3. DOE used only the forecasts from the reference case to estimate total product stock to total housing stock. For 2041−2048, DOE froze total housing stocks at the level in 2040.

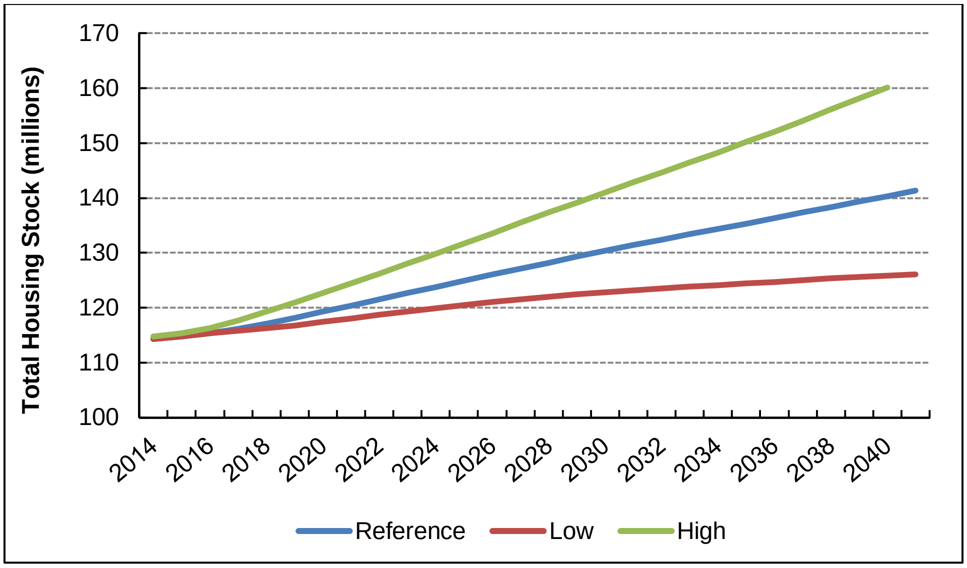

Figure 9.3.3 Forecasted Total Housing Stock, 2014 – 2040

9.3.3 Commercial Sector

As described in chapter 8, DOE estimated that 13 percent of total portable AC shipments are used in commercial settings. DOE used this percentage to estimate shipments to commercial settings for all years in the analysis period.

9.3.4 No-New-Standards Case Shipments

Figure 9.3.4 presents projected shipments of portable ACs in the no-new-standards case. The leveling off in shipments projected by the model reflects the saturation of the potential market for this product.

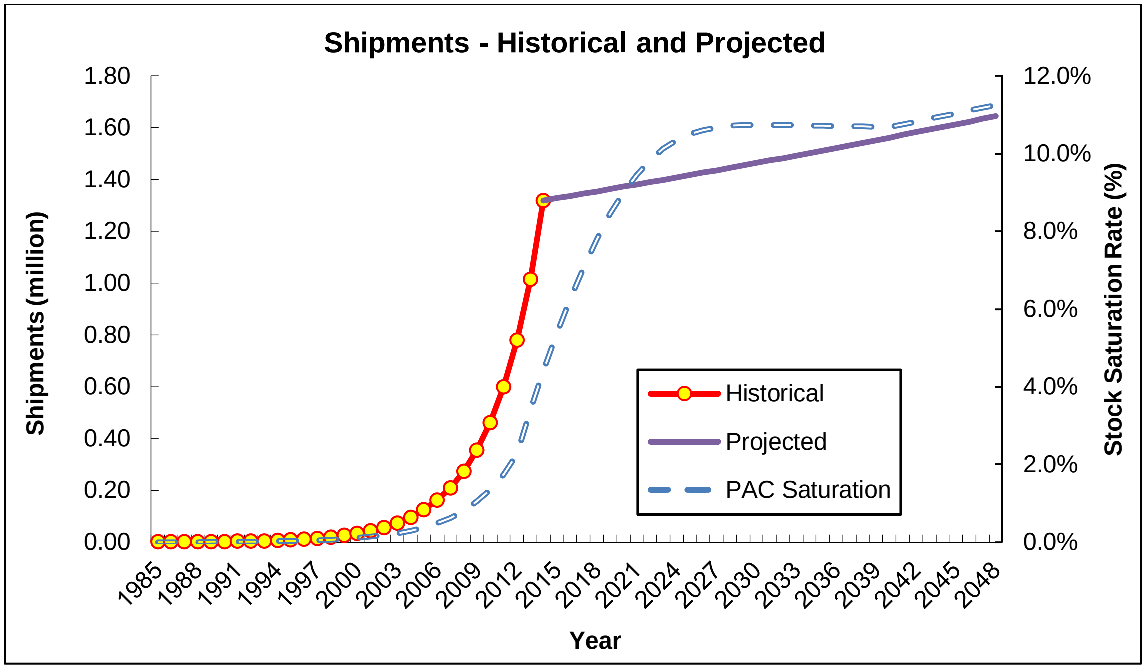

Figure 9.3.4 Portable ACs: Projected Shipments for No-New-Standards Case

9.4 IMPACT OF INCREASED PURCHASE PRICE ON SHIPMENTS

DOE conducted a literature review and an analysis of appliance price and efficiency data to estimate the effects on product shipments from increases in product purchase price and product energy efficiency.[4]

Existing studies of appliance markets suggest that the demand for durable goods, such as appliances, is price-inelastic. Other information in the literature suggests that appliances are a normal good, so that rising incomes increase the demand for appliances, and that consumer behavior reflects relatively high implicit discount rates[b] when comparing appliance prices and appliance operating costs.

DOE used the available data for the period 1989 - 2009 on household appliance purchases to evaluate broad market trends and conduct simple regression analyses. These data indicate that there has been a rise in appliance shipments and a decline in appliance purchase

[b] An implicit discount rate refers to a rate than can be inferred from observed consumer behavior with regard to future operating cost savings realized from more-efficient appliances. An implicit discount rate is not a true discount rate because the observed consumer behavior is affected by lack of information, high transaction costs, and other market barriers. However, implicit discount rates can predict consumer purchase behavior with respect to energy-efficient appliances. A high implicit discount rate with regard to operating costs means that consumer reflects a high discounting of future operating cost savings realized from more-efficient appliances. In other words, consumers are much more concerned with higher purchase prices.

price and operating costs over the time period. Other relevant variables include household income, which has also risen during this time, new residential construction, and stock failures of existing appliances. Using these data, DOE performed a regression analysis to estimate two parameters, the price elasticity of appliance demand and the shipments response to appliance efficiency, defined as follows:

$$\varepsilon_d = \frac{\frac{\Delta q}{q}}{\frac{\Delta p}{p}}$$

where:

ε_d = price elasticity of demand;
q = quantity of shipments;
p = price

$$\varepsilon_e = \frac{\frac{\Delta q}{q}}{\frac{\Delta e}{e}}$$

where:

ε_e = "efficiency elasticity;"
q = quantity of shipments;
e = product efficiency.

DOE's regression analysis suggests that the price elasticity of demand, based on aggregated data for five residential appliances, is -0.45. Thus, for example, a price increase of 10 percent would result in a shipments decrease of 4.5 percent, *all other factors held constant*. The efficiency elasticity is estimated to be +0.2 (*i.e.*, a 10 percent efficiency improvement would result in a shipments increase of 2%, *all else equal*).[c]

The price elasticity estimate of -0.45 is consistent with estimates of appliance and durables price effects in the literature. Nevertheless, DOE stresses that the measure is based on a small data set, using simple statistical analysis. More importantly, the measure is based on the assumption that economic variables, including purchase price, operating costs, and household income, explain most of the trend in appliances per household in the United States between 1989 and 2009. Changes in appliance quality and consumer preferences may have occurred during this period, but DOE did not account for them in this analysis. Despite the uncertainties, DOE believes that its estimates provide a reasonable assessment of the effect that purchase price and efficiency have on product shipments.

Because DOE's projections of shipments and national impacts from potential standards consider a 30-year period, DOE needed to consider how price elasticity evolves in the years after

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[c] Note that DOE previously combined these impacts in a variable termed "relative price elasticity." Price and efficiency impacts are now separated for greater consistency with price elasticity measures reported in the literature.

a new standard takes effect. DOE considered the price elasticity developed above to be a short-term value, but was unable to identify sources specific to appliances sufficient model differences in short- and long-term price elasticities. Therefore, to estimate how the price elasticity changes through time, DOE relied on a study pertaining to automobiles.[5] This study shows that the price elasticity of demand for automobiles changes in the years following a change in purchase price, a trend also observed in appliances and other durables.[6,d] As time passes since the change in purchase price, the price elasticity becomes more inelastic until it reaches a terminal value around the tenth year after the price change. Table 9.4.1 shows the relative change over time in the price elasticity of demand for automobiles. As shown in the table, DOE developed a time series of price elasticity for residential appliances based on the relative change over time in the price elasticity of demand for automobiles. For years not shown in the table, DOE performed a linear interpolation to obtain the price elasticity.

Table 9.4.1 Change in Relative Price Elasticity following a Change in Purchase Price

	Years Following Price Change					
	1	**2**	**3**	**5**	**10**	**20**
Change in elasticity relative to first year	1.00	0.78	0.63	0.46	0.35	0.33
Price elasticity	-0.45	-0.35	-0.28	-0.21	-0.16	-0.15

Using the following equation, DOE estimated standards-case shipments by incorporating the effect of the relative price into the base-case shipments projection. Note that in the equation below, the *relative price* and the *relative price* elasticity are functions of the year because both change with time.

$$Ship_{STD\_p}(j) = \left(Rpl_{BASE\_p}(j) + M_{BASE\_p}(j)\right) \times \left(1 - e_P(j) \times \Delta P(j)\right)$$

Where:

$Ship_{STD\_p}(j)$ = total shipments of product p in year j under the standards case,
$Rpl_{BASE\_p}(j)$ = units of product p retired and replaced in year j under the no-new-standards case,
$M_{BASE\_p}(j)$ = first-time owners of product p in year j under the no-new-standards case,
$e_P(j)$ = price elasticity in year j (equals -0.45 for year 1), and
$\Delta P(j)$ = change in price due to a standard level in year j.

[d] DOE relies on Hymens et al. (1970) for efficiency scaling factors because it provides the greatest detail out of the available studies on price elasticity over time.

9.5 AFFECTED STOCK

For any energy efficiency rulemaking, the affected stock is the in-service stock of the appliance or product that is affected by a standard level. In addition to the projection of product shipments under the no-new-standards case and each standards case, the affected stock (which represents the difference in the appliance stock for the no-new-standards case and the standards case) is a key output of DOE's shipments models. The affected stock quantifies the effect that shipments of new products under a standard level have on the appliance stock. Therefore, the affected stock consists of those in-service units that are purchased in or after the year a standard takes effect, as described by the following equation.

$$Aff\ Stock_p(j) = Ship_p(j) + \sum_{age=1}^{j-Std\_yr} Stock_p(age)$$

Where:

$Aff\ Stock_p(j)$ = affected stock of units of product *p* of all vintages that are operational in year *j*,
$Ship_p(j)$ = shipments of product *p* in year *j*,
$Stock_p(j)$ = stock of units of product *p* of all vintages that are operational in year *j*,
age = age of units (years), and
Std_yr = effective date of standard.

As required for the above equation, to calculate affected stock DOE must define the effective date of a standard. For the NES and NPV results presented in chapter 10, DOE assumed that any new energy efficiency standards for portable ACs would become effective in 2022. Thus, all appliances purchased starting in 2022 are affected by the standard level.

9.6 RESULTS

This section compares the shipments projected under the no-new-standards case with those projected for all the trial standard levels (TSLs) established for portable ACs.

Table 9.6.1 shows total projected shipments of portable ACs in the no-new-standards case and under each TSL. Because the elasticity is modeled as a delayed replacement of a portable AC, the projection for the TSLs show a decline in the early years, but an increase in later years once the delayed replacements are finally made. Recall that the elasticity parameter decreases over time, so the impact of the standards on shipments diminishes.

Table 9.6.1 Shipments Projected for No-New-Standards case and Each Standards Case (millions)

TSL	2021	2025	2030	2035	2040	2045	2050
No-new-standards case	1.38	1.41	1.46	1.50	1.55	1.60	1.65
TSL 1	1.38	1.41	1.45	1.50	1.55	1.60	1.65
TSL 2	1.38	1.38	1.44	1.48	1.53	1.58	1.63
TSL 3	1.38	1.35	1.41	1.46	1.51	1.56	1.60
TSL 4	1.38	1.33	1.40	1.45	1.50	1.55	1.60

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CHAPTER 10. NATIONAL IMPACT ANALYSIS

10.1 INTRODUCTION

This chapter describes the methods the U.S. Department of Energy (DOE) used to conduct a national impacts analysis (NIA) of potential energy efficiency standard levels for portable air conditioners (ACs). DOE evaluated the following impacts: (1) national energy savings (NES) attributable to each standard, (2) monetary value of the energy savings for consumers of portable ACs, (3) increased total installed costs of portable ACs because of standards, and (4) the net present value (NPV), which is the difference between the value of energy savings and of increased total installed costs for each standard considered.

DOE determined the NES and NPV for all the trial standard levels (TSLs) considered for portable ACs. DOE performed all calculations using a Microsoft Excel spreadsheet model, which is accessible on the Internet at (www.eere.energy.gov/buildings/appliance_standards/). The spreadsheet combines the calculations for determining the NES and NPV for each considered TSL with input from the appropriate shipments model. Details and instructions for using the NIA model are provided in appendix 10A.

Chapter 9 provides a detailed description of the shipments model that DOE used to project future purchases of portable ACs. Chapter 9 also includes descriptions of consumers' sensitivities to total installed cost (purchase price plus installation costs) and operating costs, and how DOE captured those sensitivities within the model.

DOE analyzed the benefits and burdens of four TSLs for portable ACs. The TSLs were derived from the energy efficiency levels for portable ACs that DOE developed in chapter 5 analyzed in chapter 8. Table 10.1.1 presents the TSLs, their corresponding efficiency levels, and their energy efficiency ratios (EERs) at various average capacities, which are given in British thermal units per hour (Btu/hr). TSL 4 represents the maximum technologically feasible ("max-tech") improvement in energy efficiency for portable ACs. TSLs 2 and 3 represent intermediate efficiency levels between TSL 1 and TSL 4. TSL 1 represents the first efficiency level considered that exceeds baseline efficiency.

Table 10.1.1 TSLs for Portable ACs

TSL	Efficiency Level	Average Capacity *Btu/hr*	Average CEER
--	Baseline	6,706	5.08
1	1	6,764	5.94
2	2	6,848	7.13
3	3	6,888	8.46
4	4	6,980	10.73

10.2 PROJECTED ENERGY EFFICIENCIES

A key component of DOE's estimates of NES and NPV for portable ACs is the energy efficiencies projected for the no-new-standards case (without new energy conservation standards) and each standards case (with new energy conservation standards). The projected energy efficiency represents the annual shipments-weighted energy efficiency of portable ACs during the analysis period (that is, from the assumed effective date of a new standard to 30 years after that date). Based on DOE's implementation report for energy conservation standards activities submitted pursuant to Section 141 of the Energy Policy Act of 2005, a final rule for the portable ACs being considered for this standards rulemaking is scheduled for completion in February 2017.[1] The effective date of any new energy efficiency standards for portable ACs would be 5 years after the final rule is published, or 2022.

For calculating the NES, per-unit average annual energy consumption is a direct function of product energy efficiency. For the NPV, the per-unit total installed cost is a direct function of energy efficiency; the per-unit annual operating cost, because it is a function of per-unit annual energy consumption, is indirectly dependent on product energy efficiency. The above NES and NPV inputs, as well as all other inputs for the calculation of NES and NPV, are discussed further in sections 10.3 and 10.4.

To project the no-new-standards case energy efficiency for portable ACs, DOE used as a starting point the shipments-weighted energy efficiency ratio (SWEER) for 2022 (the assumed date of compliance with a new standard). To represent the distribution of product energy efficiencies in 2022, DOE used the same market shares as used in the no-new-standards case for the life-cycle cost analysis (described in chapter 8). To project efficiencies for the no-new-standards case, DOE made assumptions regarding future improvements in efficiency, assuming an annual-increase in efficiency of 0.25 percent between 2022 and 2051.

In order to project standards-case energy efficiencies for portable ACs, DOE used a "roll-up" scenario to establish the shipments-weighted average energy efficiency for 2022. Using this approach, product energy efficiencies in the no-new-standards case that do not meet the standard level under consideration would "roll up" to meet the new standard level. Product energy efficiencies in the no-new-standards that exceed the standard level under consideration would not be affected.

In addition to a "roll-up" scenario for standards cases, DOE developed a shift scenario in which DOE applied an annual growth rate in average energy efficiency to the SWEER, as done for the no-new-standards case. To develop projected SWEERs for standards cases, DOE developed growth trends for each TSL that maintained, throughout the analysis period (2022–2051), the same difference in per-unit average total installed cost as between the no-new-standards case and each standards case found in 2022. DOE's approach to developing standards-case SWEERs assumes that the adoption of more efficient products under a standards case can occur only at a rate that ensures that the average difference in total installed cost between the standards case and no-new-standards is held constant throughout the analysis period.

Table 10.2.1 shows the market shares of no-new-standards case and standards-case products in 2022. The table also presents the energy efficiency ratios that DOE used in its NIA for portable ACs and the SWEER ratio for each considered trial standard level (TSL).

Table 10.2.1 Portable ACs: No-New-Standards Case and Standards-Case Energy Efficiency Distributions in 2022

Efficiency Level	Average Capacity	Average CEER	Market Share %				
			No-New-Std Case	TSL			
	Btu/h	*Btu/Wh*		1	2	3	4
Baseline	6,706	5.08	37	0	0	0	0
1	6,764	5.94	48	85	0	0	0
2	6,848	7.13	13	13	98	0	0
3	6,888	8.46	2	2	2	100	0
4	6,980	10.73	0	0	0	0	100
SWEER *Btu/Wh*			5.83	6.15	7.16	8.46	10.73

Figure 10.2.1 illustrates the approach DOE used to estimate SWEERs for portable ACs. The figure shows the no-new-standards case projected energy efficiency trend, and the projected energy efficiency trend for each standards case for portable ACs. Note that for the standards cases, the efficiency trend does not increase past the max-tech level.

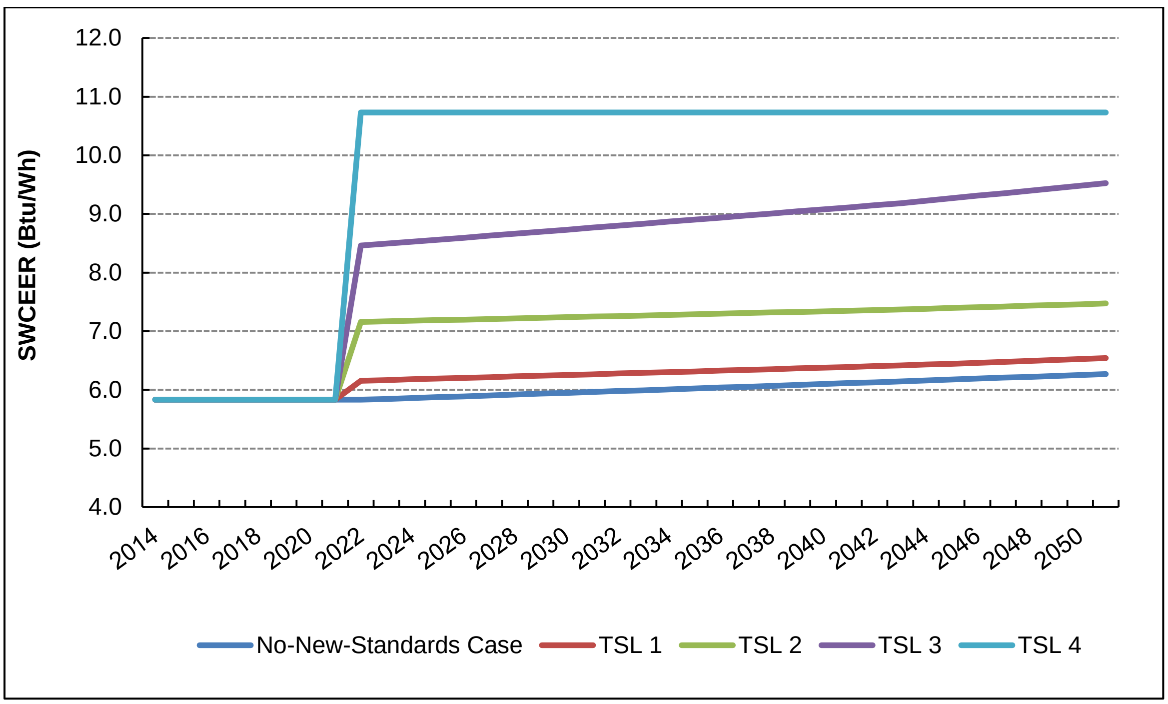

Figure 10.2.1 Projected SWEERs for the No-New-Standards Case and Each Trial Standard Case

10.3 NATIONAL ENERGY SAVINGS

DOE calculated the NES associated with the difference between the no-new-standards case and each TSL for portable ACs. DOE calculated cumulative energy savings throughout the analysis period, from 2022 to 30 years after that date (through 2051).

10.3.1 Definition of National Energy Savings

The following equation shows that DOE calculated annual national energy savings (NES) as the difference between two projections: a no-new-standards case (without new standards) and a standards case. Positive values of NES represent energy savings (that is, they show that national annual energy consumption (AEC) under a standards case is less than in the no-new-standards).

$$NES_y = AEC_{BASE} - AEC_{STD}$$

Cumulative energy savings are the sum of annual NES throughout the analysis period, from 2022 to through 2051.

DOE calculated the national annual site energy consumption by multiplying the number or stock of the product (by vintage) by its unit energy consumption (UEC; also by vintage). National annual energy consumption is calculated using the following equation.

$$AEC_y = \sum STOCK_V \times UEC_V$$

Where:

AEC	=	annual national energy consumption each year in quadrillion Btus (quads), summed over vintages of the product stock, $STOCK_V$;
NES	=	annual national energy savings (quads);
$STOCK_V$	=	stock of product (millions of units) of vintage V that survive in the year for which DOE calculated annual energy consumption;
UEC_V	=	annual energy consumption of portable ACs in kilowatt-hours (kWh);
V	=	year in which the product was purchased as a new unit; and
y	=	year in the forecast.

The stock of a product depends on annual shipments and the lifetime of the product. As described in chapter 9, DOE projected product shipments under the no-new-standards case and standards cases. To avoid including savings attributable to shipments displaced (units not purchased) because of standards, DOE used the projected trial standards-case shipments and, in turn, the standards-case stock, to calculate the AEC for the no-new-standards.

10.3.2 Inputs to Calculation of National Energy Savings

The inputs for determining NES are:

- annual energy consumption per unit,
- shipments,
- product stock (considered along with shipments),
- national annual energy consumption, and
- site-to-primary conversion factor.

10.3.2.1 Annual Energy Consumption per Unit

DOE developed per-unit annual energy consumption as a function of product energy efficiency for portable ACs (Chapter 7, Energy Use Characterization, and Chapter 8, Life-Cycle Cost and Payback Period Analysis). Because per-unit annual energy consumption depends directly on energy efficiency, DOE used the shipments-weighted energy efficiencies for the no-new-standards case and standards cases (presented in section 10.2), along with the annual energy use data presented in chapter 8, to estimate the shipments-weighted annual average per-unit energy consumption (SWAEU) under the no-new-standards and standards cases. Table 10.3.1 shows the values of AEUs and average SWAEUs applied to shipments to both the residential and commercial sectors.

Table 10.3.1 Shipments-Weighted Average Per-Unit Annual Energy Consumption in 2022, Residential and Commercial Sectors

Efficiency Level	Annual Energy Use *kWh/yr*		Market Share %				
			No-New-Std Case	TSL			
	Residential	Commercial		1	2	3	4
Baseline	804	2,015	37	0	0	0	0
1	719	1,801	48	85	0	0	0
2	618	1,547	13	13	98	0	0
3	523	1,312	2	2	2	100	0
4	422	1,055	0	0	0	0	100
SWAEU *kWh/yr*		Residential	733	702	616	523	422
		Commercial	1,837	1,758	1,542	1,312	1,055

As noted in section 10.2, DOE applied a growth rate to the SWEER to project energy efficiencies under the no-new-standards case and standards cases. Because per-unit annual energy consumption is a function of energy efficiency, the values shown in Table 10.3.1 scale with the average SWAEU throughout the analysis period. Figure 10.3.1 and Figure 10.3.2 show the evolution of the SWAEU for portable ACs in the no-new-standards case and under each TSL for residential and commercial settings, respectively.

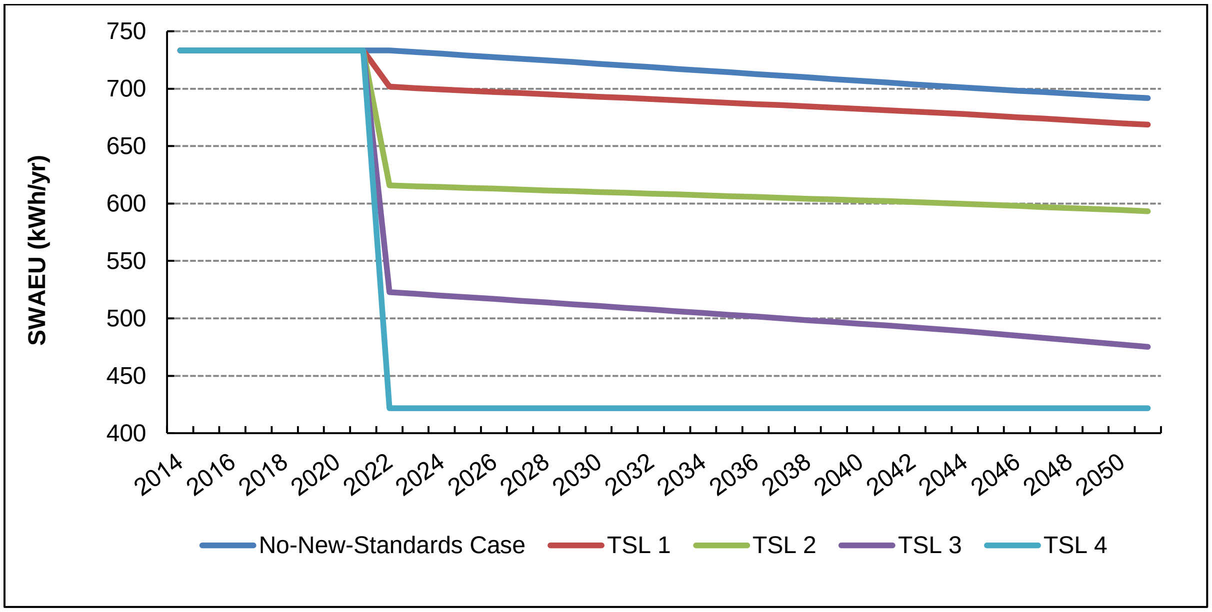

Figure 10.3.1 Projected Energy Consumption for the No-New-Standards Case and Each Trial Standards Case, Residential Sector

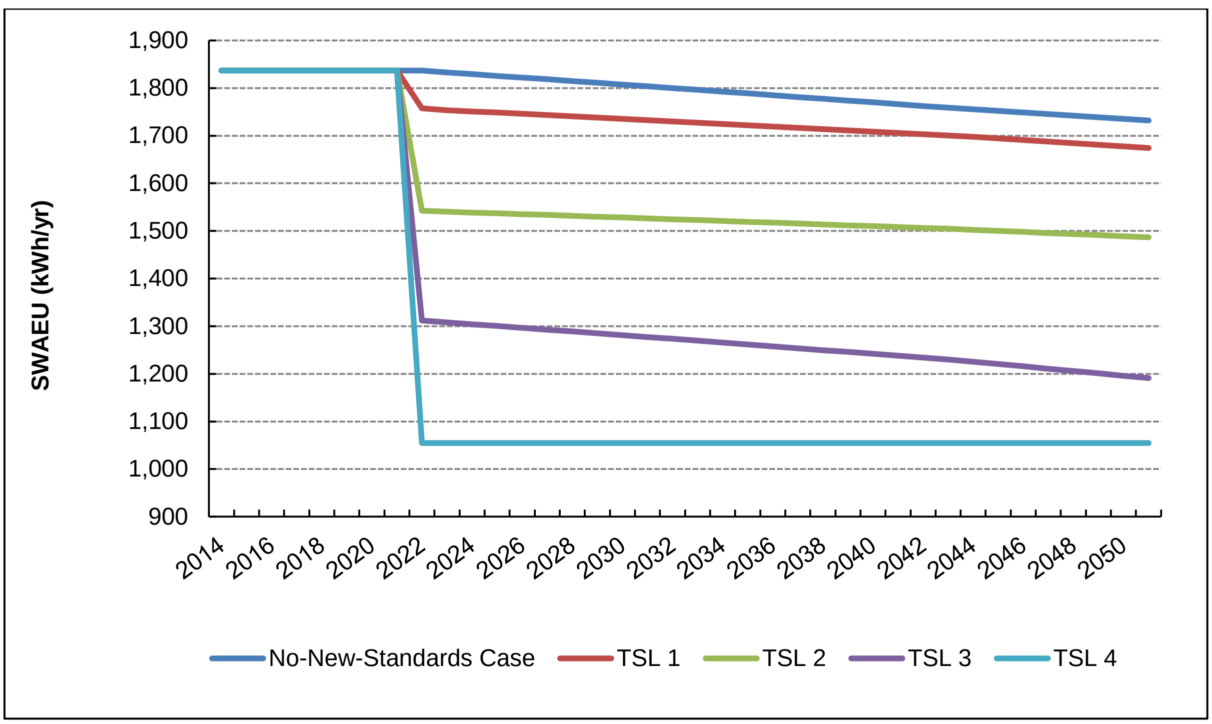

Figure 10.3.2 Projected Energy Consumption for the No-New-Standards Case and Each Trial Standards Case, Commercial Sector

As Figure 10.2.1 illustrates, because the efficiency trend in the standards cases does not surpass the max-tech level, under TSL 4 the SWAEU stays constant and equal to the max-tech level.

10.3.2.2 Shipments and Product Stock

The product stock in a given year is the number of products shipped from earlier years that survive in that year. The NIA model tracks the number of units shipped each year. DOE assumes that products have an increasing probability of retiring as they age. The probability of survival as a function of years since purchase is the survival function. Chapter 9 of this final rule TSD provides additional details on the survival function that DOE used for portable ACs.

10.3.2.3 National Annual Energy Consumption

The national annual energy consumption (AEC) is the product of the annual energy consumption per unit (UEC) and the number of units of each vintage (V). This method of calculation accounts for differences in unit energy consumption from year to year. DOE used the equation below (initially presented in section 10.3.1) to calculate annual energy consumption.

$$AEC = \sum STOCK_V \times UEC_V$$

In determining national annual energy consumption, DOE first calculated annual energy consumption at the site, then applied a conversion factor, described below, to calculate primary energy consumption.

10.3.2.4 Site-to-Power-Plant Energy Conversion Factors

In determining annual NES, DOE initially considered the annual energy consumption at a residence (for electricity, the energy in kWh consumed by a household). DOE then calculated primary (source) energy use from site energy consumption by applying a conversion factor to account for losses associated with the generation, transmission, and distribution of electricity. The site-to-source conversion factor is a multiplicative factor used to convert site energy consumption into primary, or source, energy consumption, expressed in quadrillion Btus (quads).

DOE used annual site-to-power-plant conversion factors based on the version of the national energy modeling system (NEMS)[a] that corresponds to the DOE Energy Information Administration's (EIA's) *Annual Energy Outlook 2016* (*AEO 2016*).[2] The factors are marginal values, which represent the response of the national power system to an incremental decrease in consumption. For electricity, the conversion factors change over time in response to projected changes in generation sources (the types of power plants projected to provide electricity).

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[a] For more information on NEMS, refer to the U.S. Department of Energy, Energy Information Administration documentation. A useful summary is *National Energy Modeling System: An Overview 2000*, DOE/EIA-0581(2000), March 2000. EIA approves use of the name NEMS to describe only an official version of the model with no modification to code or data.

Figure 10.3.3 shows the site-to-power-plant conversion factors for electricity between 2022 and 2040 for portable ACs. The conversion factors were generated by NEMS based on the load shape for portable ACs. NEMS output stops in 2040; DOE assumed that conversion factors remain constant at 2040 values through the end of the analysis period (2051).

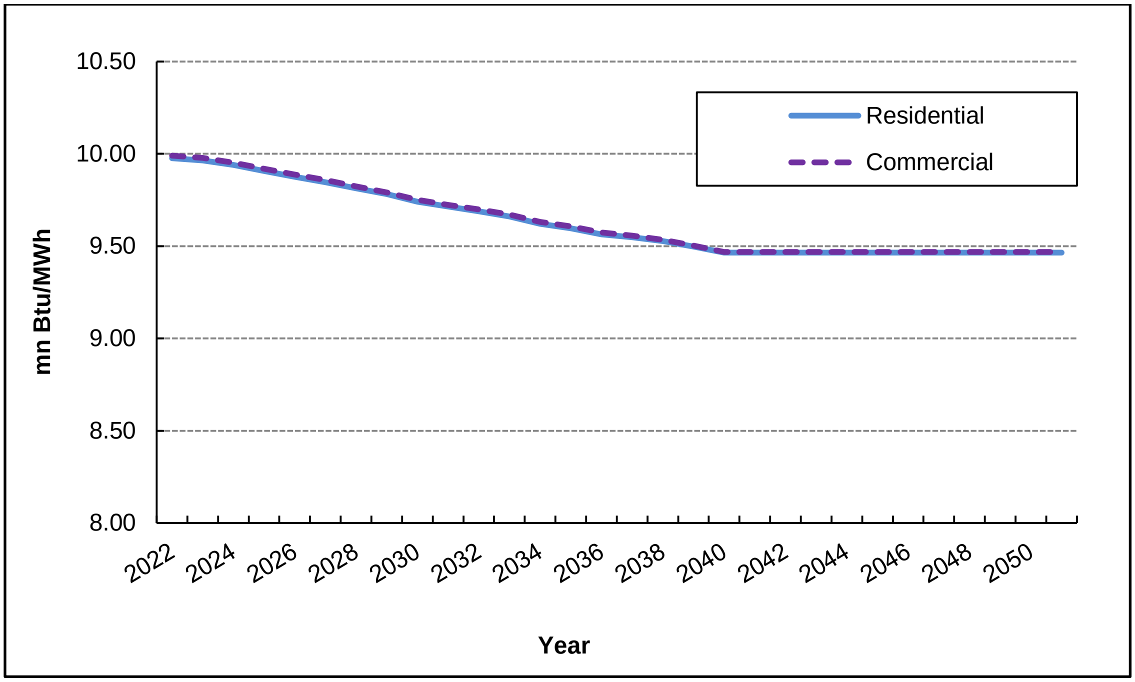

Figure 10.3.3 Site-to-Power Plant Conversion Factors for Electricity

10.3.2.5 Full-Fuel-Cycle Multipliers

The full-fuel-cycle (FFC) encompasses point-of-use (site) energy; the energy losses associated with generation, transmission, and distribution of electricity; and the energy consumed in extracting, processing, and transporting or distributing primary fuels. To estimate the FFC by including the energy consumed in extracting, processing, and transporting or distributing primary fuels, referred to as upstream activities, DOE developed FFC multipliers[b] using the data and projections generated for *AEO 2016*. The *AEO 2016* provides extensive information about the energy system, including projections of future oil, natural gas, and coal supplies; energy use for oil and gas field and refinery operations; and fuel consumption and emissions related to electric power production. The information can be used to define a set of parameters that represent the energy intensity of energy production. The method used to calculate FFC energy multipliers is described in appendix 10B.

Table 10.3.2 shows the FFC energy multipliers used for portable ACs for selected years. The 2040 values were used for the years after 2040.

[b] FFC multipliers discussed in this chapter relate to the upstream part of the FFC process.

Table 10.3.2 Full-Fuel-Cycle Energy Multipliers (based on *AEO 2016*)

Electricity (power plant energy use)	2022	2025	2030	2035	2040	2045	2051
Residential	1.041	1.043	1.045	1.044	1.045	1.045	1.045
Commercial	1.041	1.043	1.045	1.044	1.045	1.045	1.045

10.3.2.6 Rebound Effect

A rebound effect may follow an energy conservation standard, in that consumers may increase usage of a product because it costs less to operate than previous models. A rebound effect reduces the energy savings attributable to a standard. DOE generally accounts for the direct rebound effect when estimating the NES. For this final rule analysis, DOE used a rebound effect of 15 percent[3,4, 5, 6]. DOE welcomes data on rebound effects associated with portable ACs.

10.4 NET PRESENT VALUE

DOE calculated the NPV of the increased product cost and reduced operating cost associated with the difference between the no-new-standards and each TSL for portable ACs.

10.4.1 Definition of Net Present Value

The NPV is the value in the present of a time-series of costs and savings. The NPV is described by the equation:

$$NPV = PVS - PVC$$

Where:

PVS = present value of operating cost savings, and
PVC = present value of increased total installed costs (including purchase price and installation costs).

DOE determined the PVS and PVC according to the following expressions.

$$PVS = \sum OCS_y \times DF_y$$

$$PVC = \sum TIC_y \times DF_y$$

Where:

OCS = total annual-savings in operating costs each year summed over vintages of the product stock, $STOCK_V$;

DF	=	discount factor in each year;
TIC	=	total annual increases in installed cost each year summed over vintages of the product stock, $STOCK_V$; and
y	=	year in the forecast.

DOE calculated the total annual consumer savings in operating costs by multiplying the number or stock of the product (by vintage) by its per-unit operating cost savings (also by vintage). DOE calculated the total annual increases in consumer product price by multiplying the number or shipments of the product (by vintage) by its per-unit increase in consumer cost (also by vintage). Total annual operating cost savings and total annual product price increases are calculated by the following equations.

$$OCS_y = \sum STOCK_V \times UOCS_V$$

$$TIC_y = \sum SHIP_y \times UTIC_y$$

Where:

$STOCK_V$	=	stock of products of vintage *V* that survive in the year for which DOE calculated annual energy consumption,
$UOCS_V$	=	annual operating cost savings per unit of vintage *V*,
V	=	year in which the product was purchased as a new unit;
$SHIP_y$	=	shipments of the product in year *y*; and
$UTIC_y$	=	annual per-unit increase in installed product price in year *y*.

DOE determined the total increased product price for each year from 2022 to 2051. DOE determined the present value of operating cost savings for each year from 2022 to the year when all units purchased in 2051 are estimated to retire (2080). DOE calculated costs and savings as the difference between a standards case and a no-new-standards without new standards.

DOE developed a discount factor from the national discount rate and the number of years between the "present" (year to which the sum is being discounted) and the year in which the costs and savings occur. The NPV is the sum over time of the discounted net savings.

10.4.2 Inputs to Calculation of Net Present Value

The inputs to the calculation of NPV are:

- total installed cost per unit,
- total annual increases in installed cost,
- annual savings in operating cost per unit,
- total annual operating costs,
- discount factor,

- present value of costs, and
- present value of savings.

The increase in total annual installed cost is equal to the annual change in the per-unit total installed cost (difference between no-new-standards and standards cases) multiplied by the shipments forecasted for each case.

The total annual savings in operating costs are equal to the change in annual operating costs (difference between no-new-standards and standards case) per unit multiplied by the shipments forecasted for each case. The annual operating cost includes energy, repair, and maintenance costs, as described in chapter 8.

10.4.2.1 Total Installed Cost per Unit

The per-unit total installed cost of portable ACs, described in chapter 8, is a function of product energy efficiency. Because the per-unit total annual installed cost depends directly on energy efficiency, DOE used the shipments-weighted energy efficiencies distribution of the no-new-standards case and standards cases described in section 10.2, in combination with the total installed costs developed in chapter 8, to estimate the shipments-weighted average annual per-unit total installed cost under the no-new-standards case and standards cases. Table 10.4.1 shows the shipment-weighted average consumer price for portable ACs in 2022 based on the efficiency distributions that correspond to the no-new-standards case and each standards case.

Table 10.4.1 Shipments-Weighted Average Total Installed Cost in 2022

Efficiency Level	**Unit Price *2015$***		**Market Share *%***				
			No-New-Std Case	**TSL**			
	Residential	**Commercial**		**1**	**2**	**3**	**4**
Baseline	559	560	37	0	0	0	0
1	588	588	48	85	0	0	0
2	635	636	13	13	98	0	0
3	700	701	2	2	2	100	0
4	733	733	0	0	0	0	100
Total Installed Cost *2015$*		**Residential**	586	596	636	700	733
		Commercial	586	597	637	701	733

As discussed in chapter 8, DOE developed a price trend based on the producer price index series for “small electric household appliances, except fans” from 1983 to 2015. DOE used the price trend to project the prices of portable ACs sold in each year of the forecast period (2022–2051). The price in each year was estimated as an exponential function of the year, and DOE applied the same values to project prices at each TSL. For portable ACs, the estimated average annual rate of price decline is 1.96 percent. To investigate the effect of different product price projections on the consumer NPV for various efficiency levels, DOE also considered two alternative price trends. Details on how those alternative price trends were developed are documented in appendix 10C, which also presents the results of DOE's analysis of price sensitivities.

Figure 10.4.1 and Figure 10.4.2 show the projected trends in installed cost for portable AC units in the residential and commercial sectors, respectively.

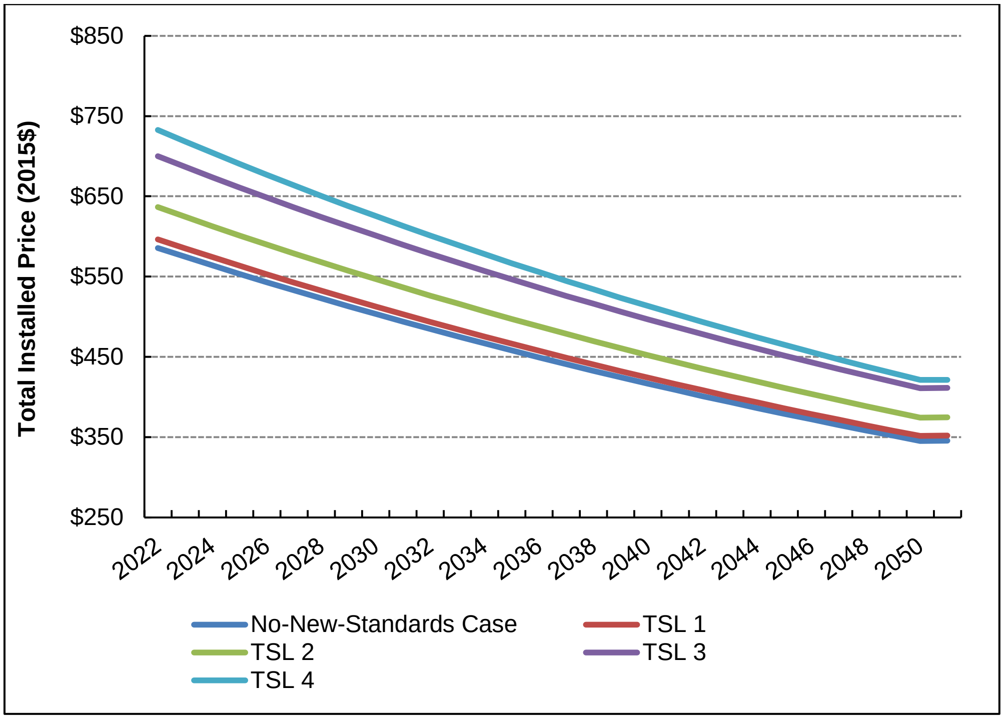

Figure 10.4.1 Total Installed Cost Projected for the No-New-Standards Case and Each Trial Standard Case, Residential Settings

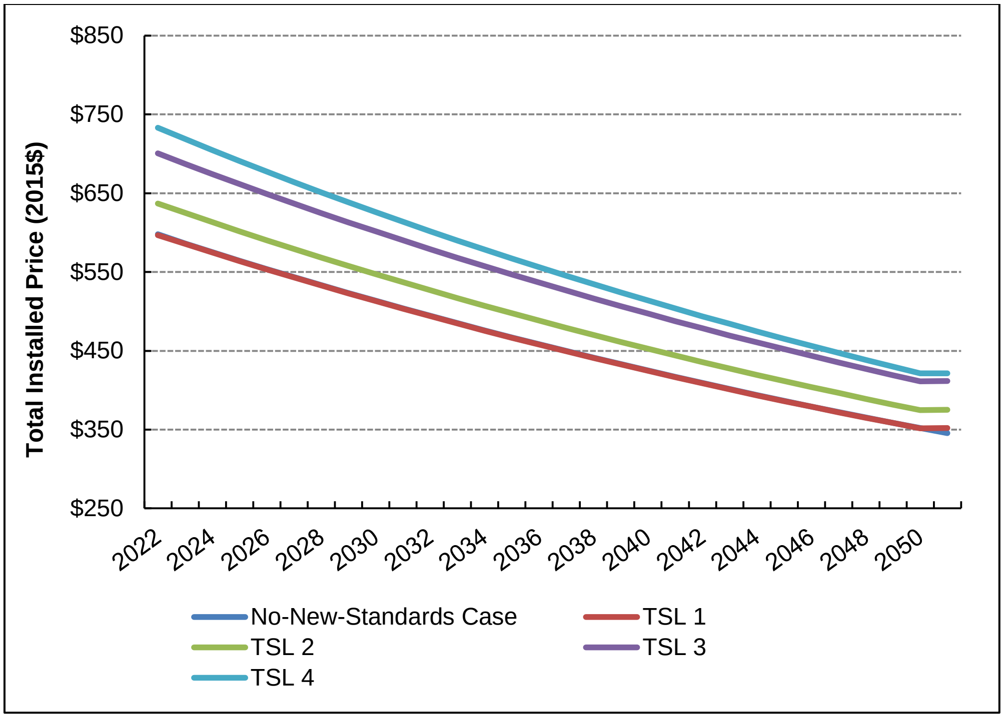

Figure 10.4.2 Total Installed Cost Projected for the No-New-Standards Case and Each Trial Standards Case, Commercial Settings

10.4.2.2 Increase in Total Annual Installed Cost

The increase in total annual installed cost for any given TSL is the product of the total installed cost increase per unit under that standard and the number of units of each vintage. This approach accounts for differences in total installed cost from year to year. DOE used the following equation (also presented in section 10.4.1) to determine the increase in total annual installed cost for a given TSL.

$$TIC\ (y) = \sum UTIC(y) \times S(y)$$

10.4.2.1 Annual Savings in Operating Costs per Unit

Per-unit annual operating costs encompass the annual costs for energy, repair, and maintenance. DOE determined the savings in per-unit annual energy cost by multiplying the savings in per-unit annual energy consumption by the appropriate energy price. Estimates of per-unit annual energy consumption for the no-new-standards and each standards case were presented in section 10.3.2.1. To estimate energy prices in future years, DOE multiplied the recent electricity prices by a projection of annual national-average residential and commercial electricity prices consistent with cases described on p. E-8 in *AEO 2016* reference case.[c] The energy prices and price trends are described in chapter 8.

10.4.2.2 Total Savings in Annual Operating Costs

The total savings in annual operating costs for a TSL is the product of the annual operating cost savings per unit under that standard and the number of units of each vintage. This approach accounts for differences in savings in annual operating costs from year to year. DOE used the following equation (also presented in section 10.4.1) to determine the total savings in annual operating cost for a given standards case.

$$OCS(y) = \sum UOCS(y) \times AffStock(y)$$

As discussed in section 10.3.1.6, a rebound effect may follow an energy conservation standard, in that consumers may increase usage of a product because it costs less to operate than previous models. The increase in energy consumption associated with the rebound effect represents increased value to consumers (*e.g.*, a more comfortable indoor environment). The net effect is the sum of (1) the change in the cost of owning a product (that is, national consumer expenditures for total installed and operating costs) and (2) the increased value of the enhanced service from the product. DOE believes that, if the increased national value (to consumers) produced by the rebound effect could be monetized, it would be similar to the monetary value of the foregone energy savings. For this analysis, DOE estimated that the increased value to consumers is equivalent to the monetary value of the energy savings that would have occurred without the rebound effect. The national economic impacts on consumers as measured by the NPV analysis, with or without the rebound effect, therefore are the same.

10.4.2.3 Discount Factors

DOE multiplies monetary values in future years by a discount factor to determine present values. The discount factor (DF) is described by the equation:

$$DF = \frac{1}{(1+r)^{(y-y_p)}}$$

[c] The standards finalized in this rulemaking will take effect before the requirements of the Clean Power Plan (CPP) as modeled in the AEO 2016 Reference case, putting downward pressure on electricity prices relative to the projections in Reference case. Consequently, DOE used the more conservative (i.e., lower) price projections found in the AEO 2016 No-CPP case.

Where:

r = discount rate,
y = year of the monetary value, and
y_P = year in which the present value is being determined.

DOE uses both a 3-percent and a 7-percent real discount rate when estimating national impacts. Those discount rates were applied to product prices of portable ACs in accordance with the Office of Management and Budget (OMB)'s guidance to Federal agencies on developing regulatory analyses (OMB Circular A-4, September 17, 2003, and section E., "Identifying and Measuring Benefits and Costs," therein). DOE defines the present year as 2016.

10.4.2.4 Present Value of Costs

The present value of increased installed costs is the annual increase in installed cost for each year (*i.e.*, the difference between the standards case and no-new-standards), discounted to the present and summed over the period for which DOE is considering the installed products (2022–2051). The increase in total installed cost refers to both product and installation costs associated with the higher energy efficiency of products purchased under a standards case compared to the no-new-standards. DOE calculated annual increases in installed cost as the difference in total cost of new products installed each year, multiplied by the shipments in the standards case.

10.4.2.5 Present Value of Savings

The present value of savings in operating costs is the annual savings in operating cost (*i.e.*, the difference between the no-new-standards case and standards case), discounted to the present and summed over the period that begins with the effective date of standards and ends when the last installed unit is retired from service. Savings represent decreases in operating costs (including costs for energy, repair, and maintenance) associated with the higher energy efficiency of products purchased in a standards case compared to the no-new-standards case. Total annual savings in operating costs are the savings per unit multiplied by the number of units of each vintage that survive in a particular year. Because a product consumes energy throughout its lifetime, the energy consumption for units installed in a given year includes energy consumed until the unit is retired from service.

10.5 RESULTS

The NIA model provides estimates of the NES and NPV associated with conservation standards at different efficiency levels. The inputs to the NIA model were discussed in sections 10.4.2 (NES Inputs) and 10.4.2 (NPV Inputs). DOE generated the NES and NPV results using a Microsoft Excel spreadsheet, which is accessible on the internet at (www.eere.energy.gov/buildings/appliance_standards/). Details and instructions for using the spreadsheet are provided in appendix 10-A, User Instructions for National Impact Analysis

Spreadsheet Model, in the section titled, “Descriptions of National Impact Analysis Worksheets”. Table 10.5.1 summarizes inputs to the NIA model.

Table 10.5.1 Inputs to Calculating National Energy Savings and Net Present Value

Input	Data Description
Shipments	Annual shipments from shipments model (chapter 9).
Effective date of standard	2022.
Energy efficiency in no-new-standards	SWEER determined for 2022. Annual growth rate of 0.25 percent assumed for determining SWEER between 2022 and 2051 (see section 10.2).
Energy efficiency in standards cases	“Roll-up + shift” scenario assumed for determining SWEER in 2022 for each standards case (see section 10.2).
Annual energy consumption per unit	Annual weighted-average values are a function of shipments-weighted UEC.
Total installed cost per unit	Annual weighted-average values are a function of efficiency distribution.
Energy cost per unit	Annual weighted-average values are a function of the annual UEC and energy prices (see chapter 8 for energy prices).
Repair and maintenance costs per unit	Annual values are a function of efficiency level (see chapter 8).
Trend in energy prices	Based on EIA's *AEO 2016* reference case (to 2040) (see chapter 8).
Energy site-to-power plant conversion	A time-series conversion factor that includes losses due to electricity generation, transmission, and distribution. Conversion, which changes yearly, is generated by DOE/EIA’s NEMS* program.
Full-fuel-cycle multiplier	Developed to include the energy consumed in extracting, processing, and transporting or distributing primary fuels.
Discount rate	3 percent and 7 percent real.
Present year	Future expenses are discounted to 2016.

* Section 10.3.2.4 provides more detail on NEMS.

10.5.2 National Energy Savings by TSL

This section provides results of calculating NES for each TSL analyzed for portable ACs. NES results, which are cumulative to 2080 (the year in which products purchased in 2051 would be expected to be retired), are shown as savings in both primary and full-fuel-cycle energy. Because DOE based the inputs to the NIA model on weighted-average values, results are discrete point values, rather than a distribution of values as produced by the life-cycle cost and payback period analysis (chapter 8). Table 10.5.2 and Table 10.5.3 show the primary and full-fuel-cycle energy savings, respectively, for the TSLs analyzed for portable ACs.

Table 10.5.2 Cumulative Primary National Energy Savings

TSL	Portable ACs in Residential Sites, *Quads*	Portable ACs in Commercial Sites, *Quads*	Portable ACs in both Sectors, *Quads*	Portable ACs in both Sectors, (15% Rebound) *Quads*
1	0.10	0.04	0.14	0.12
2	0.40	0.15	0.55	0.47
3	0.77	0.29	1.06	0.90
4	1.05	0.40	1.45	1.23

Table 10.5.3 National Energy Savings for Full-Fuel-Cycle

TSL	Portable ACs in Residential Sites *Quads*	Portable ACs in Commercial Sites *Quads*	Portable ACs in both Sectors *Quads*	Portable ACs in both Sectors, (15% Rebound) *Quads*
1	0.10	0.04	0.14	0.12
2	0.41	0.16	0.57	0.49
3	0.81	0.31	1.11	0.95
4	1.09	0.42	1.51	1.28

10.5.3 Annual Costs and Savings

Figure 10.5.1 illustrates the basic inputs to calculating the NPV under TSL 2 for the non-discounted annual increases in installed cost and annual savings in operating cost for portable ACs. The annual product cost is the sum of the increase in total installed cost for products purchased each year during the analysis period. The annual savings in operating cost is the savings for products operating in each year. The figure also shows net savings, which is the difference between the savings and costs for each year. The NPV is the difference between the cumulative annual discounted savings and the cumulative annual discounted costs. DOE could create figures like Figure 10.5.1 for each TSL.

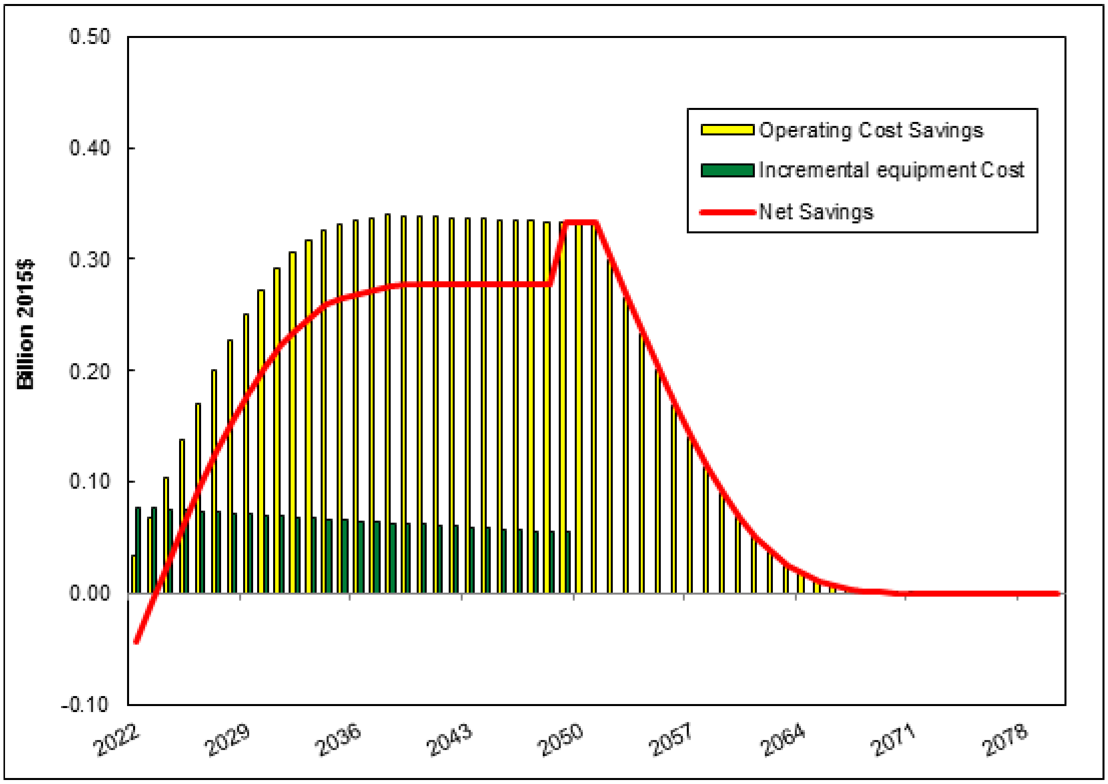

Figure 10.5.1 Non-Discounted Changes in Annual Installed Cost and Operating Costs under TSL 2

10.5.4 Consumer Net Present Value by TSL

This section provides results of calculating the net present value (NPV) of consumer benefits for each TSL considered for portable ACs. Results, which are cumulative, are shown as the discounted value of the net savings in dollar terms. DOE based the inputs to the NIA model on weighted-average values, yielding results that are discrete point values, rather than a distribution of values as in the life-cycle cost and payback period analysis.

Table 10.5.4 shows the results of calculating the NPV for the TSLs analyzed for portable ACs. The table presents the NPV at both a 3-percent and a 7-percent discount rate.

Table 10.5.4 Cumulative Consumer Net Present Value for Each TSL

TSL	NPV at 3% Discount Rate *Billion, 2015$*			NPV at 7% Discount Rate *Billion, 2015$*		
	Residential	**Commercial**	**Total**	**Residential**	**Commercial**	**Total**
1	0.62	0.20	0.81	0.26	0.09	0.35
2	2.30	0.76	3.06	0.93	0.32	1.25
3	4.15	1.41	5.56	1.59	0.58	2.17
4	5.98	1.99	7.96	2.37	0.84	3.21

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CHAPTER 11. CONSUMER SUBGROUP ANALYSIS

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CHAPTER 11. CONSUMER SUBGROUP ANALYSIS

11.1 INTRODUCTION

The consumer subgroup analysis evaluates impacts on groups or consumers who may be disproportionately affected by any national energy conservation standard. The U.S. Department of Energy (DOE) evaluates impacts on particular subgroups of consumers by analyzing the impacts on life-cycle cost (LCC) and payback period (PBP) for those consumers that may arise due to the adoption of the proposed efficiency levels.

DOE determined the impact on portable air conditioner (AC) consumer subgroups based on a subset of the portable AC consumer samples derived using the same methodology discussed in chapter 8 of this final rule Technical Support Document (TSD). DOE evaluated the impacts of the proposed efficiency levels for the different consumer subgroups for portable air conditioners (ACs). In particular, the consumer subgroup analysis for the residential sector investigates the impact any standard may have on low-income households and on senior-only households. For the commercial sector, the impact on small-businesses was investigated. This chapter describes the subgroup identification in further detail and gives the results of the LCC and PBP analyses for the considered subgroups.

11.2 SUBGROUP DEFINITIONS

11.2.1 Low-Income and Senior-Only Households

Of the 12,083 households in RECS 2009, 2,656 have room ACs which are used as a proxy for portable AC ownership. Table 11.2.1 shows the low-income household and senior-only household sample size for room ACs.

Table 11.2.1 Household Population Data for Room ACs from RECS 2009

	No. of Records
General Population	2,656
Low-Income Households	513
Senior Households	432

As defined in the Energy Information Administration's 2009 Residential Energy Consumption Survey (RECS 2009) survey[1], low-income households are those at or below the "poverty line." The poverty line varies with household size, head of household age, and family income. RECS includes a group of households with incomes below the poverty level in 2009 as defined by the U.S. Bureau of the Census[2]. The RECS survey classifies approximately 15 percent of U.S. households as low-income.

Senior-only households comprise occupants who are all at least 65 years of age. Based on DOE's Energy Information Administration's Residential Energy Consumption Survey of 2009 (RECS), senior-only households represent 17 percent of U.S. households.

11.2.2 Small Businesses

The Small Business Administration (SBA) defines a small business by its annual receipts or its number of employees. DOE assumed that portable ACs are used by small businesses with the same distribution of applications and sectors as all portable ACs in the commercial sector, so DOE did not assign a different distribution.

The capital asset pricing model (CAPM) underestimates the cost of capital for small companies. In CAPM, the risk premium β is used to account for the higher returns associated with greater risk. However, for small companies, particularly very small companies, historic returns have been significantly higher than the CAPM equation predicts. This additional return can be accounted for by adding a size premium to the cost of equity for small firms:

$$k_e = R_f + (\beta \times ERP) + S$$

Where:

- k_e = Cost of equity,
- R_f = Expected return on risk-free assets,
- β = Risk coefficient of the firm,
- ERP = Equity risk premium, and
- S = Size Premium.

DOE obtained size premium data from Ibbotson Associates' *Stocks, Bonds, Bills, and Inflation Yearbook* (Table 11.2.2).[3] For each year, the size premium is the historical average difference in performance between small companies and the market average. For example, for the period of 1926-2008, the average size premium for the smallest companies in all industries is 3.74%, implying that on average, historic performance of small companies was 3.74% higher than the CAPM estimate of the small company cost of equity over this period.

Table 11.2.2 Size Premium by Year

Year	Maximum Market Capitalization ($mil)	Size Premium ("Microcap" Companies)[a]
2004	505	4.02%
2005	586	3.95%
2006	627	3.88%
2007	723	3.65%
2008	456	3.74%
2009	431	3.99%
2010	478	4.07%
2011	423	3.89%
2012	514	3.81%
2013[b]	514	3.81%

DOE calculated the real weighted-average cost of capital (as described in chapter 8) using the cost of equity including a size premium for small companies instead of the CAPM cost of equity.[4] Table 11.2.3 presents DOE's estimates of the discount rates for entire sectors, small companies specifically, and the small company discount rate premium. To estimate the impact of standards specifically on small businesses, DOE applied the small company discount rate distributions for each sector in the LCC and PBP calculation, instead of the distributions described in chapter 8 of this final rule TSD.

[a] "Microcap" companies are defined as companies with market capitalization in the 9th decile or lower (i.e., the smallest two deciles of companies). DOE uses the microcap size premium as it results in a conservative estimate of small company NPV of energy cost savings.

[b] As data were not yet available for 2013, DOE applies the 2012 size premium to WACC calculations.

Table 11.2.3 Discount Rate Difference between Small Company and Sector Average

Sector		Discount Rate		
		Average	**Standard Deviation**	**Small Company Discount Rate Premium**
Retail	Entire Sector	5.00%	1.07%	2.21%
	Small Companies	7.21%	2.06%	
Lodging	Entire Sector	5.96%	1.65%	1.19%
	Small Companies	7.15%	2.14%	
Food Service	Entire Sector	4.90%	0.95%	2.59%
	Small Companies	7.49%	1.86%	
Office	Entire Sector	5.08%	1.28%	1.46%
	Small Companies	6.54%	2.10%	
Other	Entire Sector	5.04%	1.07%	1.97%
	Small Companies	7.01%	2.44%	

11.3 RESULTS

Table 11.3.1 compares the results from the sample of subgroup consumers to the results for the total sample of consumers used in the overall LCC analysis. LCC savings are provided by trial standard level (TSL) and include only affected customers, *i.e.*, those with non-zero savings. Note that the impact on small businesses may be overestimated, since many small buildings may be owned by the same company, as is the case with retail and restaurant chains.

Table 11.3.1 Comparison of LCC Savings and PBP for Consumer Subgroups and All Consumers

	Average Life-Cycle Cost Savings (2014$)				Simple Payback Period (years)			
TSL	**Low-income households**	**Senior-only households**	**Small Businesses**	**Reference Case - All Consumers**	**Low-income households**	**Senior-only households**	**Small Businesses**	**Reference Case - All Consumers**
1	96	72	143	84	1.9	2.3	1.2	2.2
2	142	106	218	125	2.3	2.8	1.4	2.6
3	195	141	312	169	2.9	3.5	1.7	3.2
4	304	226	477	268	2.6	3.2	1.6	2.9

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CHAPTER 12. MANUFACTURER IMPACT ANALYSIS

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CHAPTER 12. MANUFACTURER IMPACT ANALYSIS

12.1 INTRODUCTION

In determining whether a standard is economically justified, the U.S. Department of Energy (DOE) is required to consider "the economic impact of the standard on the manufacturers and on the consumers of the products subject to such a standard." (42 U.S.C. 6295(o)(2)(B)(i)) The statute also calls for an assessment of the impact of any lessening of competition as determined in writing by the Attorney General. *Id*. DOE conducted a manufacturer impact analysis (MIA) to estimate the financial impact of energy conservation standards on manufacturers of portable air conditioners (ACs), and assess the impact of such standards on direct employment and manufacturing capacity.

The MIA has both quantitative and qualitative aspects. The quantitative part of the MIA primarily relies on the Government Regulatory Impact Model (GRIM), an industry cash-flow model adapted to the product classes covered by this rulemaking. The GRIM inputs include information on industry cost structure, shipments, and pricing strategies. The GRIM's key output, the industry net present value (INPV), is the sum of discounted industry annual cash-flows over the analysis period. The model estimates the financial impact of energy conservation standards by comparing changes in INPV between a no-new-standards case and the various trial standard levels (TSLs) in the standards case. The qualitative part of the MIA addresses product characteristics, manufacturer characteristics, market and product trends, as well as the impact of standards on any subgroups of manufacturers.

12.2 METHODOLOGY

DOE conducted the MIA in three phases. Phase I, "Industry Profile," consisted of preliminary research directed at characterizing the portable AC manufacturing industry. This research involved collecting data on market share, sales volumes and trends, pricing, employment, and the industry financial structure.

In Phase II, "Industry Cash Flow Model and Interview Guide," DOE created a framework GRIM to analyze the economic impact of new energy conservation standards on the portable AC manufacturing industry as a whole. DOE also developed a manufacturer interview guide to gather additional information on the potential impacts on manufacturers in Phase III.

In Phase III, "Subgroup Impact Analysis," DOE interviewed manufacturers representing an estimated 70 percent of the portable AC market. During interviews, DOE discussed financial topics specific to each manufacturer and obtained each manufacturer's view of the industry in order to evaluate the impacts of new energy conservation standards on manufacturer cash flows, investments, and employment. Additionally, the interviews provided DOE with valuable information about the technologies available in the industry and informed adjustments to the engineering analysis between the preliminary analysis and notice of proposed rulemaking (NOPR) stages.

12.2.1 Phase I: Industry Profile

In Phase I of the MIA, DOE prepared a profile of the portable AC industry that built upon the market and technology assessment prepared for this rulemaking (see chapter 3 of this final rule technical support document (TSD)). Before initiating the detailed impact studies, DOE collected information on the present and past market structure and characteristics of the industry, tracking trends in market share, product attributes, product shipments, manufacturer markups, and the cost structure for various manufacturers.

The profile also included a top-down analysis of manufacturers in the industry using U.S. Securities and Exchange Commission (SEC) 10–K filings,[a] Standard & Poor's (S&P) stock reports,[b] and corporate annual reports released by both public and privately held companies. DOE used this and other publicly available information to derive preliminary financial inputs for the GRIM (*e.g.*, revenues; cost of goods sold; depreciation; selling, general and administrative expenses (SG&A); and research and development (R&D) expenses).

12.2.2 Phase II: Industry Cash-Flow Model and Interview Guide

Phase II focused on the financial impacts of new energy conservation standards on the portable AC manufacturing industry as a whole. New energy conservation standards can affect manufacturer cash flows in three distinct ways: (1) by creating a need for increased investment, (2) by raising production costs per unit, and (3) by altering revenue due to higher per-unit prices and/or possible changes in sales volumes. DOE created a framework GRIM to analyze the economic impact of new energy conservation standards on the portable AC manufacturing industry as a whole. In preparing the GRIM, DOE used the financial values derived during Phase I and the shipment assumptions from the national impact analysis (NIA). Additionally, DOE prepared a written guide for manufacturer interviews to collect additional data critical to developing other inputs for the GRIM. See appendix 12A of this final rule TSD for the NOPR-stage interview guide.

12.2.2.1 Industry Cash-Flow Analysis

The GRIM uses several factors to determine a series of annual cash flows over a period from the announcement year of the new energy conservation standards until 30 years after the standards' compliance date. INPV is the sum of these annual cash flows discounted by the industry weighted average cost of capital. Inputs to the GRIM include the manufacturing costs, markups, and shipment forecasts developed in other analyses as well as the industry weighted average financial parameters developed in Phase I. DOE derived the manufacturing costs from the engineering analysis as presented in chapter 5 of this final rule TSD, information provided by the industry, publicly available financial reports, and interviews with manufacturers. To examine the range of possible impacts, DOE developed alternative markup scenarios based on discussions with manufacturers. DOE's shipments analysis, presented in chapter 9 of this final rule TSD, provided the basis for the shipment projections. DOE derived the financial parameters using

[a] Available online at www.sec.gov.
[b] Available online at www2.standardandpoors.com.

publicly available reports and revised them using information received during confidential manufacturer interviews. DOE used the GRIM to compare INPV in the no-new-standards case with INPV at various TSLs (the standards cases). The difference in INPV between the base and standards cases represents the financial impact of the new standard on manufacturers.

12.2.2.2 Interview Guide

During Phase III of the MIA, DOE interviewed manufacturers of portable ACs to gather information on the effects of new energy conservation on revenues and finances, direct employment, capital assets, and industry competitiveness. Before the interviews, DOE distributed an interview guide to representatives of each participating manufacturer. The interview guide provided a starting point to help identify relevant issues and understand the impacts of new energy conservation standards on individual manufacturers or subgroups of manufacturers. The information DOE received from these meetings is protected by non-disclosure agreements and resides with DOE's contractors. The topics covered as part of these interviews include the following: (1) key issues related to this rulemaking; (2) engineering and life cycle cost; (3) manufacturer markups and profitability; (4) financial parameters; and (5) conversion costs. The NOPR-stage interview guide is presented in appendix 12A of this final rule TSD.

12.2.3 Phase III: Manufacturer Interviews and Additional Analyses

Using the interview guides developed in Phase II, DOE conducted structured, detailed interviews with representative manufacturers. These interviews were conducted during both the preliminary and NOPR stages of this rulemaking.

Additionally, DOE evaluated whether subgroups of manufacturers may be disproportionately impacted by new standards or may not be accurately represented by the average cost assumptions used to develop the industry cash flow analysis. Such manufacturer subgroups may include small business manufacturers, low-volume manufacturers (LVMs), niche players, and/or manufacturers exhibiting a cost structure that largely differs from the industry average. DOE identified one manufacturer subgroup for a separate impact analysis: small business manufacturers.

Finally, using preliminary industry research and feedback obtained during interviews, DOE evaluated impacts of new energy conservation standards on domestic manufacturing capacity and direct employment, as well as on cumulative regulatory burdens facing portable AC manufacturers.

12.2.3.1 Manufacturing Interviews

The information gathered in Phase I and the cash-flow analysis performed in Phase II are supplemented with information gathered from manufacturer interviews in Phase III. The interview process provides an opportunity for interested parties to express their views on important issues privately, allowing confidential or sensitive information to be considered in the rulemaking process.

During these interviews, DOE discussed engineering, manufacturing, procurement, and financial topics to validate assumptions used in the GRIM and to identify key issues or concerns. A description of the key issues raised by portable AC manufacturers during interviews conducted for the NOPR that DOE published on June 13, 2016 (June 2016 NOPR, 81 FR 38398) can be found in section IV.J.3 of that notice. See section IV.J.3 of the final rule notice for a description of public comments submitted by interested parties in response to the June 2016 NOPR.

12.2.3.2 Small-Business Manufacturer

DOE used the U.S. Small Business Administration (SBA) small business size standards and the North American Industry Classification System (NAICS) code, presented in Table 12.2.1, to determine whether any small entities would be affected by the rulemaking.[c] For the products under review, the SBA bases its small business definition on the total number of employees for a business including the total employee count of a parent company and its subsidiaries. An aggregated business entity with fewer employees than the listed limit is considered a small business.

As there are currently no energy conservation standards for portable ACs, DOE used the public certification database compiled by the California Energy Commission (CEC)[1], Association of Home Appliance Manufacturers (AHAM) membership directory[2], and additional web searches to identify portable AC manufacturers. DOE then checked this list of portable AC manufacturers against the employee limit for small businesses using reports from vendors such as Hoovers.[3] DOE also consulted publicly available data from the SBA to determine the presence of any additional small businesses in the industry. Further, DOE asked interested parties and industry representatives if they were aware of other small business manufacturers and checked any companies identified against the small business criteria.

Based on the size standards published by the SBA, to be categorized as a small business manufacturer of portable ACs under NAICS codes 333415 ("Air-Conditioning and Warm Air Heating Equipment and Commercial and Industrial Refrigeration Equipment Manufacturing"), a portable AC manufacturer and its affiliates may employ a maximum of 1,250 employees. The 1,250-employee threshold includes all employees in a business' parent company and any other subsidiaries. Using this classification in conjunction with the above-mentioned resources, DOE identified one small domestic business responsible for the design and distribution of a dual-duct portable AC.

[c] The size standards are codified at 13 CFR Part 121. The standards are listed by NAICS code and industry description and are available on the SBA's website at: https://www.sba.gov/sites/default/files/files/Size_Standards_Table.pdf

Table 12.2.1 SBA and NAICS Classification of Small Businesses Potentially Affected by This Rulemaking

Industry Description	Revenue Limit	Employee Limit	NAICS
Air-Conditioning and Warm Air Heating Equipment and Commercial and Industrial Refrigeration Equipment Manufacturing	N/A	1,250	333415

Section 12.5 provides further detail on the small business manufacturer subgroup analysis.

12.2.3.3 Manufacturing Capacity Impact

One possible outcome of new energy conservation standards is the obsolescence of existing manufacturing assets, including tooling and production equipment. The manufacturer interview guide contains a series of questions to help identify impacts of new standards on manufacturing capacity, specifically capacity utilization and plant location decisions in the United States and North America, with and without new standards; the ability of manufacturers to upgrade or remodel existing facilities to accommodate the new requirements; the nature and value of any stranded assets; and estimates for any one-time changes to existing plant, property, and equipment (PP&E). DOE's estimates of the one-time capital changes and stranded assets, found in section 12.3.8, affect the annual cash flow projections in the GRIM. DOE's discussion of the manufacturing capacity impact can be found in section 12.6.2.

12.2.3.4 Direct Employment Impact

Employment impacts from energy conservation standards include direct and indirect impacts. Direct employment impacts are any changes in the number of employees of manufacturers of the products subject to standards. Indirect employment impacts are changes in national employment that occur due to the shift in expenditures and capital investment caused by the purchase and operation of more efficient equipment.

To quantitatively assess the direct employment impacts of amended energy conservation standards, DOE used statistical data from the U.S. Census Bureau's 2014 *Annual Survey of Manufactures* (*ASM*), the results of the engineering analysis, and interviews with manufacturers to determine the inputs necessary to calculate industry-wide labor expenditures and domestic employment levels. Labor expenditures are the amount the industry spends on worker wages, including the cost of benefits. The labor expenditures are a calculation based on the labor cost of products at each efficiency level, the number of units sold and the distribution of efficiencies sold, and an assumption that wages remain fixed in real terms over time. The total labor expenditures in each year are calculated by multiplying the manufacturer production costs (MPCs) by the labor percentage of MPCs and by the number of units sold for each efficiency level.

When DOE models the TSLs, each standard has the potential to affect the total shipments volume and the distribution of efficiencies sold. This, in turn, affects the industry labor expenditures and total jobs. DOE used the GRIM to estimate the domestic labor expenditures and number of employees in the no-new-standards case and at each TSL. The direct employment impacts are reported in section 12.6.1.

12.2.3.5 Cumulative Regulatory Burden

DOE seeks to mitigate the overlapping effects of regulation on manufacturers of portable ACs. These effects may be the result of other regulatory actions affecting portable ACs, or of new energy conservation standards for other products and equipment made by the same manufacturers. DOE identified regulations relevant to portable AC manufacturers using its own research and discussions with manufacturers. A discussion of the cumulative regulatory burden of energy conservation standards and the impact on manufacturers of multiple, product-specific regulatory actions can be found in section 12.6.3.

12.3 GRIM INPUTS AND ASSUMPTIONS

The GRIM serves as the main tool for assessing the impacts on industry due to new energy conservation standards. DOE relies on several sources to obtain inputs for the GRIM. Data and assumptions from these sources are then fed into an accounting model that calculates the industry cash flow both with and without new energy conservation standards.

12.3.1 Overview of the GRIM

The basic structure of the GRIM, illustrated in Figure 12.3.1, is an annual cash flow analysis that uses manufacturer prices, manufacturing costs, shipments, and industry financial information as inputs to arrive at a series of annual cash flows, beginning with the base year of the analysis, 2017, and continuing to 2051. The model calculates the INPV by summing the annual discounted cash flows during this period.[4]

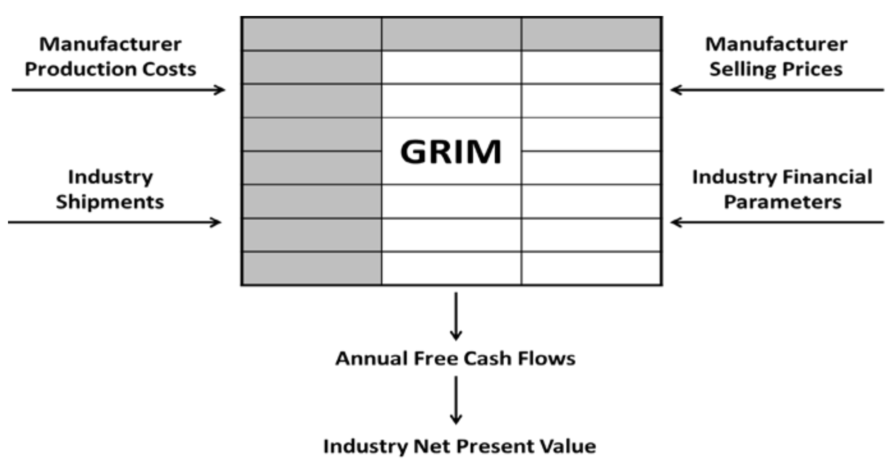

Figure 12.3.1 Using the GRIM to Calculate Cash Flow

The GRIM projects cash flows using standard accounting principles and compares INPV between the no-new-standards case and the standard case scenarios. The difference in INPV between the no-new-standards case and the standard case(s) represents the estimated financial impact of the new energy conservation standards on manufacturers. Appendix 12B provides more technical details and user information for the GRIM.

12.3.2 Sources for GRIM Inputs

The GRIM uses several different sources for data inputs in determining industry cash flow. These sources include corporate annual reports, company profiles, U.S. Census data, credit ratings, the shipments model, the engineering analysis, and the manufacturer interviews.

12.3.2.1 Corporate Annual Reports

Corporate annual reports for publicly held companies are freely available to the general public through the SEC as filings of Form 10-K. Additionally, some privately held companies publish annual financial reports on their corporate websites. DOE developed initial financial inputs to the GRIM by examining the publicly available annual reports of companies primarily engaged in the manufacture of home appliances whose combined product range includes portable ACs. As these companies do not provide detailed information about their individual product lines, DOE used the aggregate financial information at the corporate level in developing its initial estimates of the financial parameters to be used in the GRIM. In doing so, DOE assumes that the industry-average figures calculated for these companies were representative of manufacturing for portable ACs. These figures were later revised using feedback from interviews to be representative of the portable AC manufacturing industry. DOE used corporate annual reports to derive the following initial inputs to the GRIM:

- Tax rate;
- Working capital;
- SG&A;
- R&D;
- Depreciation;
- Capital expenditures; and
- Net PP&E.

12.3.2.2 Standard and Poor's Credit Ratings

S&P provides independent credit ratings, research, and financial information. DOE relied on S&P reports to determine the industry's average cost of debt when calculating the weighted average cost of capital.

12.3.2.3 Shipments Model

The GRIM used shipment projections derived from DOE's shipments model in the NIA. The model relied on historical shipments data for portable ACs. Chapter 9 of the final rule TSD describes the methodology and analytical model DOE used to forecast shipments.

12.3.2.4 Engineering and Markups Analysis

DOE conducted the engineering analysis for this rulemaking using a hybrid approach, combining the design-option and reverse-engineering approaches, to develop a cost for each efficiency level for portable ACs. During this analysis, DOE used a manufacturing cost model to develop MPC estimates for portable ACs. The analysis yielded the labor, materials, overhead, and total production costs for products at each efficiency level. The markups analysis estimated a manufacturer markup to determine the manufacturer selling price (MSP) for each product at every efficiency level. Chapter 5 of the final rule TSD describes the engineering analysis and Chapter 6 of the final rule TSD describes the markups analysis.

12.3.2.5 Manufacturer Interviews

As part of the MIA, DOE conducted interviews with a representative cross-section of manufacturers. Through these discussions, DOE obtained information to determine and verify GRIM input assumptions. Key topics discussed during the interviews and reflected in the GRIM include:

- Capital conversion costs (one-time investments in PP&E);
- Product conversion costs (one-time investments in research, product development, testing, and marketing);
- Product cost structure, or the portion of the MPCs related to materials, labor, overhead, and depreciation costs;
- Projected total shipments and shipments distribution mix; and
- MPCs estimated in the engineering analysis.

12.3.3 Financial Parameters

In the manufacturer interviews, DOE used the financial parameters from 2008 to 2014 for four publicly held manufacturers of portable ACs as a starting point for determining the portable AC industry financial parameters. The industry financial parameters were determined by weighting each manufacturer's individual financial parameters by their respective estimated market share, and correcting for the fraction of the market that was not represented. Table 12.3.1 below shows the data used to determine the initial financial parameter estimates.

Table 12.3.1 Financial Parameters based on 2008–2014 Weighted Company Financial Data

Parameter	Industry-Weighted Average	Manufacturer 1	Manufacturer 2	Manufacturer 3	Manufacturer 4
Tax Rate *(% of Taxable Income)*	28.0	32.9	21.8	28.2	30.3
Working Capital *(% of Revenue)*	16.6	2.9	8.5	-0.6	76.2
SG&A *(% of Revenue)*	18.0	18.1	14.0	15.7	28.1
R&D *(% of Revenue)*	1.7	2.6	0.6	2.0	2.2
Depreciation *(% of Revenue)*	2.1	3.5	0.4	3.1	2.5
Capital Expenditures *(% of Revenue)*	2.5	4.2	0.6	3.1	2.7
Net Property, Plant, and Equipment *(% of Revenues)*	10.6	17.8	3.3	15.3	9.4

During interviews, manufacturers were asked to provide their own figures for the parameters listed in Table 12.3.1. Where applicable, DOE adjusted the financial parameters according to the manufacturers' feedback.

12.3.4 Corporate Discount Rate

A company's assets are financed by a combination of debt and equity, and the weighted average cost of capital (WACC) represents the minimum rate of return necessary to cover the debt and equity obligations manufacturers use to finance operations. The WACC is the total cost of debt and equity weighted by their respective proportions in the capital structure of the company.

DOE estimated the WACC for the portable AC manufacturing industry based on three representative companies, using the following formula:

WACC = After-Tax Cost of Debt × (Debt Ratio) + Cost of Equity × (Equity Ratio)

The cost of equity is the rate of return that equity investors (including, potentially, the company) expect to earn on a company's stock. These expectations are reflected in the market price of the company's stock. The capital asset pricing model (CAPM) provides one widely used means to estimate the cost of equity. According to the CAPM, the cost of equity (expected return) is:

Cost of Equity = Risk-free Rate of Return + β × Risk Premium

where:

Risk-free rate of return is the rate of return on a "safe" benchmark investment, typically considered the short-term Treasury Bill (T-Bill) yield. In practice, investors use a variety of different maturity T-Bills to estimate the risk-free rate. DOE used the 10-year T-Bill return because it captures long-term inflation expectations and is less volatile than short-term rates. The risk-free rate is estimated to be approximately 5.25 percent, which is the average 10-year T-Bill return between 1928 and 2014.

Risk premium is the difference between the expected return on stocks and the risk-free rate of return. DOE used the average annual return on the S&P 500 between 1928 and 2014 as the expected return on stocks to arrive at an estimated market risk premium of 6.2 percent.

Beta (β) is the correlation between the movement in the price of the stock and that of the broader market. In this case, Beta equals one if the stock is perfectly correlated with the S&P 500 market index. A Beta lower than one means the stock is less volatile than the market index. Values for Beta are only available for publicly traded companies.

DOE used the capital asset pricing model to calculate the cost of equity for four publicly-held portable AC manufacturers. DOE determined that the industry-average cost of equity for the portable AC industry is 11.05 percent (see Table 12.3.2).

Table 12.3.2 Cost of Equity Calculation

Parameter	Industry Weighted Average	Manufacturer 1	Manufacturer 2	Manufacturer 3	Manufacturer 4
(a) Average Beta	0.94	0.76	1.15	1.58	0.77
(b) Yield on 10 Year T-Bill (1928–2013) (%)	5.06				
(c) Market Risk Premium (1928–2013) (%)	6.35				
Cost of Equity (b) + [(a)*(c)] (%)	11.05				
Equity/Total Capital (%)	74.25	60.95	84.07	63.35	86.44

Bond ratings are a tool to measure default risk and arrive at a cost of debt. Each bond rating is associated with a particular spread. One way of estimating a company's cost of debt is to treat it as a spread (usually expressed in basis points) over the risk-free rate. DOE used this method to calculate the cost of debt for four manufacturers by using S&P and other estimates of corporate credit ratings and adding the relevant spread to the risk-free rate.

Because proceeds from debt issuance are tax deductible, DOE adjusted the gross cost of debt by the industry-average tax rate to determine the net cost of debt for the industry. DOE determined that the after-tax industry-average cost of debt for the portable AC industry is 4.51 percent. Table 12.3.3 presents the derivation of the cost of debt and the capital structure of the industry (*i.e.*, the debt ratio (debt/total capital)).

Table 12.3.3 Cost of Debt Calculation

Parameter	Industry Weighted Average	Manufacturer 1	Manufacturer 2	Manufacturer 3	Manufacturer 4
S&P Bond Rating		BBB	AAA	BBB	A
(a) Yield on 10 year T-Bill (1928–2013) (%)	5.06				
(b) Gross Cost of Debt (%)	6.27	7.06	5.46	7.06	6.06
(c) Tax Rate (%)	27.97	32.93	21.83	28.22	30.33
Net Cost of Debt (b) x [1-(c)] (%)	4.51				
Debt/Total Capital (%)	25.75	39.05	15.93	36.65	13.56

Correcting for an inflation rate of 3.1 percent over the analysis period, DOE's calculated value for the portable AC industry's inflation-adjusted WACC and the initial estimate of the discount rate is 6.35 percent.

12.3.5 Trial Standard Levels

DOE developed TSLs to analyze the impact on manufacturers of new energy efficiency standards for portable ACs. Table 12.3.4 presents the TSLs and the corresponding efficiency levels based on the performance ratio (PR) for each analyzed efficiency level that would be used to determine the minimum allowable CEER in Btu/Wh. See chapter 5 of this final rule TSD for a discussion of the CEER equation and the PR values.

TSL 4 represents the maximum technologically feasible ("max-tech") efficiency level. TSL 3 consists of an intermediate efficiency level below the max-tech level, corresponding to the single highest efficiency observed in the combined DOE and AHAM test data sample. TSL 2 represents the maximum available efficiency across the full range of capacities, and TSL 1 represents an intermediate level between the baseline and TSL 2.

Table 12.3.4 Trial Standard Levels for Portable Air Conditioners

Product class		No-New-Standards Case	TSL 1	TSL 2	TSL 3	TSL 4
Single-duct and Dual-duct Portable Air Conditioners	Efficiency Level	Baseline	EL 1	EL 2	EL 3	EL 4
	Performance Ratio (PR)	0.67	0.85	1.04	1.18	1.62

$$Minimum\ CEER = PR \times \frac{SACC}{(3.7117 \times SACC^{0.6384})}$$

12.3.6 National Impact Analysis Shipments Forecast

The GRIM estimates manufacturer revenues based on total unit-shipments forecasts and the distribution of these values by efficiency level. Changes in the efficiency mix at each standard level are a key driver of manufacturer finances. For this analysis, the GRIM used portable AC shipment data from the NIA. Chapter 9 of the final rule TSD explains DOE's calculations of total shipments in detail.

Table 12.3.5 shows total shipments forecasts for the single product class of portable ACs in 2022, the year new standards for single-duct and dual-duct portable ACs would take effect.

Table 12.3.5 Total No-New-Standards Case 2022 NIA Shipments

Product Class	Total Industry Shipments
Single-duct and Dual-duct Portable Air Conditioners	1,387,462

12.3.6.1 No-New-Standards Case Shipments Forecast

As part of the shipments analysis, DOE estimated the distribution of shipments by efficiency level for portable ACs. DOE held the no-new-standards case energy efficiency distribution constant throughout the forecast period. Table 12.3.6 shows the no-new-standards case distributions of shipments by efficiency level estimated in the NIA for portable ACs.

Table 12.3.6 No-New-Standards Case Distribution of Efficiencies for Portable Air Conditioners in 2022

Efficiency Level	Baseline	EL 1	EL 2	EL 3	EL 4
Performance Ratio (PR)	0.67	0.85	1.04	1.18	1.62
% of Shipments	37.0%	47.8%	13.0%	2.2%	0.0%

12.3.6.2 Standards-Case Shipments Forecasts

To examine the impact of new energy conservation standards on shipments, which in turn affects the INPV, DOE used the no-new-standards case shipments described in the previous section as a point of comparison for shipments forecast in the standards cases. For each TSL described in the standards case, DOE used the shipments forecasts developed in the NIA for portable ACs. The portion of shipments for products that fall below the new energy conservation standards are assumed to "roll-up" to the new standards efficiency level on the compliance date and thereafter.

As in the shipments analysis, DOE applied a price elasticity parameter to estimate the effect of new standards on portable AC shipments. Based on evidence that the price elasticity of demand is significantly different over the short run and long run for other consumer goods (*i.e.*, automobiles), DOE assumed that the relative price elasticity declines over time.

12.3.7 Production Costs

Changes in the MPCs of portable ACs can affect revenues, gross margins, and cash flow of the industry, making product cost data key GRIM inputs for DOE's analysis. Generally, manufacturing higher efficiency products is more costly than manufacturing baseline products due to the use of more complex components.

In the engineering analysis, DOE created a cost-efficiency curve for single-duct and dual-duct portable ACs using data from product teardowns to develop the baseline MPCs and the incremental costs that correspond to each efficiency level.

To disaggregate MPCs in the GRIM, DOE used the material, labor, and depreciation percentages determined by the engineering cost model. The remainder of the total MPC was allocated to overhead. The MPCs and engineering analysis are described in further detail in chapter 5 of the final rule TSD.

The MSP is comprised of direct production costs (MPCs), non-production costs (indirect costs including SG&A), and profit. DOE calculated the MSPs for portable ACs by multiplying the MPCs by the manufacturer markup. Table 12.3.7 shows the production cost estimates, in 2015 dollars, used in the GRIM for single-duct and dual duct portable ACs.

Table 12.3.7 MPC Breakdown for Portable Air Conditioners

EL	Materials	Labor	Depreciation	Overhead	MPC	Mfr. Markup	MSP
EL1	$285.73	$5.69	$19.76	$23.78	$334.97	1.42	$475.66
EL2	$316.73	$5.87	$19.80	$24.19	$366.59	1.42	$520.56
EL3	$359.87	$6.15	$20.08	$23.77	$409.87	1.42	$582.02
EL4	$380.63	$6.47	$19.85	$24.60	$431.55	1.42	$612.80

12.3.8 Conversion Costs

New or amended energy conservation standards typically cause manufacturers to incur one-time conversion costs to bring their production facilities and product designs into compliance with new regulations. For the MIA, DOE classified these one-time conversion costs into two major groups: product conversion costs and capital conversion costs. Capital conversion costs are investments in property, plant, and equipment needed to adapt or change existing production facilities so that new product designs can be fabricated and assembled. Product conversion costs are investments in research, development, testing, marketing, and other noncapitalized costs focused on making product designs that comply with the new energy conservation standard. The following sections describe the inputs DOE used in the GRIM in greater detail.

12.3.8.1 Portable Air Conditioner Product and Captial Conversion Costs

During confidential manufacturer interviews conducted in support of the June 2016 NOPR, DOE asked manufacturers to estimate their investments in product development and new manufacturing capital at various efficiency levels as defined in the preliminary analysis. As a result of feedback during these interviews, DOE updated its standards analysis and proposal for the June 2016 NOPR. For the final rule, similar to the June 2016 NOPR analysis, DOE supplemented per-platform conversion cost estimates obtained through manufacturer interviews following the preliminary analysis with estimates developed in the updated engineering analysis, as well as with the conversion cost assumptions used in a recent final rule published for dehumidifier energy conservation standards. 81 FR 38338 (June 13, 2016).

DOE expects that manufacturers would rely on larger heat exchangers (with increases in area of up to 20 percent), with corresponding larger chassis, more efficient compressors and blower motors, and less energy consumptive controls to achieve higher efficiencies. For portable ACs, DOE determined that the design changes required for product platforms at each efficiency level could be classified into two categories – partial and full redesigns. For certain manufacturers and product platforms, the design option changes at higher efficiency levels would require changes to manufacturing, but many parts within the product would remain unchanged (*i.e.*, "partial redesign"). DOE also expects that, at higher efficiency levels, a portion of platforms would need a complete platform redesign (*i.e.*, "full redesign") to incorporate the largest heat exchangers (increases in area of 20 percent) and corresponding larger chassis, and to incorporate variable-speed compressors. At this stage, DOE expects that manufacturers would completely redesign their products to incorporate the significantly different components, with high associated re-tooling and R&D costs. DOE's estimates of per-platform conversion costs associated with partial and full redesigns are listed in Table 12.3.8 below.

Table 12.3.8 Per-Platform Capital and Product Conversion Costs for Portable Air Conditioners

Design Changes Required	**Capital Conversion Costs** *(Millions 2015$)*	**Product Conversion Costs** *(Millions 2015$)*
Partial redesign	$3.2	$2.4
Full redesign	$6.4	$3.5

DOE then reviewed public information in the CEC product database to estimate a count of product platforms that are currently sold in the U.S. market. For this final rule, DOE estimated that approximately 54 distinct portable AC platforms are available in the U.S. market. Using the test sample efficiency distribution (including AHAM-provided data points), DOE then estimated the percent of existing product platforms that would require either partial or full redesigns to reach each higher efficiency level. DOE used these percentages to derive total industry estimates of product and capital conversion costs. Chapter 5 of this final rule TSD explains how DOE determined which products would require updates at each efficiency level.

Table 12.3.9 and Table 12.3.10 show DOE's estimates of the product and capital conversion costs necessary at each efficiency level analyzed.

Table 12.3.9 Product Conversion Costs for Portable Air Conditioners

EL	**Product Conversion Costs** *(Millions 2015$)*
EL1	$33.1
EL2	$124.4
EL3	$179.0
EL4	$192.2

Table 12.3.10 Capital Conversion Costs for Portable Air Conditioners

EL	**Capital Conversion Costs** *(Millions 2015$)*
EL1	$52.3
EL2	$196.5
EL3	$314.3
EL4	$344.5

12.3.9 Markup Scenarios

MSPs include direct manufacturing production costs (*i.e.*, labor, material, overhead, and depreciation estimated in the engineering analysis) and all non-production costs (*i.e.*, SG&A, R&D, and interest), along with profit. To calculate the MSPs in the GRIM, DOE applied manufacturer markups to the MPCs estimated in the engineering analysis. Based on publicly available financial information for manufacturers of single-duct and dual-duct portable ACs and comments from manufacturer interviews, DOE assumed the industry average no-new-standards case markup on production costs to be 1.42. This markup takes into account the two sourcing structures that characterize the portable AC market. Single-duct and dual-duct portable ACs sold in the United States are manufactured by overseas original equipment manufacturers (OEMs) either for sale by contract to an importer or for direct sale to retailers and builders. The engineering analysis, as detailed in chapter 5 of this final rule TSD, estimates the cost of manufacturing at the OEM. For the OEM-to-importer sourcing structure, this production cost is marked up once by the OEM and again by the contracting the company who imports the product and sells it to retailers. In the standards case, DOE modeled two markup scenarios to represent the uncertainty about the potential impacts on prices and profitability following the implementation of new energy conservation standards: (1) a preservation of gross margin percentage markup scenario, and (2) a preservation of per-unit operating profit markup scenario. Modifying these markups from the no-new-standards case to the standards cases yields different sets of impacts on manufacturers by changing industry revenue and cash flow.

12.3.9.1 Preservation of Gross Margin Percentage Markup Scenario

The preservation of gross margin percentage markup scenario assumes that the baseline markup of 1.42 is maintained for all products in the standards case. As production costs increase with efficiency, this scenario implies that the absolute dollar markup will increase as well. This scenario represents the upper bound of industry profitability as manufacturers are able to fully mark up and pass through higher production costs to their customers.

12.3.9.2 Preservation of Per-Unit Operating Profit Markup Scenario

DOE also modeled the preservation of per-unit operating profit markup scenario to estimate a lower bound of profitability for the industry. This is similar to the preservation of gross margin percentage markup scenario with the exception that in the standards case, minimally compliant products lose a fraction of the baseline markup. The lower markup for minimally compliant products is derived by calibrating the markup for minimally compliant products such that industry-wide per-unit operating profit in the year after standards go into effect matches per-unit operating profit of the same year in the no-new-standards case. This scenario represents a more substantial impact to the portable AC industry in the form of reduced gross margin percentage as manufacturers vie to maintain the lowest possible prices for marginally compliant products while securing the same level of per-unit operating profit they generated prior to new standards.

While all compliant products receive the 1.42 markup in the preservation of gross margin percentage markup scenario, Table 12.3.11 lists the calibrated markups used in the preservation of per-unit operating profit markup scenario.

Table 12.3.11 Preservation of Per-Unit Operating Profit Markups for Portable Air Conditioners

EL	Minimally Compliant EL			
	EL 1	EL 2	EL 3	EL4
EL 1	1.416			
EL 2	1.420	1.403		
EL 3	1.420	1.420	1.387	
EL 4	1.420	1.420	1.420	1.381

12.4 INDUSTRY FINANCIAL IMPACTS

Using the inputs and scenarios described in the previous sections, DOE used the GRIM to estimate the financial impacts on the portable AC industry. The MIA uses two key financial metrics: INPV and annual cash flows. The main results of the MIA are reported in this section.

12.4.1 Introduction

The INPV measures the industry value and is used in the MIA to compare the economic impacts of different TSLs in the standards case. The INPV is different from DOE's NPV, which is applied to the U.S. economy at large. The INPV is specific to the portable AC manufacturing industry, and is the sum of all annual net cash flows discounted at the industry's WACC. The GRIM for the portable AC industry models cash flows from 2017 to 2051. This timeframe models both the short-term impacts on the industry from the announcement of the standard until the compliance date in 2022, and a long-term assessment over the 30-year analysis period immediately thereafter.

In the MIA, DOE compares the INPV at the no-new-standards case to that at each TSL in the standards case. The difference between the no-new-standards case and a standards case INPV is an estimate of the economic impacts that implementing that particular TSL would have on the industry. For the portable AC industry, DOE examined the two markup scenarios described above: the preservation of gross margin percentage markup scenario and the preservation of per-unit operating profit markup scenario. DOE's estimates of INPV for the full analysis period (2017–2051) for the no-new-standards case and at each TSL in the standards case are presented in Table 12.4.1 and Table 12.4.2 below. While INPV is useful for evaluating the long-term effects of new energy conservation standards, short-term changes in cash flow are also important indicators of the industry's financial situation. For example, a large investment over one or two years could strain the industry's capital reserves and cash flow. Consequently, the sharp drop in financial performance could cause investors to flee, even if recovery is possible. Thus, a short-term disturbance can have long-term effects that the INPV cannot capture. To get an idea of the behavior of annual net cash flows, Figure 12.4.1 and Figure 12.4.2 below present the annual net or free cash flows from 2017 through 2051 for the no-new-standards case and each TSL in the standards case.

Annual cash flows are discounted to the base year, 2017. Between 2017 and the 2022 compliance date, cash flows are driven by the level of conversion costs and the portion of these investments made each year. After the standard announcement date (*i.e.*, the publication date of the final rule), industry cash flows begin to decline as companies use their financial resources to prepare for the new energy conservation standard. The more stringent the new energy conservation standard, the greater the impact on industry cash flows in the years leading up to the compliance date, as product conversion costs lower cash flows from operations and capital conversion costs increase outlays of cash for capital expenditures.

Free cash flow in the year the new energy conservation standards take effect is driven by two competing factors. In addition to capital and product conversion costs, new energy conservation standards could create stranded assets, *i.e.*, the residual un-depreciated value of tooling and equipment that would have enjoyed longer use if the energy conservation standard had not made them obsolete. In this year, manufacturers write down the remaining book value of existing tooling and equipment, the value of which is affected by the new energy conservation standards. This one-time write down acts as a tax shield that mitigates decreases in cash flow from operations in the year of the write-down. In this year, there is also an increase in working capital that reduces cash flow from operations. A large increase in working capital can be attributed to more costly production components and materials, higher inventory carrying to sell more expensive products, and higher accounts receivable for more expensive products. Depending on these two competing factors, cash flow can either be positively or negatively affected in the year the standard takes effect.

In the years following the compliance date of the standard, the impact on cash flow depends on the operating revenue. Under the preservation of gross margin percentage markup scenario, more stringent TSLs typically have a positive impact on cash flows relative to the no-new-standards case because in marking up more costly products, manufacturers are able to earner higher operating profit, which increases cash flow from operations. There is very little impact on cash flow from operations under the preservation of per-unit operating profit scenario because this scenario is calibrated to have the same earnings before interest and taxes in the standards case at each TSL as the no-new-standards case as in the year after the standard takes effect. In this scenario production costs increase, but per-unit operating profit remains approximately equal to the no-new-standards case, effectively decreasing profit margins as a percentage of revenue.

12.4.2 Portable Air Conditioner Industry Financial Impacts

Table 12.4.1 and Table 12.4.2 provide the INPV estimates for the single-duct and dual-duct portable AC manufacturing industry. Figure 12.4.1 and Figure 12.4.2 present the annual net cash flows for the portable AC manufacturing industry for each of the markup scenarios.

Table 12.4.1 Manufacturer Impact Analysis for Portable Air Conditioners – Preservation of Gross Margin Percentage Markup Scenario

	Units	No-New-Standards Case	Trial Standard Level			
			1	**2**	**3**	**4**
INPV	2015$ Millions	738.5	684.7	526.1	406.5	373.0
Change in INPV	2015$ Millions	-	(53.8)	(212.4)	(332.0)	(365.5)
	%	-	(7.3%)	(28.8%)	(45.0%)	(49.5%)

*For tables in section 12.4, parentheses indicate negative (-) values.

Table 12.4.2 Manufacturer Impact Analysis for Portable Air Conditioners – Preservation of Per-Unit Operating Profit Markup Scenario

	Units	No-New-Standards Case	Trial Standard Level			
			1	2	3	4
INPV	2015$ Millions	738.5	676.8	485.1	324.7	248.1
Change in INPV	2015$ Millions	-	(61.8)	(253.4)	(413.9)	(490.4)
	%	-	(8.4%)	(34.3%)	(56.0%)	(66.4%)

*For tables in section 12.4, parentheses indicate negative (-) values.

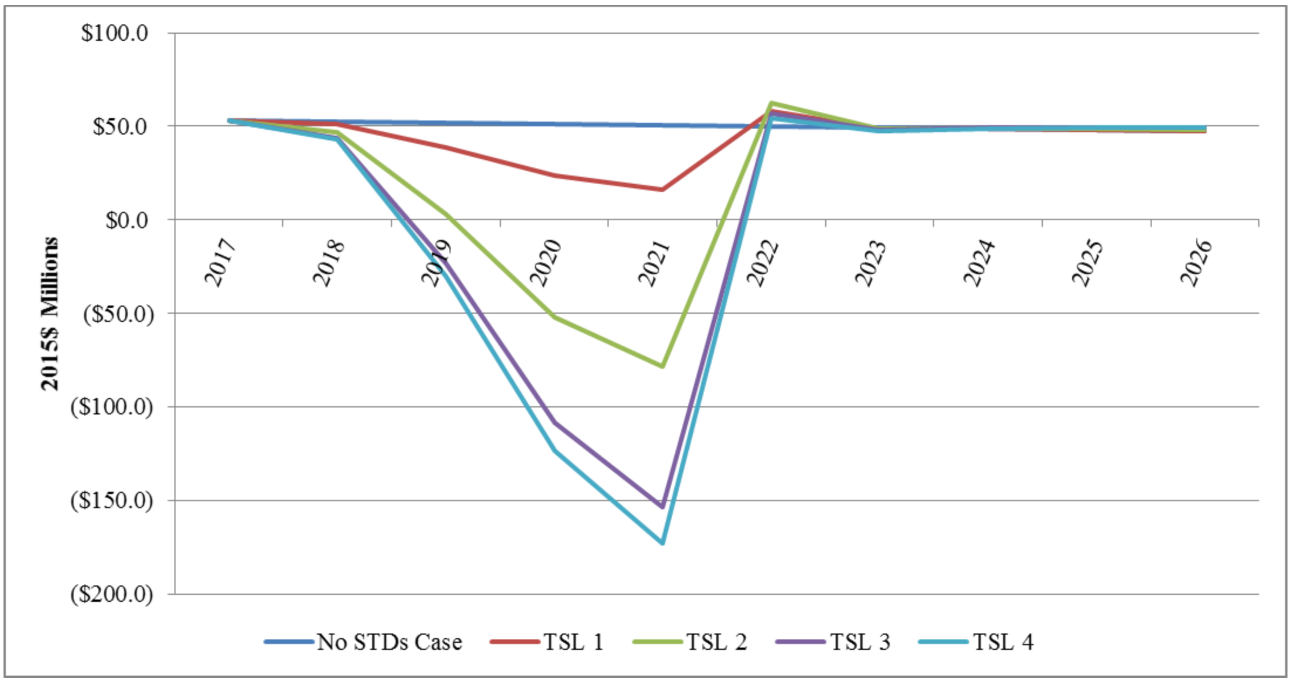

Figure 12.4.1 Annual Industry Net Cash Flows for Portable Air Conditioners (Preservation of Gross Margin Markup Scenario)

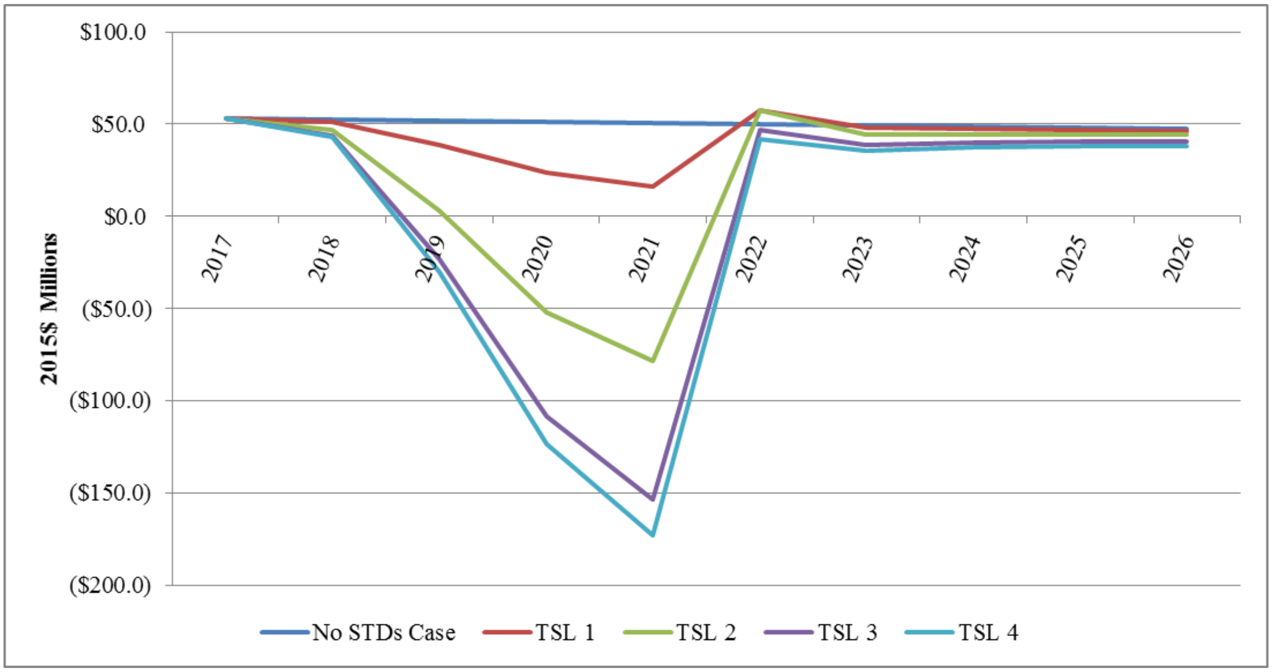

Figure 12.4.2 Annual Industry Net Cash Flows for Portable Air Conditioners (Preservation of Per-Unit Operating Profit Markup Scenario)

12.5 IMPACTS ON SMALL BUSINESS PORTABLE AIR CONDITIONER MANUFACTURERS

For manufacturers of portable ACs, the SBA has set a size threshold that defines those entities classified as "small businesses" for the purposes of the statute. DOE used the SBA's small business size standards to determine whether any small entities would be subject to the requirements of the rule. These size standards are codified at 13 CFR part 121 and are listed by NAICS code and industry description.[d] Portable AC manufacturers are classified under NAICS 333415, "Air-Conditioning and Warm Air Heating Equipment and Commercial and Industrial Refrigeration Equipment Manufacturing Other Major Household Appliance Manufacturing." Effective on February 26, 2016, the SBA sets a threshold of 1,250 employees or less for an entity to be considered as a small business for this category.

To estimate the number of companies that could be small business manufacturers of products covered by this rulemaking, DOE conducted a market survey using all available public information. To identify small business manufacturers, DOE surveyed the AHAM membership directory,[e] CEC's Appliance Database,[f] and individual company websites. DOE screened out

[d] The SBA's small business size standards are available at http://www.sba.gov/sites/default/files/files/Size_Standards_Table.pdf.
[e] https://www.aham.org/AHAM/AuxCurrentMembers
[f] https://cacertappliances.energy.ca.gov/Pages/ApplianceSearch.aspx

companies that do not themselves manufacture products covered by this rulemaking, do not meet the definition of a "small business," or are foreign owned and operated. In the June 2016 NOPR, DOE estimated that there were no domestic manufacturers of portable ACs that meet the SBA's definition of a "small business." DOE subsequently identified one small, domestic business responsible for the design and distribution of a dual-duct portable AC. Based upon available information, DOE does not believe that this company is a manufacturer. Further, because the product sold by this company incorporates the highest-efficiency variable-speed compressor currently available on the market, DOE believes that the product will comply with the standard efficiency level adopted in this final rule (EL 2). Therefore, DOE does not expect this small business to incur any design or capital-related costs.

This small business may, however, incur costs associated with certification, testing, and marketing updates. The product sold by this company is listed in the CEC's Appliance Database, indicating that this company already allocates a portion of its resources to testing and certification of its portable AC product under ANSI/ASHRAE 128-2001. Preemption of California's standard by the standard adopted in this final rule implies that the small business would divert its existing testing budget to testing according to DOE's test procedure in appendix CC. Testing and certifying under appendix CC would add costs relative to testing to ANSI/ASHRAE 128-2001 due to the dual test condition requirement for dual-duct portable ACs (the product configuration sold by the small business). While DOE does not have third-party test laboratory quotes for portable AC testing costs, DOE expects that the costs would be similar to testing whole-home dehumidifiers[g] because both require ducted test setups within environmentally-controlled chambers. Based on this assumption, DOE estimates that testing of one portable AC platform under appendix CC may cost an additional $7,000 compared to current testing. Additionally, based on feedback from manufacturers, DOE estimates that updates to marketing materials and product literature for this company may total $3,000. DOE assumes these upfront costs will be spread over a 5-year period leading up to the compliance year. Accordingly, on an annual basis, the estimated upfront product conversion costs equate to less than 1 percent of this entity's annual revenues.

12.6 OTHER IMPACTS

12.6.1 Employment

DOE used the GRIM to estimate the domestic labor expenditures and number of domestic production workers in the no-new-standards case and at each TSL from 2017 to 2051. DOE used statistical data from the most recent U.S. Census Bureau's 2014 *ASM*,[5] the results of the engineering analysis, and interviews with manufacturers to determine the inputs necessary to calculate industry-wide labor expenditures and domestic employment levels.

[g] Test Procedure Final Rule for Dehumidifiers, 80 FR 45802 (July 31, 2015).

However, DOE estimates that none of the portable ACs subject to the standards considered in this final rule analysis (single-duct and dual-duct portable ACs) are produced domestically. Therefore, DOE does not provide an estimate of direct employment impacts. Indirect employment impacts in the broader U.S. economy are documented in chapter 16 of this final rule TSD.

12.6.2 Production Capacity

As noted in the previous section, no single-duct or dual-duct portable ACs are manufactured in the United States. Therefore, new energy conservation standards would have no impact on U.S. production capacity.

12.6.3 Cumulative Regulatory Burden

While any one regulation may not impose a significant burden on manufacturers, the combined effects of several impending regulations may have serious consequences for some manufacturers, groups of manufacturers, or an entire industry. Regulatory burdens can prompt companies to exit the market or reduce their equipment offerings, potentially reducing competition. Smaller companies in particular can be affected by regulatory costs since these companies have lower sales volumes over which they can amortize the costs of meeting new regulations. Assessing the impact of a single regulation may overlook this cumulative regulatory burden. A potential new standard is not economically justified if it contributes to an unacceptable level of cumulative regulatory burden.

For the cumulative regulatory burden, DOE considers the impacts of other Federal regulations affecting manufacturers of portable ACs that will take effect approximately 3 years before and after the 2022 compliance date of the standards established in this final rule. In addition to new energy conservation regulations, several other Federal regulations apply to portable ACs. While this analysis focuses on the impacts on manufacturers born of other DOE requirements, DOE also has described some of other non-DOE regulations in section 12.6.3.2 because it recognizes that these regulations also impact the equipment covered by this rulemaking.

12.6.3.1 DOE Regulations for Other Products Produced by Portable AC Manufacturers

Companies that produce a wide range of regulated products and equipment may face more capital and product development expenditures than competitors with a narrower scope of products and equipment. The majority of single-duct and dual-duct portable AC manufacturers also produce other appliances and consumer products. In addition to the new energy conservation standards for single-duct and dual-duct portable ACs, these manufacturers contend with several other Federal regulations and pending regulations that apply to other products and equipment. DOE recognizes that each regulation can significantly affect a manufacturer's financial operations. Multiple regulations affecting the same manufacturer can quickly strain manufacturers' profits and possibly cause an exit from the market. Table 12.6.1 lists the other energy conservation standards affecting portable AC manufacturers that have compliance dates 3 years before and after the portable AC compliance date (and also 8 years before the portable AC compliance date). For each rule, the table lists the rule's standard compliance year, the total number of manufacturers operating in that given industry, the number of portable AC manufacturers affected by the rule, and the approximate year that compliance with standards will be required. The table also contains expected industry conversion costs for the given rule, as well as industry conversion costs as a percentage of conversion period industry revenues.

Table 12.6.1 Other DOE and Federal Actions Affecting the Portable Air Conditioner Industry

Federal Energy Conservation Standard	Number of Manufacturers*	Number of Manufacturers in Portable ACs Rule**	Approx. Standards Year	Industry Conversion Costs (Millions $)	Industry Conversion Costs / Revenue***
Dehumidifiers 81 FR 38338 (June 13, 2016)	30	6	2019	$52.5 million (2014$)	4.5%
Kitchen Ranges and Ovens 81 FR 60784 (Sep. 2, 2016)	21	3	2019	$119.2 million (2015$)	less than 1%
Miscellaneous Refrigeration Products 81 FR 75194 (October 28, 2016)	48	2	2019	$75.6 million (2015$)	4.9%
Res. Clothes Washers 77 FR 32308 (May 31, 2012)†	13	1	2018	$418.5 million (2010$)	2.3%
PTACs 80 FR 43162 (July 21, 2015)†	12	3	2017	N/A††	N/A††
Microwave Ovens 78 FR 36316 (June 17, 2013)†	12	2	2016	43.1 Million (2011$)	less than 1%
External Power Supplies 79 FR 7846 (February 10, 2014)†	243	1	2015	43.4 Million (2012$)	2.3%
Residential Central Air Conditioners and Heat Pumps 76 FR 37408 (June 27, 2011)†	45	2	2015	18.0 Million (2009$)	less than 1%

*This column presents the total number of manufacturers identified in the energy conservation standard rule contributing to cumulative regulatory burden.
**This column presents the number of OEMs producing portable ACs that are also listed as manufacturers in the listed energy conservation standard contributing to cumulative regulatory burden.
***This column presents conversion costs as a percentage of cumulative revenue for the industry during the conversion period. The conversion period is the timeframe over which manufacturers must make conversion costs investments and lasts from the announcement year of the final rule to the standards year of the final rule. This period typically ranges from 3 to 5 years, depending on the energy conservation standard.
†Consistent with Chapter 12 of the TSD, DOE has assessed whether this rule will have significant impacts on manufacturers that are also subject to significant impacts from other EPCA rules with compliance dates within 3 years of this rule's compliance date. However, DOE recognizes that a manufacturer incurs costs during some period before a compliance date as it prepares to comply, such as by revising product designs and manufacturing processes,

testing products, and preparing certifications. As such, to illustrate a broader set of rules that may also create additional burden on manufacturers, DOE has included additional rules with compliance dates that fall within 8 years before the compliance date of this rule by expanding the timeframe of potential cumulative regulatory burden. Note that the inclusion of any given rule in this Table does not indicate that DOE considers the rule to contribute significantly to cumulative impact. DOE has chosen to broaden its list of rules in order to provide additional information about its rulemaking activities. DOE will continue to evaluate its approach to assessing cumulative regulatory burden for use in future rulemakings to ensure that it is effectively capturing the overlapping impacts of its regulations. DOE plans to seek public comment on the approaches it has used here (*i.e.*, both the 3- and 8-year timeframes from the compliance date) in order to better understand at what point in the compliance cycle manufacturers most experience the effects of cumulative and overlapping burden from the regulation of multiple products.

[††]As detailed in the energy conservation standards final rule for PTACs and PTHPs, DOE established amended energy efficiency standards for PTACs at the minimum efficiency level specified in the ANSI/ASHRAE/IES Standard 90.1-2013 for PTACs. For PTHPs, DOE is not amending energy conservation standards, which are already equivalent to the PTHP standards in ANSI/ASHRAE/ Illuminating Engineering Society (IES) Standard 90.1-2013. Accordingly, there were no conversion costs associated with amended energy conservation standards for PTACs and PTHPs.

DOE plans to seek public comment on the approaches it has used here (*i.e.*, both the 3- and 8-year timeframes from the compliance date) in order to better understand at what point in the compliance cycle manufacturers most experience the effects of cumulative and overlapping burden from the regulation of multiple product classes.

12.6.3.2 Other Regulations That Could Impact Portable Air Conditioners

Refrigerant Recycling

One manufacturer cited State-level regulations of the disposal and recycling of refrigerants as an area of cumulative burden. This manufacturer provided New York as an example, which regulates that manufacturers are responsible for the lawful recovery of refrigerants from their refrigerant-containing appliances when those appliances are discarded by residents.

Refrigerant Restrictions

The same manufacturer also mentioned concerns about the regulations on permissable refrigerants for portable ACs sold in the United States. In light of the Significant New Alternatives Policy (SNAP) final rule, published by the U.S. Environmental Protection Agency (EPA) on April 10, 2015 (80 FR 19454), approving the use of propane (R-290) and R-32 for portable ACs, this manufacturer is concerned that conversion to a low global warming potential (GWP) refrigerant will soon be a requirment. At the same time, this manufacturer cited current Underwriters' Laboratories (UL) safety standards as a limiting force on the use of propane refrigerants in portable ACs sold in the United States.

12.7 CONCLUSION

The following section summarizes the scenarios DOE believes are most likely to capture the range of impacts on portable AC manufacturers at each TSL in the standards case. While these scenarios bound the range of the most plausible impacts on manufacturers, some circumstances could cause manufacturers to experience impacts outside this range.

At TSL 1, DOE estimates the impact on INPV for manufacturers of single-duct and dual-duct portable ACs to range from -61.8 million to -$53.8 million, or a decrease in INPV of 8.4 percent to 7.3 percent under the preservation of per-unit operating profit markup scenario and the preservation of gross margin percentage markup scenario, respectively. At this TSL, industry free cash flow is estimated to decrease by approximately 68.0 percent to $16.1 million, compared to the no-new-standards case value of $50.5 million in 2021, the year before the projected compliance date.

At TSL 1, the industry as a whole is expected to incur $33.1 million in product conversion costs attributed to upfront research, development, testing, and certification, as well as $52.3 million in one-time investments in property, plant, and equipment (PP&E) necessary to manufacture updated platforms. The industry conversion cost burden at TSL 1 would be associated with updates for single-duct and dual-duct portable ACs sold in the United States that are currently at the baseline, approximately 22 percent of platforms and 37 percent of shipments. At TSL 1, roughly two-thirds of non-compliant platforms will require some new components, including a larger heat exchangers (with increases in area of up to 20 percent), which may necessitate larger chassis sizes. The remaining non-compliant single-duct and dual-duct portable ACs will likely require a complete platform redesign, necessitating all new components and high associated re-tooling and R&D costs.

At TSL 2, DOE estimates the impact on INPV for manufacturers of single-duct and dual-duct portable ACs to range from -$253.4 million to -$212.4 million, or a decrease in INPV of 34.3 percent to 28.8 percent under the preservation of per-unit operating profit markup scenario and the preservation of gross margin percentage markup scenario, respectively. At this TSL, industry free cash flow is estimated to decrease by approximately 255.5 percent to -$78.6 million, compared to the no-new-standards case value of $50.5 million in 2021, the year before the projected compliance date.

At TSL 2, the industry as a whole is expected to incur $124.4 million in product conversion costs associated with the upfront research, development, testing, and certification, as well as $196.5 million in one-time investments in PP&E for products requiring platform updates. The industry conversion cost burden at this TSL would be associated with updates for single-duct and dual-duct portable ACs sold in the United States that are currently below the efficiency level corresponding to TSL 2, approximately 83 percent of platforms and 85 percent of shipments. At TSL 2, roughly two-thirds of non-compliant platforms will require some new components, including a larger heat exchangers (with increases in area of up to 20 percent), which may necessitate larger chassis sizes. The remaining non-compliant single-duct and dual-duct portable ACs will likely require a complete platform redesign, necessitating all new components and high associated re-tooling and R&D costs.

At TSL 3, DOE estimates the impact on INPV for manufacturers of single-duct and dual-duct portable ACs to range from -$413.9 million to -$332.0 million, or a decrease in INPV of 56.0 percent to 45.0 percent under the preservation of per-unit operating profit markup scenario and the preservation of gross margin percentage markup scenario, respectively. At this TSL, industry free cash flow is estimated to decrease by approximately 403.6 percent to -$153.4

million, compared to the no-new-standards case value of $50.5 million in 2021, the year before the projected compliance date.

At TSL 3, the industry as a whole is expected to incur $179.0 million in product conversion costs associated with the upfront research, development, testing, and certification, as well as $314.3 million in one-time investments in PP&E for products requiring platform redesigns. Again, the industry conversion cost burden at this TSL would be associated with updates for single-duct and dual-duct portable ACs sold in the United States that are currently below the efficiency level corresponding to TSL 3, approximately 98 percent of platforms and 98 percent of shipments. At TSL 3, roughly 14 percent of non-compliant platforms will require some new components, including larger heat exchangers (with increases in area of up to 20 percent), which may necessitate larger chassis sizes. The remaining 86 percent of non-compliant single-duct and dual-duct portable ACs will likely require a complete platform redesign, necessitating all new components and high associated re-tooling and R&D costs.

At TSL 4, DOE estimates the impact on INPV for manufacturers of single-duct and dual-duct portable ACs to range from -$490.4 million to -$365.5 million, or a decrease in INPV of 66.4 percent to 49.5 percent under the preservation of per-unit operating profit markup scenario and the preservation of gross margin percentage markup scenario, respectively. At this TSL, industry free cash flow is estimated to decrease by approximately 442.3 percent to -$173.0 million, compared to the base-case value of $50.5 million in 2021, the year before the projected compliance date.

At TSL 4, the industry as a whole is expected to spend $192.2 million in product conversion costs associated with the research and development and testing and certification, as well as $344.5 million in one-time investments in PP&E for complete platform redesigns. The industry conversion cost burden at this TSL would be associated with updates for single-duct and dual-duct portable ACs sold in the United States that are currently below the efficiency level corresponding to TSL 4. DOE estimates that all platforms and shipments are currently below TSL 4, and that all single-duct and dual-duct portable ACs will likely require a complete platform redesign to reach TSL 4, necessitating all new components and high associated re-tooling and R&D costs.

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CHAPTER 13. EMISSIONS IMPACT ANALYSIS

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CHAPTER 13. EMISSIONS IMPACT ANALYSIS

13.1 INTRODUCTION

The emissions analysis consists of two components. The first component estimates the effect of potential energy conservation standards on power sector emissions and, if present, site combustion emissions of carbon dioxide (CO_2), nitrogen oxides (NO_X), sulfur dioxide (SO_2) and mercury (Hg). The second component estimates the impacts of potential standards on emissions of two additional greenhouse gases, methane (CH_4) and nitrous oxide (N_2O), as well as the impacts to emissions of all species due to "upstream" activities in the fuel production chain. These upstream activities comprise extraction, processing, and transporting fuels to the site of combustion. The associated emissions are referred to as upstream emissions. Together, these emissions account for the full-fuel-cycle (FFC), in accordance with DOE's FFC Statement of Policy. 76 FR 51282 (Aug. 18, 2011).

The analysis of power sector emissions uses marginal emissions intensity factors calculated by DOE. The methodology is based on results published for the *Annual Energy Outlook 2016 (AEO 2016),* including a set of side cases that implement a variety of efficiency-related policies.[1] The methodology is described in appendix 13A to this TSD, and in the report "Utility Sector Impacts of Reduced Electricity Demand" (Coughlin, 2014).

The emissions intensity factors are expressed in terms of physical units per MWh or MMBtu of site energy savings. Total emissions reductions are estimated by multiplying the emissions intensity factor by the energy savings calculated in the national impact analysis (chapter 10). The emissions factors used in the calculations are provided in appendix 13A. For power sector emissions, the factors depend on the sector and end use. The results presented here use factors for the power plant types that supply electricity for space cooling in homes and commercial buildings.

13.2 AIR QUALITY REGULATIONS AND EMISSIONS IMPACTS

Each annual version of the Annual Energy Outlook (AEO) incorporates the projected impacts of existing air quality regulations on emissions. *AEO 2016* generally represents current Federal and State legislation and final implementation regulations in place as of the end of February 2016. DOE's estimation of impacts accounts for the presence of the emissions control programs discussed in the following paragraphs.

SO_2 emissions from affected electric generating units (EGUs) are subject to nationwide and regional emissions cap and trading programs. Title IV of the Clean Air Act sets an annual emissions cap on SO_2 for affected EGUs in the 48 contiguous states and the District of Columbia (D.C.). SO_2 emissions from 28 eastern states and D.C. were also limited under the Clean Air Interstate Rule (CAIR), which created an allowance-based trading program that operates along with the Title IV program in those States and D.C. 70 FR 25162 (May 12, 2005). CAIR was remanded to EPA by the U.S. Court of Appeals for the District of Columbia Circuit (D.C. Circuit) but parts of it remained in effect. On July 6, 2011 EPA issued a replacement for CAIR, the Cross-State Air Pollution Rule (CSAPR). 76 FR 48208 (August 8, 2011). On August 21, 2012, the D.C. Circuit issued a decision to vacate CSAPR.[a] The court ordered EPA to continue administering CAIR. On April 29, 2014, the U.S. Supreme Court reversed the judgment of the D.C. Circuit and remanded the case for further proceedings consistent with the Supreme Court's opinion.[b] On October 23, 2014, the D.C. Circuit lifted the stay of CSAPR.[c] Pursuant to this action, CSAPR went into effect (and CAIR ceased to be in effect) as of January 1, 2015.[d] *AEO2016* assumes implementation of CSAPR.

The attainment of emissions caps is typically flexible among affected Electric Generating Units (EGUs) and is enforced through the use of emissions allowances and tradable permits. Under existing EPA regulations, any excess SO_2 emissions allowances resulting from the lower electricity demand caused by the imposition of an efficiency standard could be used to permit offsetting increases in SO_2 emissions by any regulated EGU. In past rulemakings, DOE recognized that there was uncertainty about the effects of efficiency standards on SO_2 emissions covered by the existing cap-and-trade system, but it concluded that no reductions in power sector emissions would occur for SO_2 as a result of standards.

Beginning in 2016, however, SO_2 emissions will fall as a result of the Mercury and Air Toxics Standards (MATS) for power plants. 77 FR 9304 (Feb. 16, 2012). In the final MATS rule, EPA established a standard for hydrogen chloride as a surrogate for acid gas hazardous air pollutants (HAP), and also established a standard for SO_2 (a non-HAP acid gas) as an alternative equivalent surrogate standard for acid gas HAP. The same controls are used to reduce HAP and non-HAP acid gas; thus, SO_2 emissions will be reduced as a result of the control technologies installed on coal-fired power plants to comply with the MATS requirements for acid gas. *AEO 2016* assumes that, in order to continue operating, coal plants must have either flue gas desulfurization or dry sorbent injection systems installed by 2016. Both technologies, which are used to reduce acid gas emissions, also reduce SO_2 emissions. Under the MATS, emissions will be far below the cap established by CSAPR, so it is unlikely that excess SO_2 emissions allowances resulting from the lower electricity demand would be needed or used to permit offsetting increases in SO_2 emissions by any regulated EGU. Therefore, DOE believes that efficiency standards will reduce SO_2 emissions in 2016 and beyond.

CSAPR established a cap on NO_x emissions in 28 eastern States and the District of Columbia.[e] Energy conservation standards are expected to have little effect on NO_x emissions in those States covered by CSAPR because excess NO_x emissions allowances resulting from the lower electricity demand could be used to permit offsetting increases in NO_x emissions.

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[a] See *EME Homer City Generation, LP v. EPA*, 696 F.3d 7, 38 (D.C. Cir. 2012).

[b] *See EPA v. EME Homer City Generation*, 134 S.Ct. 1584, 1610 (U.S. 2014). The Supreme Court held in part that EPA's methodology for quantifying emissions that must be eliminated in certain States due to their impacts in other downwind States was based on a permissible, workable, and equitable interpretation of the Clean Air Act provision that provides statutory authority for CSAPR.

[c] *See Georgia v. EPA*, Order (D.C. Cir. filed October 23, 2014) (No. 11-1302).

[d] On July 28, 2015, the D.C. Circuit issued its opinion regarding CSAPR on remand from the Supreme Court. The court largely upheld CSAPR, but remanded to EPA without vacatur certain States' emission budgets for reconsideration. *EME Homer City Generation, LP v. EPA*, 795 F.3d 118 (D.C. Cir. 2015).

[e] CSAPR also applies to NO_X and it supersedes the regulation of NO_X under CAIR.

However, standards would be expected to reduce NO_x emissions in the States not affected by CSAPR, so DOE estimated NOx emissions reductions from potential standards for those States.

The MATS limit mercury emissions from power plants, but they do not include emissions caps and, as such, DOE's energy conservation standards would likely reduce Hg emissions. DOE estimated marginal mercury emissions reductions using the reference and side cases published with *AEO 2016*, which incorporate the MATS.

The *AEO2016* Reference case assumes implementation of the Clean Power Plan, which is the EPA program to regulate CO_2 emissions at existing fossil-fired electric power plants.[f] Because there is uncertainty regarding the implementation of the CPP, DOE used the AEO 2016 No CPP case as a basis for developing emissions factors for the electric power sector.

13.3 EMISSIONS IMPACT RESULTS

Table 13.3.1 presents the estimated cumulative emissions reductions for the lifetime of products sold in 2022-2051 for each TSL. Negative values indicate that emissions increase.

[f] U.S. Environmental Protection Agency, "Carbon Pollution Emission Guidelines for Existing Stationary Sources: Electric Utility Generating Units" (Washington, DC: October 23, 2015). https://www.federalregister.gov/articles/2015/10/23/2015-22842/carbon-pollution-emission-guidelines-for-existing-stationary-sources-electric-utility-generating.

Table 13.3.1 Cumulative Emissions Reduction for Potential Standards for Portable Air Conditioners

	TSL			
	1	**2**	**3**	**4**
Power Sector Emissions				
CO_2 (million metric tons)	6.05	24.23	47.00	63.95
SO_2 (thousand tons)	4.07	16.23	31.31	42.73
NO_X (thousand tons)	3.08	12.33	23.93	32.54
Hg (tons)	0.01	0.06	0.12	0.16
CH_4 (thousand tons)	0.63	2.52	4.89	6.65
N_2O (thousand tons)	0.09	0.36	0.70	0.95
Upstream Emissions				
CO_2 (million metric tons)	0.34	1.35	2.63	3.58
SO_2 (thousand tons)	0.04	0.16	0.30	0.41
NO_X (thousand tons)	4.94	19.84	38.60	52.41
Hg (tons)	0.00	0.00	0.00	0.00
CH_4 (thousand tons)	30.4	122.3	238.0	323.2
N_2O (thousand tons)	0.00	0.01	0.02	0.02
Total Emissions				
CO_2 (million metric tons)	6.39	25.59	49.64	67.52
SO_2 (thousand tons)	4.11	16.38	31.61	43.14
NO_X (thousand tons)	8.01	32.17	62.53	84.95
Hg (tons)	0.01	0.06	0.12	0.16
CH_4 (thousand tons)	31.1	124.8	242.9	329.8
N_2O (thousand tons)	0.09	0.37	0.71	0.97

Figure 13.3.1 through Figure 13.3.6 show the annual reductions for total emissions for each type of emission from each TSL. The reductions reflect the lifetime impacts of products sold in 2022-2051.

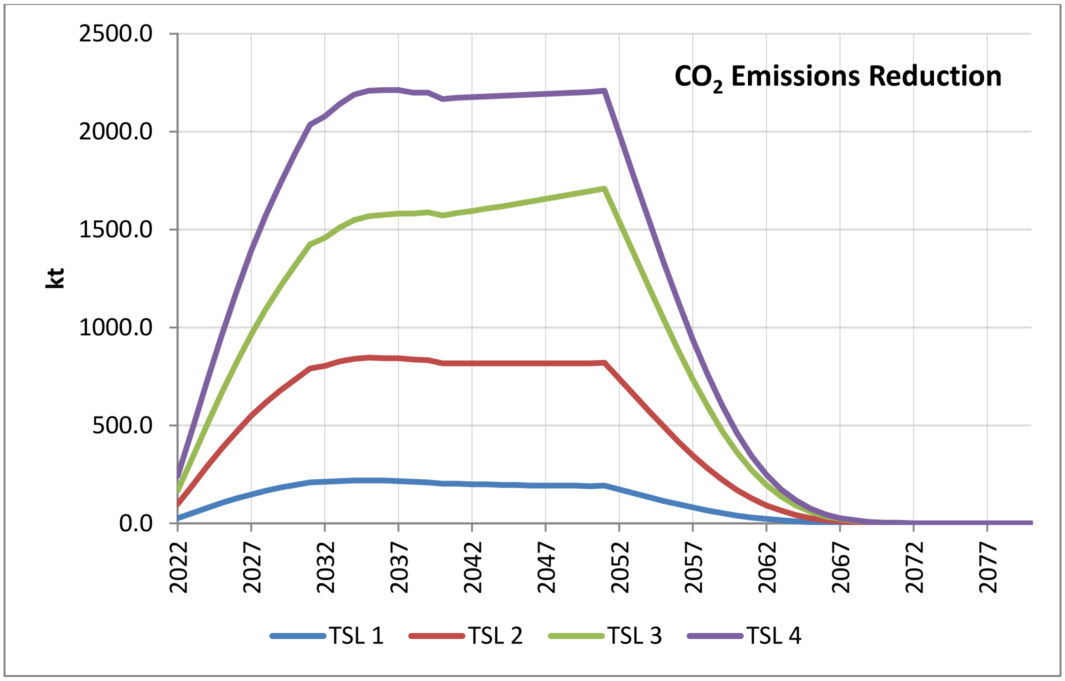

Figure 13.3.1 Portable Air Conditioners: CO_2 Total Emissions Reduction

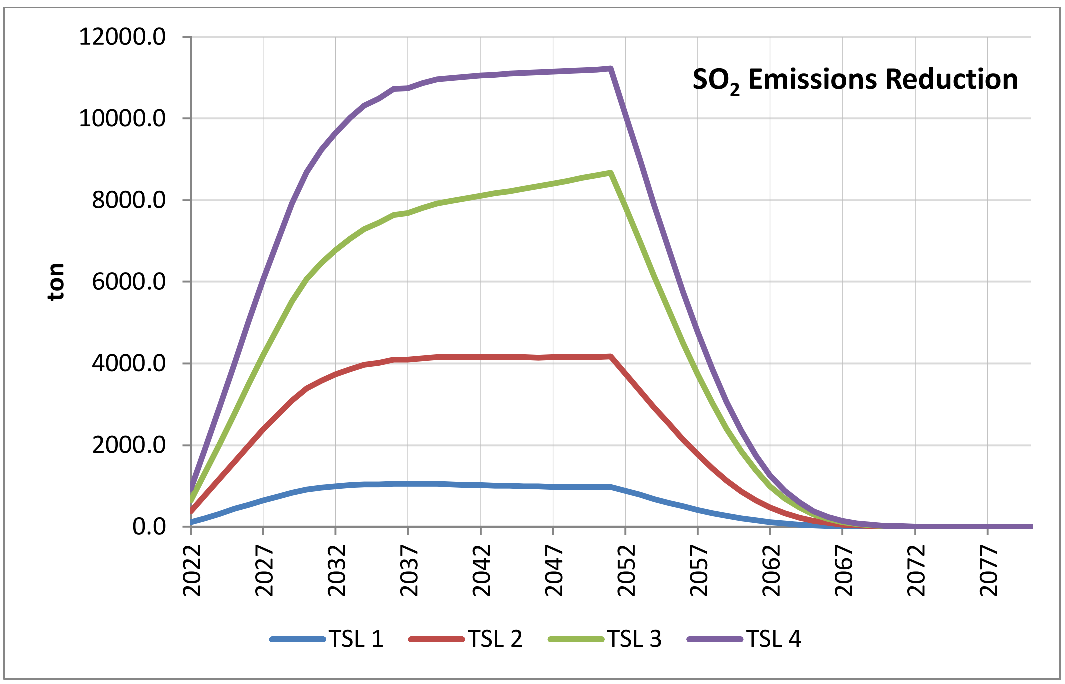

Figure 13.3.2 Portable Air Conditioners: SO_2 Total Emissions Reduction

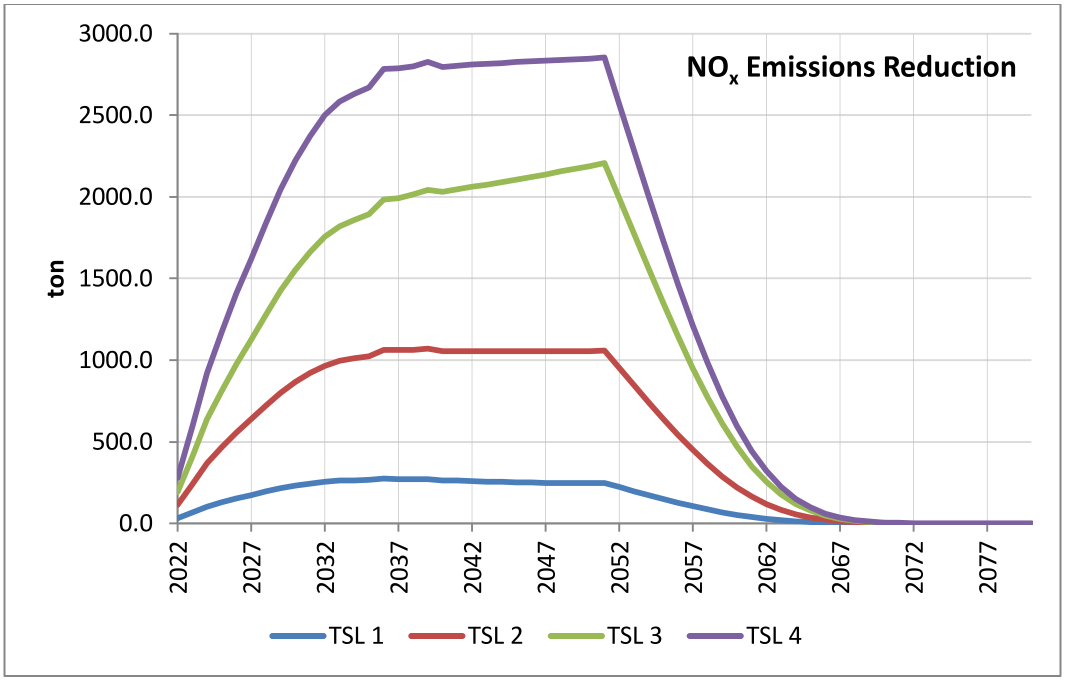

Figure 13.3.3 Portable Air Conditioners: NO_x Total Emissions Reduction

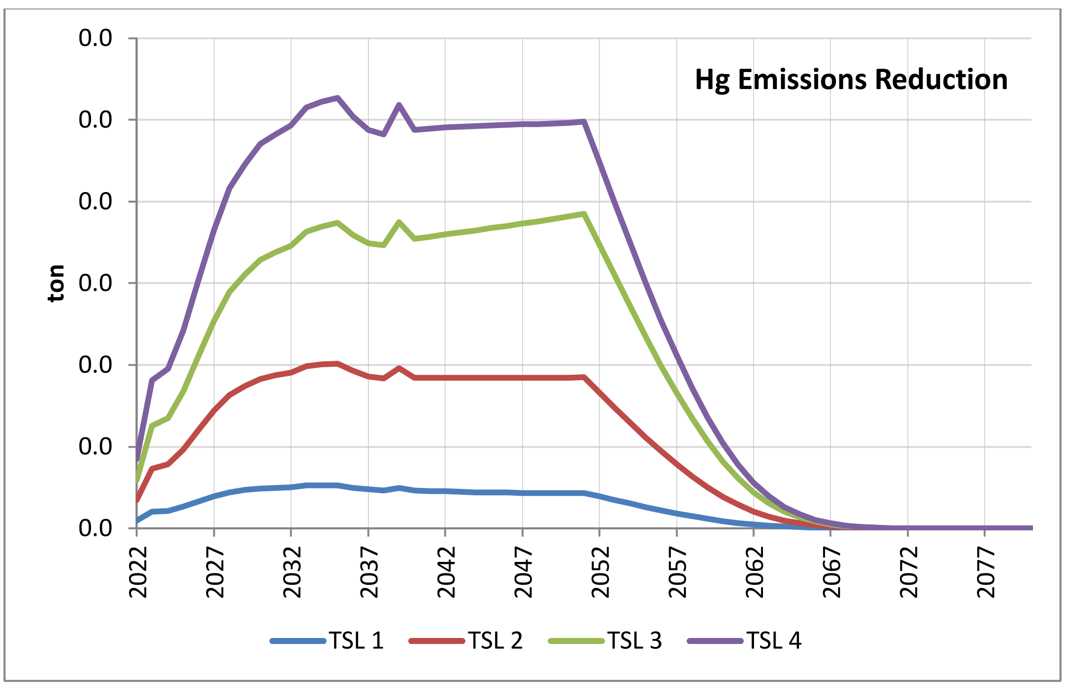

Figure 13.3.4 Portable Air Conditioners: Hg Total Emissions Reduction

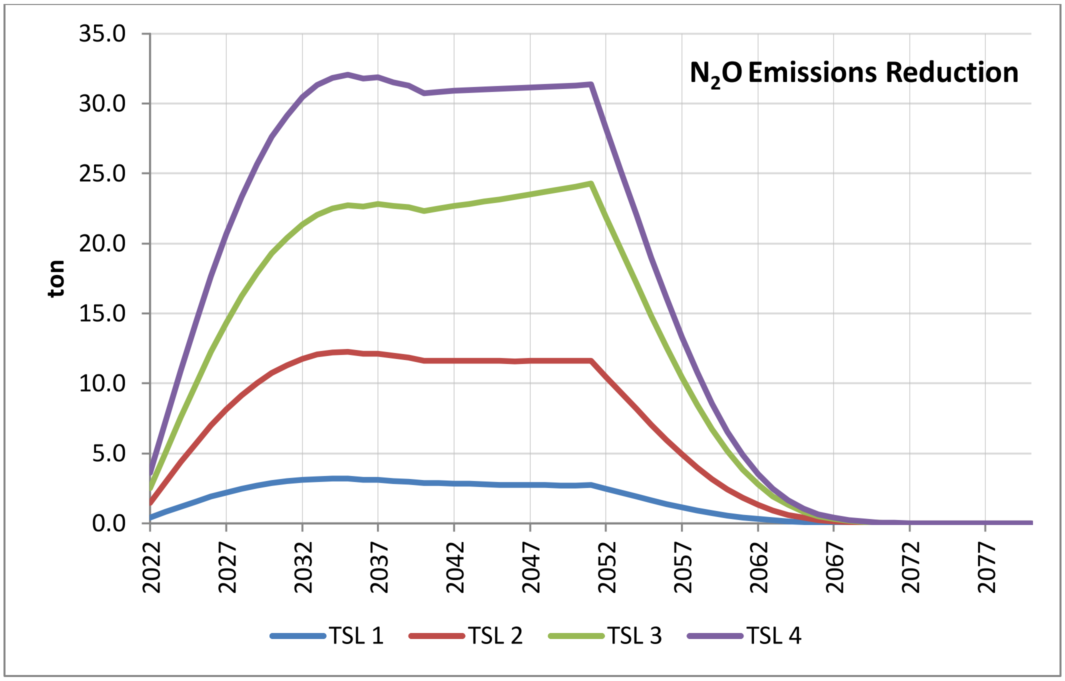

Figure 13.3.5 Portable Air Conditioners: N_2O Total Emissions Reduction

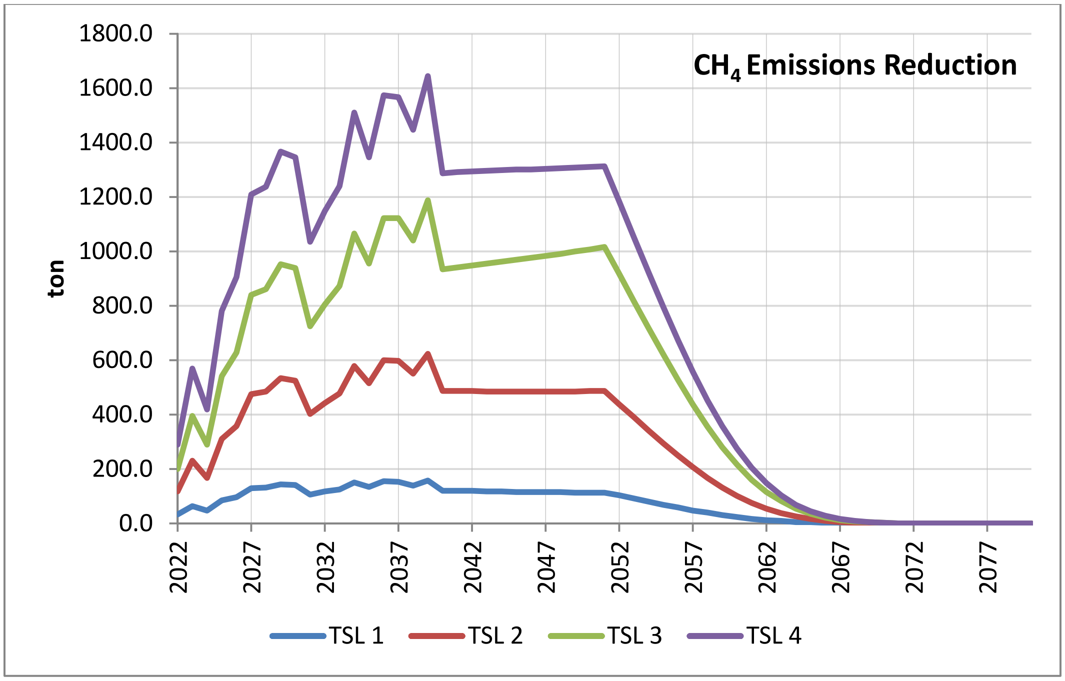

Figure 13.3.6 Portable Air Conditioners: CH_4 Total Emissions Reduction

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2. U.S. Environmental Protection Agency, *Compilation of Air Pollutant Emission Factors, AP-42, Fifth Edition, Volume I: Stationary Point and Area Sources*. 1998. http://www.epa.gov/ttn/chief/ap42/index.html

3. Coughlin, K., *Projections of Full-Fuel-Cycle Energy and Emissions Metrics*, 2013. Lawrence Berkeley National Laboratory. Report No. LBNL-6025E. http://ees.lbl.gov/sites/all/files/lbnl6025e_ffc.pdf.

4. Coughlin, K., *Utility Sector Impacts of Reduced Electricity Demand*, 2014. Lawrence Berkeley National Laboratory. Report No. LBNL-6864E. http://www.osti.gov/scitech/biblio/1165372/

CHAPTER 14. MONETIZATION OF EMISSIONS REDUCTION BENEFITS

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CHAPTER 14. MONETIZATION OF EMISSIONS REDUCTION BENEFITS

14.1 INTRODUCTION

As part of its assessment of energy conservation standards for portable air conditioners, the U.S. Department of Energy (DOE) estimated the monetary benefits likely to result from the reduced emissions of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and nitrogen oxides (NO_X) that are expected to result from each trial standard level (TSL) considered for this rulemaking. This chapter summarizes the basis for the monetary values used for each of these emissions and presents the estimated benefits.

14.2 MONETIZING CARBON DIOXIDE EMISSIONS

14.2.1 Social Cost of Carbon

The social cost of carbon (SCC) is an estimate of the monetized damages associated with an incremental increase in carbon emissions in a given year. It is intended to include (but is not limited to) changes in net agricultural productivity, human health, property damages from increased flood risk, and the value of ecosystem services. Estimates of the SCC are provided in dollars per metric ton of carbon dioxide. A domestic SCC value is meant to reflect the value of damages in the United States resulting from a unit change in carbon dioxide emissions, while a global SCC value is meant to reflect the value of damages worldwide.

Under section 1(b) of Executive Order 12866, agencies must, to the extent permitted by law, "assess both the costs and the benefits of the intended regulation and, recognizing that some costs and benefits are difficult to quantify, propose or adopt a regulation only upon a reasoned determination that the benefits of the intended regulation justify its costs." The purpose of the SCC estimates presented here is to allow agencies to incorporate the monetized social benefits of reducing CO_2 emissions into cost-benefit analyses of regulatory actions that have small, or "marginal," impacts on cumulative global emissions. The estimates are presented with an acknowledgement of the many uncertainties involved and with a clear understanding that they should be updated over time to reflect increasing knowledge of the science and economics of climate impacts.

As part of the interagency process that developed these SCC estimates, technical experts from numerous agencies met on a regular basis to explore the technical literature in relevant fields, discuss key model inputs and assumptions, and consider public comments. The main objective of this process was to develop a range of SCC values using a defensible set of input assumptions grounded in the existing scientific and economic literatures. In this way, key uncertainties and model differences transparently and consistently inform the range of SCC estimates used in the rulemaking process.

14.2.2 Monetizing Carbon Dioxide Emissions

When attempting to assess the incremental economic impacts of carbon dioxide emissions, the analyst faces a number of serious challenges. A report from the National Research Council[1] points out that any assessment will suffer from uncertainty, speculation, and lack of information about (1) future emissions of greenhouse gases, (2) the effects of past and future emissions on the climate system, (3) the impact of changes in climate on the physical and biological environment, and (4) the translation of these environmental impacts into economic damages. As a result, any effort to quantify and monetize the harms associated with climate change will raise serious questions of science, economics, and ethics and should be viewed as provisional.

Despite the limits of both quantification and monetization, SCC estimates can be useful in estimating the social benefits of reducing carbon dioxide emissions. Most Federal regulatory actions can be expected to have marginal impacts on global emissions. For such policies, the agency can estimate the benefits from reduced (or costs from increased) emissions in any future year by multiplying the change in emissions in that year by the SCC value appropriate for that year. The net present value of the benefits can then be calculated by multiplying each of these future benefits by an appropriate discount factor and summing across all affected years. This approach assumes that the marginal damages from increased emissions are constant for small departures from the baseline emissions path, an approximation that is reasonable for policies that have effects on emissions that are small relative to cumulative global carbon dioxide emissions.

In 2009, an interagency process was initiated to offer a preliminary assessment of how best to quantify the benefits from reducing carbon dioxide emissions. To ensure consistency in how benefits are evaluated across agencies, the Administration sought to develop a transparent and defensible method, specifically designed for the rulemaking process, to quantify avoided climate change damages from reduced CO_2 emissions. The interagency group did not undertake any original analysis. Instead, it combined SCC estimates from the existing literature to use as interim values until a more comprehensive analysis could be conducted. These interim values represented the first sustained interagency effort within the U.S. government to develop an SCC for use in regulatory analysis. The results of this preliminary effort were presented in several proposed and final rules.

14.2.3 Current Approach and Key Assumptions

After the release of the interim values, the interagency group reconvened on a regular basis to generate improved SCC estimates. Specifically, the group considered public comments and further explored the technical literature in relevant fields. The interagency group relied on three integrated assessment models (IAMs) commonly used to estimate the SCC: the FUND, DICE, and PAGE models. These models are frequently cited in the peer-reviewed literature and were used in the last assessment of the Intergovernmental Panel on Climate Change. Each model was given equal weight in the SCC values that were developed.

Each model takes a slightly different approach to model how changes in emissions result in changes in economic damages. A key objective of the interagency process was to enable a consistent exploration of the three models while respecting the different approaches to quantifying damages taken by the key modelers in the field. An extensive review of the literature was conducted to select three sets of input parameters for these models: (1) climate sensitivity; (2) socio-economic and emissions trajectories; and (3) discount rates. A probability distribution for climate sensitivity was specified as an input into all three models. In addition, the interagency group used a range of scenarios for the socio-economic parameters and a range of values for the discount rate. All other model features were left unchanged, relying on the model developers' best estimates and judgments.

In 2010 the interagency group selected four SCC values for use in regulatory analyses.[2] Three values are based on the average SCC from three integrated assessment models, at discount rates of 2.5, 3, and 5 percent. The fourth value, which represents the 95th percentile SCC estimate across all three models at a 3 percent discount rate, is included to represent higher-than-expected impacts from temperature change further out in the tails of the SCC distribution. The values grow in real terms over time. Additionally, the interagency group determined that a range of values from 7 percent to 23 percent should be used to adjust the global SCC to calculate domestic effects,[a] although preference is given to consideration of the global benefits of reducing CO_2 emissions.

In 2013 the interagency working group issued revised SCC values that were generated using the most recent versions of the three integrated assessment models that have been published in the peer-reviewed literature. These values, which were slightly revised in July 2015, were used in the current analysis.[3] Table 14.2.1 shows the updated sets of SCC estimates in five year increments from 2010 to 2050. Appendix 14A provides the full set of SCC estimates. The central value that emerges is the average SCC across models at the 3 percent discount rate. However, for purposes of capturing the uncertainties involved in regulatory impact analysis, the interagency group emphasizes the importance of including all four sets of SCC values.

[a] It is recognized that this calculation for domestic values is approximate, provisional, and highly speculative. There is no a priori reason why domestic benefits should be a constant fraction of net global damages over time.

Table 14.2.1 Annual SCC Values from 2013 Interagency Update (Revised July 2015), 2010–2050 (in 2007 dollars per metric ton CO_2)

Year	Discount Rate %			
	5	3	2.5	3
	Average	Average	Average	95th Percentile
2010	10	31	50	86
2015	11	36	56	105
2020	12	42	62	123
2025	14	46	68	138
2030	16	50	73	152
2035	18	55	78	168
2040	21	60	84	183
2045	23	64	89	197
2050	26	69	95	212

It is important to recognize that a number of key uncertainties remain, and that current SCC estimates should be treated as provisional and revisable since they will evolve with improved scientific and economic understanding. The interagency group also recognizes that the existing models are imperfect and incomplete. The National Research Council report mentioned above points out that there is tension between the goal of producing quantified estimates of the economic damages from an incremental ton of carbon and the limits of existing efforts to model these effects. There are a number of concerns and problems that should be addressed by the research community, including research programs housed in many of the agencies participating in the interagency process to estimate the SCC. The interagency group intends to periodically review and reconsider estimates of the SCC used for cost-benefit analyses to reflect increasing knowledge of the science and economics of climate impacts, as well as improvements in modeling.

DOE converted the values from the 2013 interagency report (revised July 2015) to 2015$ using the implicit price deflator for gross domestic product (GDP) from the Bureau of Economic Analysis. For example, for each of the four cases specified, the values used for emissions in 2020 are $13.5, $47.4, $69.9, and $139 per metric ton avoided. DOE derived values after 2050 based on the trend in 2010-2050 in each of the four cases.

DOE multiplied the CO_2 emissions reduction estimated for each year by the SCC value for that year in each of the four cases. To calculate a present value of the stream of monetary values, DOE discounted the values in each of the four cases using the specific discount rate that had been used to obtain the SCC values in each case.

14.3 MONETIZING METHANE AND NITROUS OXIDE EMISSIONS

While carbon dioxide is the most prevalent greenhouse gas emitted into the atmosphere, other GHGs are also important contributors. These include methane and nitrous oxide. Global warming potentials (GWPs) are often used to convert emissions of non-CO_2 GHGs to CO_2-equivalents to facilitate comparison of policies and inventories involving different GHGs. While GWPs allow for some useful comparisons across gases on a physical basis, using the social cost of carbon to value the damages associated with changes in CO_2-equivalent emissions is not optimal. This is because non-CO_2 GHGs differ not just in their potential to absorb infrared radiation over a given time frame, but also in the temporal pathway of their impact on radiative forcing, which is relevant for estimating their social cost but not reflected in the GWP. Physical impacts other than temperature change also vary across gases in ways that are not captured by GWP.

In light of these limitations and the paucity of peer-reviewed estimates of the social cost of non-CO_2 gases in the literature, the 2010 SCC Technical Support Document did not include an estimate of the social cost of non-CO_2 GHGs and did not endorse the use of GWP to approximate the value of non-CO_2 emission changes in regulatory analysis. Instead, the Interagency Working Group (IWG) noted that more work was needed to link non-CO_2 GHG emission changes to economic impacts.

Since that time, new estimates of the social cost of non-CO_2 GHG emissions have been developed in the scientific literature, and a recent study by Marten *et al*. (2015) provided the first set of published estimates for the social cost of CH_4 and N_2O emissions that are consistent with the methodology and modeling assumptions underlying the IWG SC-CO_2 estimates.[b] Specifically, Marten *et al.* used the same set of three integrated assessment models, five socioeconomic and emissions scenarios, equilibrium climate sensitivity distribution, three constant discount rates, and the aggregation approach used by the IWG to develop the SC-CO2 estimates. An addendum to the IWG's Technical Support Document on Social Cost of Carbon for Regulatory Impact Analysis under Executive Order 12866 summarizes the Marten *et al.* methodology and presents the social cost of methane (SC-CH_4) and social cost of nitrous oxide (SC-N_2O) estimates from that study as a way for agencies to incorporate the social benefits of reducing CH_4 and N_2O emissions into benefit-cost analyses of regulatory actions that have small, or "marginal," impacts on cumulative global emissions.[c]

The methodology and estimates described in the addendum have undergone multiple stages of peer review and their use in regulatory analysis has been subject to public comment.

[b] Marten, A.L., Kopits, E.A., Griffiths, C.W., Newbold, S.C., and A. Wolverton. 2015. Incremental CH_4 and N_2O Mitigation Benefits Consistent with the U.S. Government's SC-CO2 Estimates. Climate Policy. 15(2): 272-298 (published online, 2014).

[c] United States Government–Interagency Working Group on Social Cost of Greenhouse Gases. Addendum to Technical Support Document on Social Cost of Carbon for Regulatory Impact Analysis under Executive Order 12866: Application of the Methodology to Estimate the Social Cost of Methane and the Social Cost of Nitrous Oxide. August 2016. https://www.whitehouse.gov/sites/default/files/omb/inforeg/august_2016_sc_ch4_sc_n2o_addendum_final_8_26_16.pdf.

The estimates are presented with an acknowledgement of the limitations and uncertainties involved and with a clear understanding that they should be updated over time to reflect increasing knowledge of the science and economics of climate impacts, just as the IWG has committed to do for the SC-CO_2. The OMB has determined that the use of the Marten *et al.* estimates in regulatory analysis is consistent with the requirements of OMB's Information Quality Guidelines Bulletin for Peer Review and OMB Circular A-4.

The SC-CH_4 and SC-N_2O estimates are presented in Table 14.3.1. Following the same approach as with the SC-CO_2 values for 2010, 2020, 2030, 2040, and 2050 are calculated by combining all outputs from all scenarios and models for a given discount rate. Values for the years in between are calculated using linear interpolation. The full set of annual SC-CH_4 and SC-N_2O estimates between 2010 and 2050 is reported in appendix 14A of the final rule TSD. DOE derived values after 2050 based on the trend in 2010–2050 in each of the four cases in the IWG addendum.

Table 14.3.1 Annual SC-CH_4 and SC-N_2O Estimates from 2016 IWG Addendum (2007$ per Metric Ton CO_2)

Year	SC-CH_4				SC-N_2O			
	Discount Rate and Statistic				Discount Rate and Statistic			
	5%	3%	2.5%	3%	5%	3%	2.5 %	3%
	Average	Average	Average	95th percentile	Average	Average	Average	95th percentile
2010	370	870	1,200	2,400	3,400	12,000	18,000	31,000
2015	450	1,000	1,400	2,800	4,000	13,000	20,000	35,000
2020	540	1,200	1,600	3,200	4,700	15,000	22,000	39,000
2025	650	1,400	1,800	3,700	5,500	17,000	24,000	44,000
2030	760	1,600	2,000	4,200	6,300	19,000	27,000	49,000
2035	900	1,800	2,300	4,900	7,400	21,000	29,000	55,000
2040	1,000	2,000	2,600	5,500	8,400	23,000	32,000	60,000
2045	1,200	2,300	2,800	6,100	9,500	25,000	34,000	66,000
2050	1,300	2,500	3,100	6,700	11,000	27,000	37,000	72,000

DOE multiplied the CH_4 and N_2O emissions reduction estimated for each year by the SC-CH_4 and SC-N_2O estimates for that year in each of the four cases. To calculate a present value of the stream of monetary values, DOE discounted the values in each of the four cases using the specific discount rate that had been used to obtain the SC-CH_4 and SC-N_2O estimates in each case.

14.4 VALUATION OF OTHER EMISSIONS

As noted in chapter 13, new or amended energy conservation standards would reduce NO_X emissions from electricity generation in those 22 States that are not affected by caps. For each of the considered TSLs, DOE estimated monetized values of NO_X emissions reductions from electricity generation using benefit-per-ton estimates for NO_X associated with $PM_{2.5}$ from the *Regulatory Impact Analysis for the Clean Power Plan Final Rule,* published in October 2015 by EPA's Office of Air Quality Planning and Standards.[d] The report includes low and high values for 2020, 2025, and 2030 that use discount rates of 3 percent and 7 percent (see Tables 4A-3, 4A-4, and 4A-5 in the report). The results reported in this chapter use the low benefit per ton estimates to be conservative.[e]

DOE refined the data provided by EPA to estimate monetized values of NO_X emissions reduction by sector. For this analysis DOE used linear interpolation to define values for the years between 2020 and 2025 and between 2025 and 2030; for years beyond 2030 the value is held constant. Appendix 14B provides methodological details and NOx values from the approach DOE developed. The results presented here use NOx monetized values for the residential sector. DOE multiplied the emissions reduction (in tons) in each year by the associated $/ton values, and then discounted each series using discount rates of 3 percent and 7 percent as appropriate.

DOE is evaluating appropriate values to use to monetize avoided SO_2 and Hg emissions. DOE did not monetize these emissions for the current analysis.

14.5 RESULTS

Table 14.5.1 Global Present Value of CO_2 Emissions Reduction for Potential Standards for Portable Air Conditioners

TSL	SCC Case			
	5% discount rate, average	3% discount rate, average	2.5% discount rate, average	3% discount rate, 95th percentile
	Million 2015$			
1	46	208	330	635
2	182	829	1,316	2,529
3	347	1,595	2,535	4,866
4	477	2,182	3,464	6,656

[d] Available at http://www.epa.gov/sites/production/files/2015-08/documents/cpp-final-rule-ria.pdf.

[e] For the monetized NO_X benefits associated with PM2.5, the reported benefits are based on an estimate of premature mortality derived from the ACS study (Krewski et al. 2009), which is the lower of the two EPA central tendencies. Using the lower value is more conservative when making the policy decision concerning whether a particular standard level is economically justified. If the benefit-per-ton estimates were based on the Six Cities study (Lepuele et al. 2012), the values would be nearly two-and-a-half times larger.

Table 14.5.2 Domestic Present Value of CO_2 Emissions Reduction for Potential Standards for Portable Air Conditioners

TSL	SCC Case			
	5% discount rate, average	3% discount rate, average	2.5% discount rate, average	3% discount rate, 95th percentile
	Million 2015$			
1	3.2 to 10.6	14.6 to 47.9	23.1 to 76.0	44.5 to 146.2
2	12.7 to 41.8	58.1 to 190.7	92.1 to 302.7	177.0 to 581.6
3	24.3 to 79.8	111.7 to 366.9	177.4 to 583.0	340.6 to 1,119.2
4	33.4 to 109.6	152.8 to 501.9	242.5 to 796.8	465.9 to 1,530.8

Table 14.5.3 Present Value of Methane Emissions Reduction for Potential Standards for Portable Air Conditioners

TSL	SC-CH_4 Case			
	5% Discount Rate, Average	3% Discount Rate, Average	2.5% Discount Rate, Average	3% Discount Rate, 95th Percentile
	Million 2015$			
1	10	31	44	83
2	40	125	177	333
3	76	242	344	646
4	104	330	468	880

Table 14.5.4 Present Value of Nitrous Oxide Emissions Reduction for Potential Standards for Portable Air Conditioners

TSL	SC-N_2O Case			
	5% Discount Rate, Average	3% Discount Rate, Average	2.5% Discount Rate, Average	3% Discount Rate, 95th Percentile
	Million 2015$			
1	0.25	1.03	1.63	2.75
2	0.97	4.11	6.50	10.95
3	1.86	7.92	12.54	21.10
4	2.55	10.83	17.13	28.84

Table 14.5.5 Present Value of NO_X Emissions Reduction for Potential Standards for Portable Air Conditioners

TSL	3% discount rate	7% discount rate
	Million 2015$	
1	14.1	5.8
2	55.8	22.6
3	106.6	42.4
4	146.5	59.0

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CHAPTER 15. UTILITY IMPACT ANALYSIS

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CHAPTER 15. UTILITY IMPACT ANALYSIS

15.1 INTRODUCTION

In the utility impact analysis, the U.S. Department of Energy (DOE) analyzes the changes in electric installed capacity and power generation that result for each trial standard level (TSL).

The utility impact analysis is based on output of the DOE/Energy Information Administration (EIA)'s National Energy Modeling System (NEMS).[a] NEMS is a public domain, multi-sectored, partial equilibrium model of the U.S. energy sector. Each year, DOE/EIA uses NEMS to produce an energy forecast for the United States, the Annual Energy Outlook (AEO). The EIA publishes a Reference case, which incorporates all existing energy-related policies at the time of publication, and a variety of side cases which analyze the impact of different policies, energy price and market trends. DOE's methodology is based on results published for the *Annual Energy Outlook 2016(AEO 2016)*.[2]

DOE's *AEO*-based methodology has a number of advantages:

- The assumptions used in the AEO reference case and side cases are fully documented and receive detailed public scrutiny.
- NEMS is updated each year, with each edition of the AEO, to reflect changes in energy prices, supply trends, regulations, *etc.*
- The comprehensiveness of NEMS permits the modeling of interactions among the various energy supply and demand sectors.
- Using EIA published reference and side cases to estimate the utility impacts enhances the transparency of DOE's analysis.

The details of the methodology vary based on the number and type of side cases published with each edition of the *AEO*. The approach adopted for *AEO 2016* is described in appendix 15A. A more detailed discussion of the general approach is presented in K. Coughlin, *Utility Sector Impacts of Reduced Electricity Demand*.[3]

This chapter presents the results for portable air conditioners.

15.2 METHODOLOGY

DOE estimates the marginal impacts of reduction in energy demand on the energy supply sector. In principle, marginal values should provide a better estimate of the actual impact of energy conservation standards. DOE represents these marginal impacts using time series of *impact factors.*

[a] For more information on NEMS, refer to the U.S. Department of Energy, Energy Information Administration documentation. A useful summary is *National Energy Modeling System: An Overview.*[1]

The impact factors are calculated based on output from NEMS for the *AEO 2016*. NEMS uses predicted growth in demand for each end use to build up a projection of the total electric system load growth. The system load shapes are converted internally to load duration curves, which are then used to estimate the most cost-effective additions to capacity. When electricity demand deviates from the AEO reference case, in general there are three inter-related effects: the annual generation (TWh) from the stock of electric generating capacity changes, the total generation capacity itself (GW) may change, and the mix of capacity types and technologies may change. Technology changes lead to a change in the proportion of fuel consumption to electricity generated (referred to as the heat rate). Each of these effects can vary for different types of end use. The change in total generating capacity is sensitive to the degree to which the end-use is peak coincident, while the capacity mix is sensitive to the hourly load shape associated with the end use. Changes in generation by fuel type lead in turn to changes in total power sector emissions of SO_2, NO_x, Hg and CO_2.

DOE defined impact factors describing the change in emissions, installed capacity, and fuel consumption per unit reduction of site electricity demand. The impact factors vary by sector and end-use, as well as by year. DOE multiplied the impact factors by the stream of site energy savings calculated in the NIA (chapter 10) to produce estimates of the utility impacts. The utility impact factors are presented in appendix 15A. For portable air conditioners DOE used the impact factors for space cooling in homes and commercial buildings.

15.3 UTILITY IMPACT RESULTS

15.3.1 Installed Capacity

The figures in this section show the changes in U.S. electricity installed capacity that result for each TSL by major plant type for selected years. The changes have been calculated based on the impact factors for capacity presented in appendix 15A. Units are megawatts of capacity per gigawatt-hour of site electricity use (MW/GWh).[b] Note that a negative number means an increase in capacity under a TSL.

[b] These units are identical to GW/TWh.

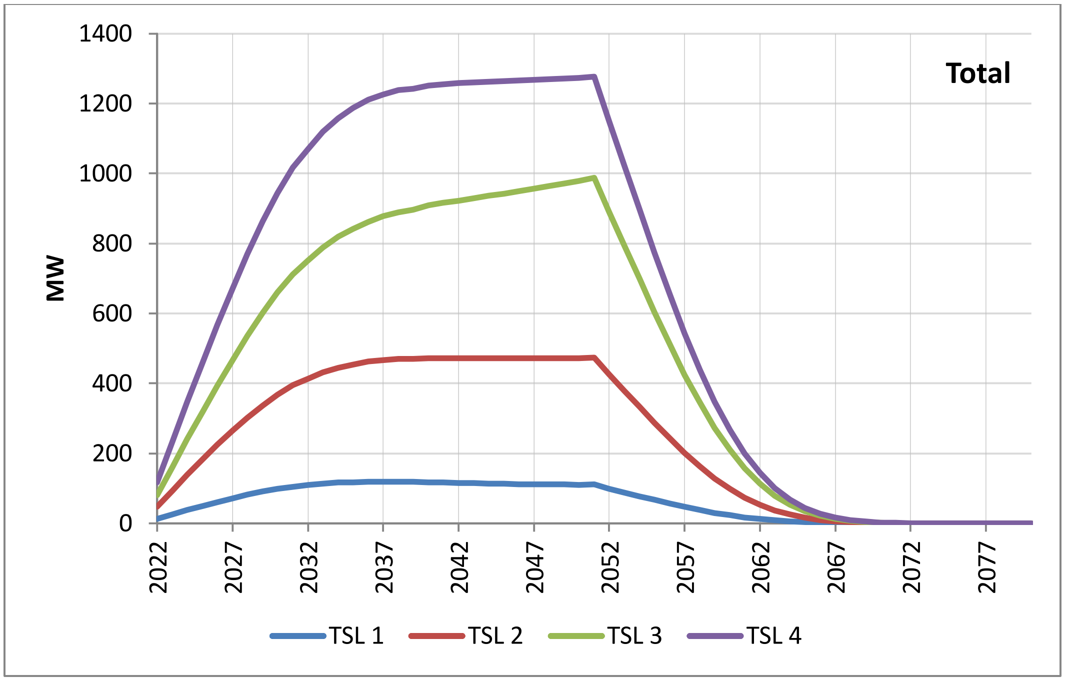

Figure 15.3.1 Portable Air Conditioners: Total Electric Capacity Reduction

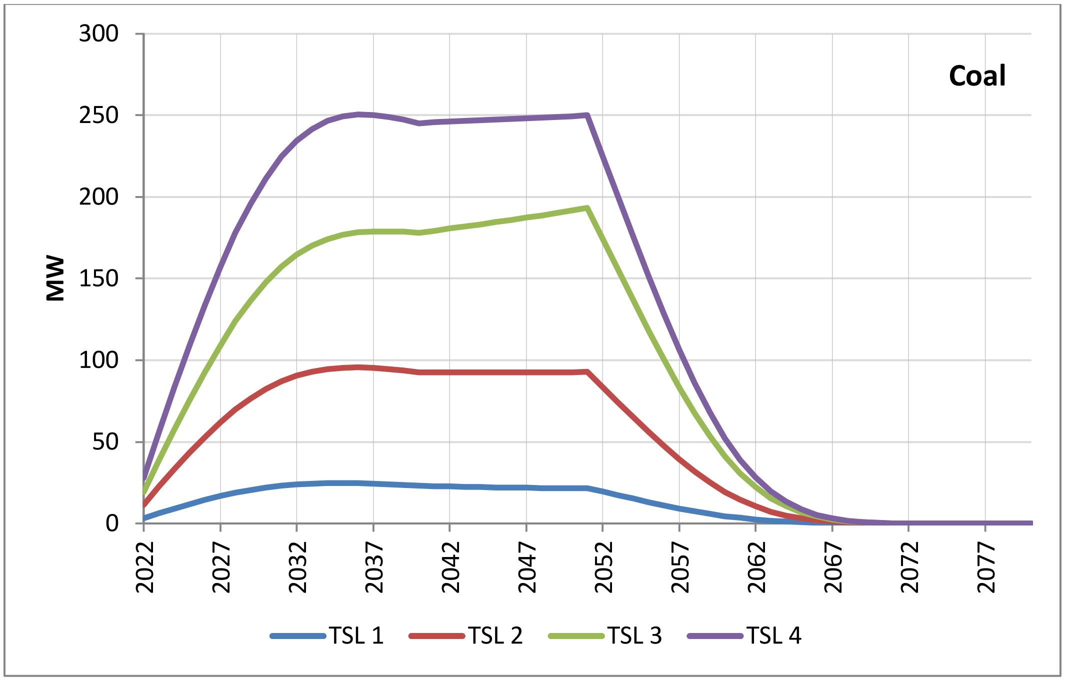

Figure 15.3.2 Portable Air Conditioners: Coal Capacity Reduction

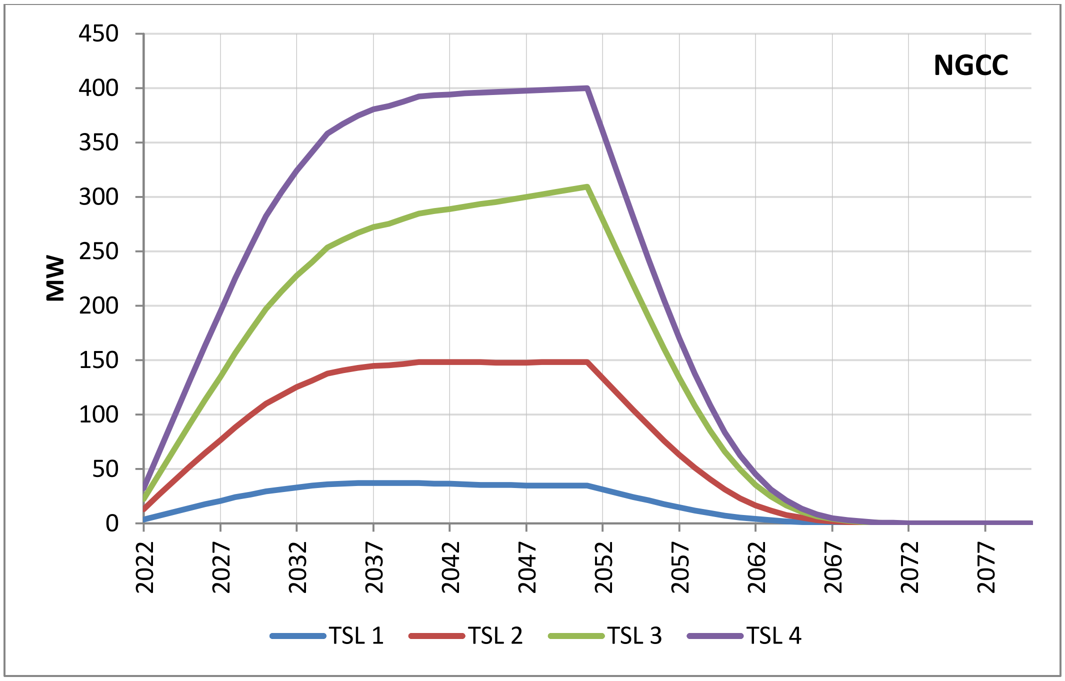

Figure 15.3.3 Portable Air Conditioners: Gas Combined Cycle Capacity Reduction

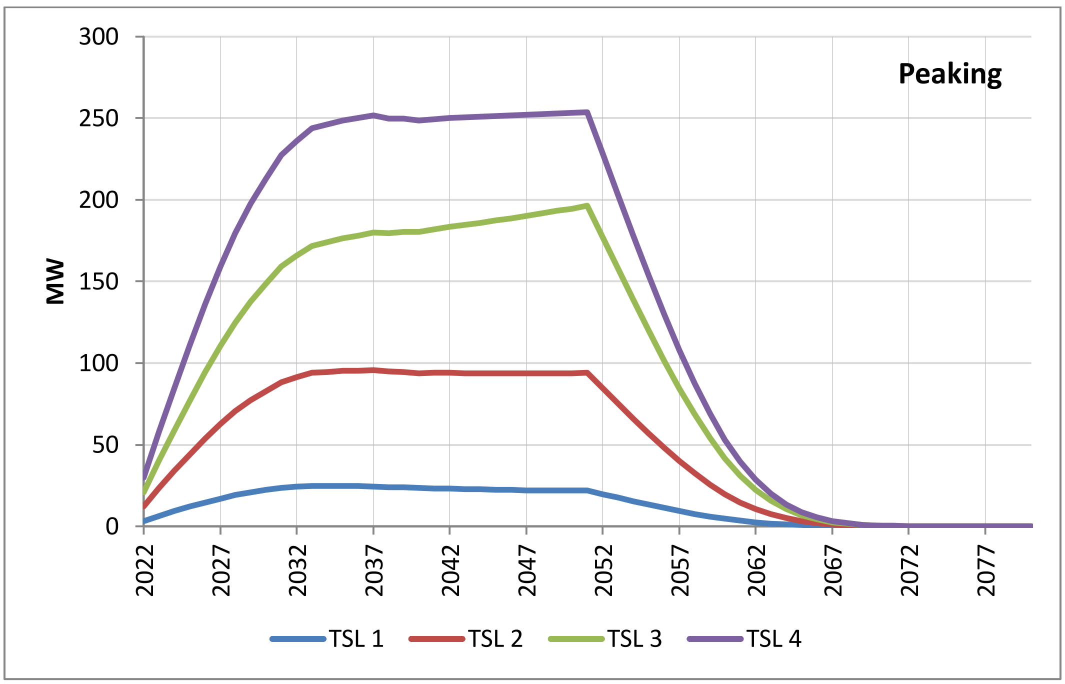

Figure 15.3.4 Portable Air Conditioners: Peaking Capacity Reduction

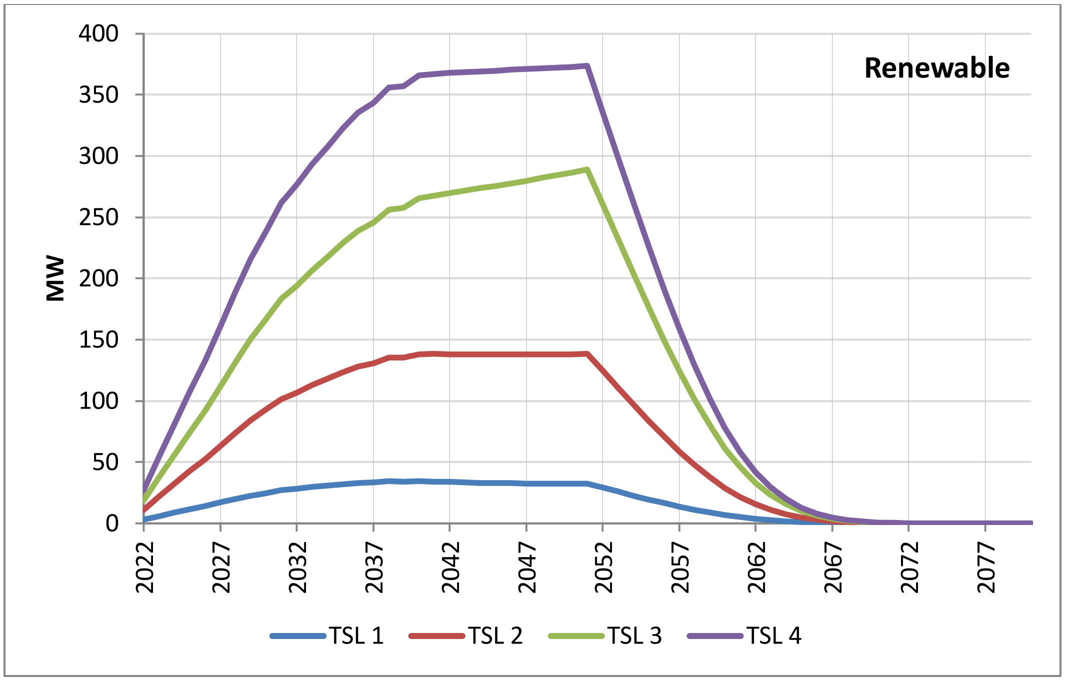

Figure 15.3.5 Portable Air Conditioners: Renewables Capacity Reduction

15.3.2 Electricity Generation

The figures in this section show the annual change in electricity generation that result for each TSL by fuel type. The change by fuel type has been calculated based on factors calculated as described in appendix 15A.

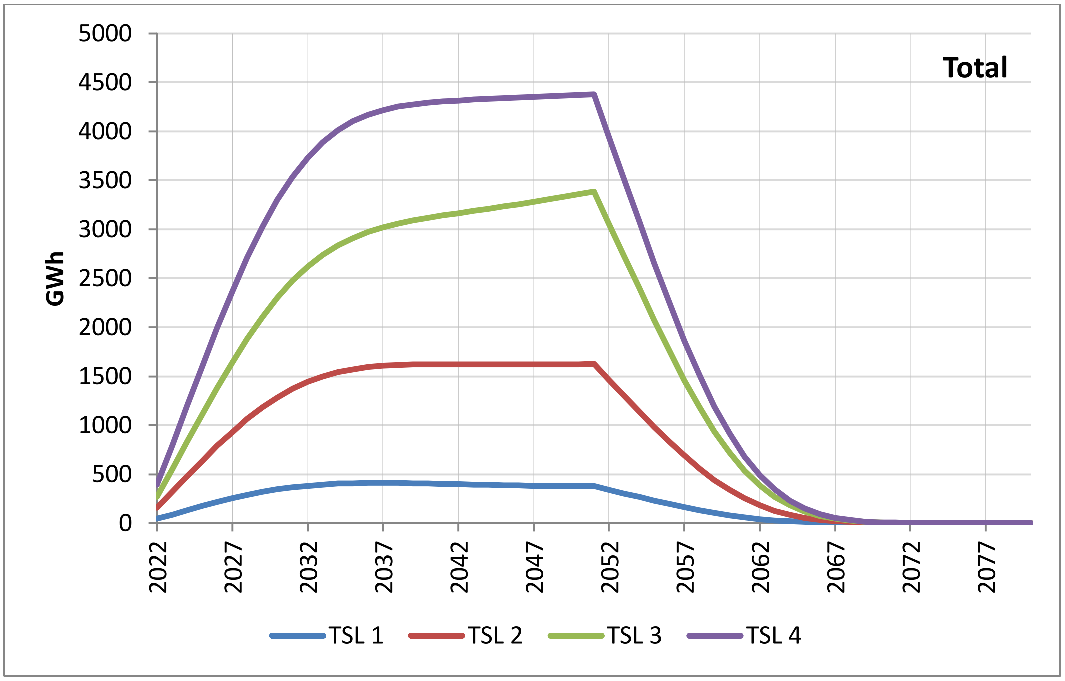

Figure 15.3.6 Portable Air Conditioners: Total Generation Reduction

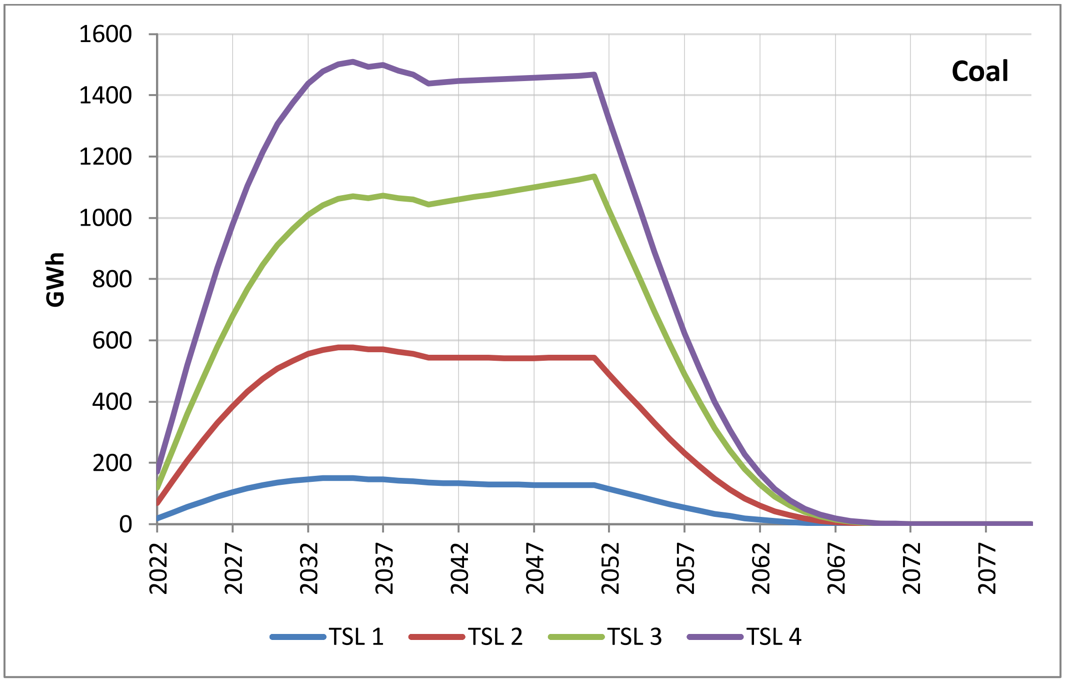

Figure 15.3.7 Portable Air Conditioners: Coal Generation Reduction

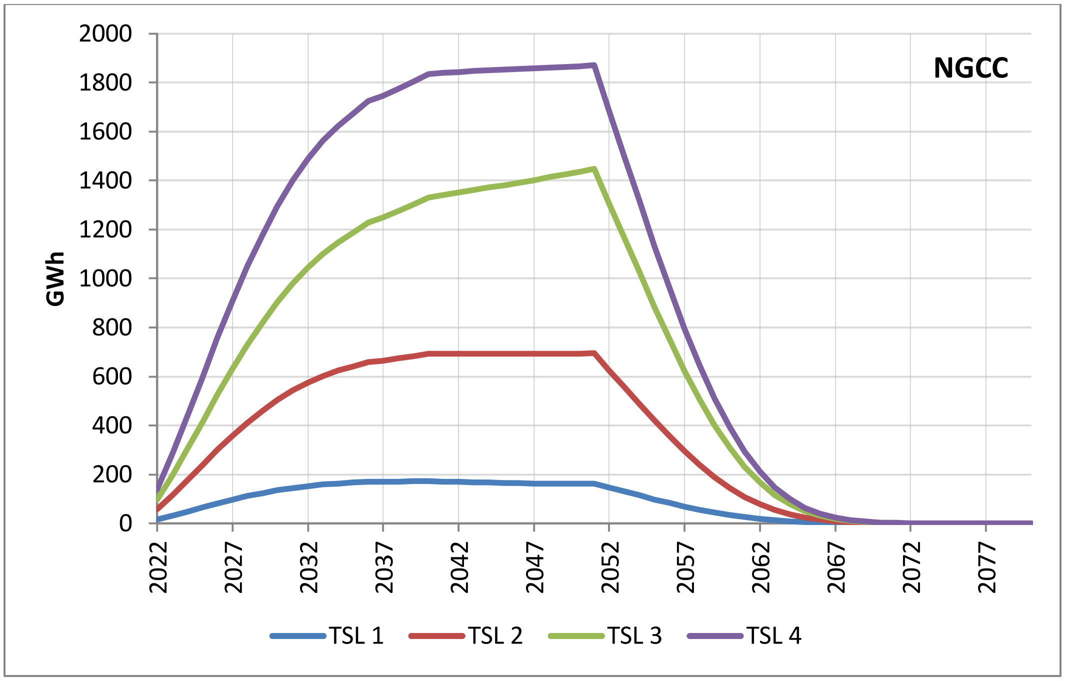

Figure 15.3.8 Portable Air Conditioners: Gas Combined Cycle Generation Reduction

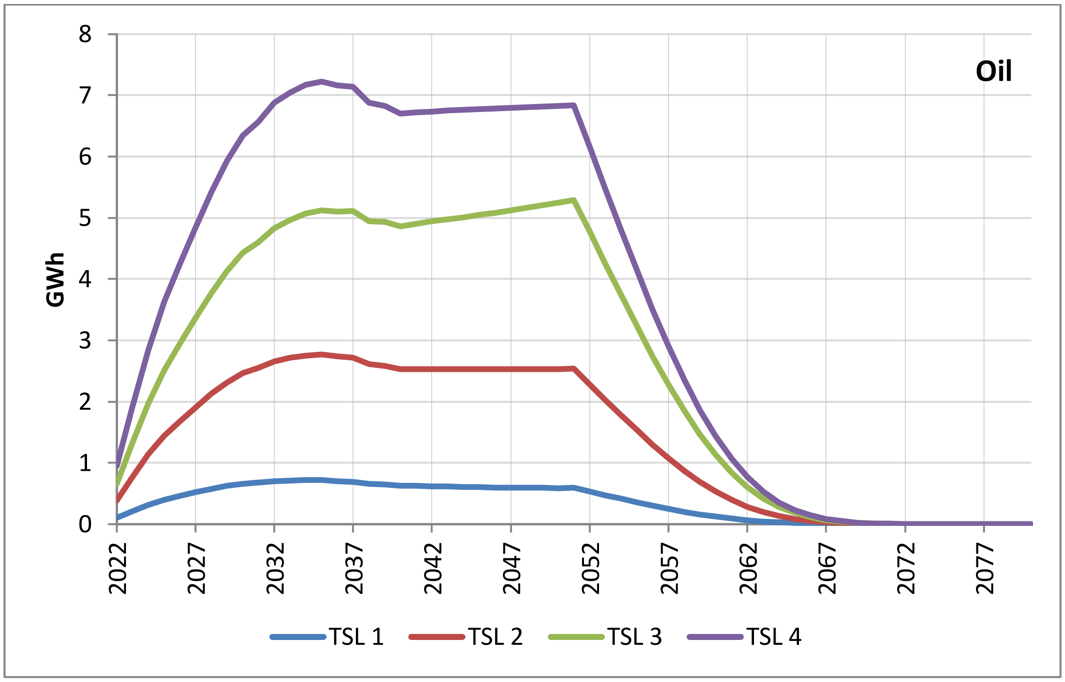

Figure 15.3.9 Portable Air Conditioners: Oil Generation Reduction

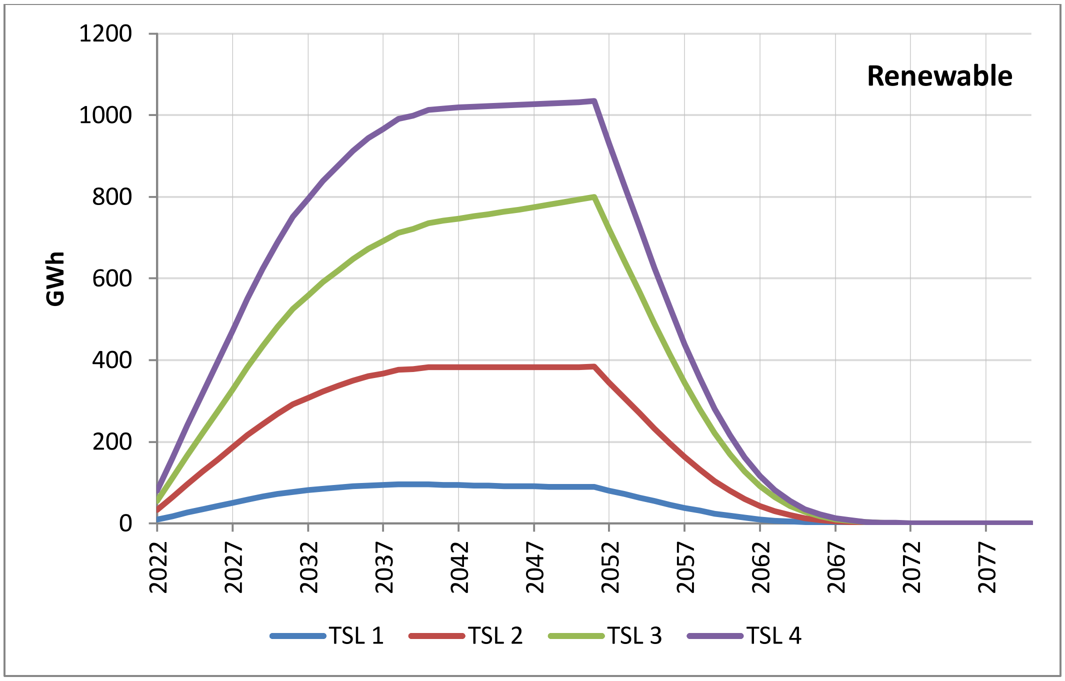

Figure 15.3.10 Portable Air Conditioners: Renewables Generation Reduction

15.3.3 Results Summary

Table 15.3.1 presents a summary of the utility impact results for portable air conditioners.

Table 15.3.1 Portable Air Conditioners: Summary of Utility Impact Results

	TSL			
	1	**2**	**3**	**4**
Installed Capacity Reduction (MW)				
2022	13	48	81	118
2025	50	183	318	459
2030	99	368	660	945
2035	118	455	843	1187
2040	118	473	909	1252
Electricity Generation Reduction (GWh)				
2022	44	160	271	391
2025	175	638	1109	1602
2030	344	1284	2303	3298
2035	408	1571	2911	4102
2040	405	1621	3116	4293

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CHAPTER 16. EMPLOYMENT IMPACT ANALYSIS

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CHAPTER 16. EMPLOYMENT IMPACT ANALYSIS

16.1 INTRODUCTION

DOE's employment impact analysis is designed to estimate indirect national job creation or elimination resulting from possible standards due to reallocation of the associated expenditures for purchasing and operating portable air conditioners (PAC). Job increases or decreases reported in this chapter are separate from the direct PAC production sector employment impacts reported in the manufacturer impact analysis (chapter 12), and reflect the net employment impact of efficiency standards on all sectors of the economy.

16.2 ASSUMPTIONS

DOE expects energy conservation standards to decrease energy consumption, and therefore to reduce energy expenditures. The savings in energy expenditures may be spent on new investment or not at all (*i.e.*, they may remain "saved"). The standards may increase the purchase price of products, including the retail price plus sales tax, and increase installation costs.

Using an input/output econometric model of the U.S. economy, this analysis estimated the short-term effect of these expenditure impacts on net economic output and employment. DOE intends for this analysis to quantify the indirect employment impacts of these expenditure changes. It evaluated direct employment impacts at manufacturers' facilities in the manufacturer impact analysis (see chapter 12).

DOE notes that ImSET is not a general equilibrium forecasting model, and understands the uncertainties involved in projecting employment impacts, especially changes in the later years of the analysis.[1] Because ImSET does not incorporate price changes, the employment effects predicted by ImSET would over-estimate the magnitude of actual job impacts over the long run for this rule. Because input/output models do not allow prices to bring markets into equilibrium, they are best used for short-run analysis. DOE therefore include a qualitative discussion of how labor markets are likely to respond in the longer term. In future rulemakings, DOE may consider the use of other modeling approaches for examining long run employment impacts.

16.3 METHODOLOGY

The Department based its analysis on an input/output model of the U.S. economy that estimates the effects of standards on major sectors of the economy related to buildings and the net impact of standards on jobs. The Pacific Northwest National Laboratory developed the model, ImSET 4[2] (Impact of Sector Energy Technologies) as a successor to ImBuild,[3] a special-purpose version of the IMPLAN[4] national input/output model. ImSET estimates the employment and income effects of building energy technologies. In comparison with simple economic multiplier approaches, ImSET allows for more complete and automated analysis of the economic impacts of energy-efficiency investments in buildings.

In an input/output model, the level of employment in an economy is determined by the relationship of different sectors of the economy and the spending flows among them. Different sectors have different levels of labor intensity and so changes in the level of spending (e.g., due to the effects of an efficiency standard) in one sector of the economy will affect flows in other sectors, which affects the overall level of employment.

ImSET uses a 187-sector model of the national economy to predict the economic effects of residential and commercial buildings technologies. ImSET collects estimates of initial investments, energy savings, and economic activity associated with spending the savings resulting from standards (e.g., changes in final demand in personal consumption, business investment and spending, and government spending). It provides overall estimates of the change in national output for each input-output sector. The model applies estimates of employment and wage income per dollar of economic output for each sector and calculates impacts on national employment and wage income.

Energy-efficiency technology primarily affects the U.S. economy along three spending pathways. First, general investment funds are diverted to sectors that manufacture, install, and maintain energy-efficient products. The increased cost of products leads to higher employment in the product manufacturing sectors and lower employment in other economic sectors. Second, commercial firm and residential spending are redirected from utilities and energy producers toward firms that supply production inputs for energy-efficient products. Third, investment funds from utilities and energy producers are released for use in other sectors of the economy. When consumers use less energy, utilities experience relative reductions in demand which leads to reductions in utility sector investment and employment.

DOE also notes that the employment impacts estimated with ImSET for the entire economy differ from the employment impacts in the residential furnace manufacturing sector estimated in Chapter 12 using the Government Regulatory Impact Model (GRIM). The methodologies used and the sectors analyzed in the ImSET and GRIM models are different.

16.4 SHORT-TERM RESULTS

The results in this section refer to impacts of portable air conditioner standards relative to the base case. DOE disaggregated the impact of standards on employment into three component effects: increased capital investment costs, decreased energy costs, and changes in operations and maintenance costs. DOE presents the summary impact.

Conceptually, one can consider the impact of a standard in its first year on three aggregate sectors, the residential furnace production sector, the energy generation sector, and the general consumer goods sector (as mentioned above ImSET's calculations are made at a much more disaggregate level). By raising energy efficiency, the standard generally increases the purchase price of furnaces; this increase in expenditures causes an increase in employment in this sector. At the same time, the improvements in energy efficiency reduce consumer expenditures on energy. The reduction in energy demand causes a reduction in employment in that sector. Finally, based on the net impact of increased expenditures on furnaces and reduced expenditures on energy, consumer expenditures on everything else are either positively or negatively affected, increasing or reducing jobs in that sector accordingly. The model also captures any indirect jobs created or lost by changes in consumption due to changes in employment (as more workers are hired they consume more goods, which generates more employment, the converse is true for workers laid off).

Table 16.4.1 presents the modeled net employment impact from the standards in 2021, rounded to the nearest ten jobs. For context, the U.S. labor force had approximately 158 million people in December 2015.[a]

Virtually 100% of portable air conditioners are imported. The net employment impact estimate is sensitive to assumptions regarding the return to the U.S. economy of money spent on imported PAC. The two scenarios bounding the ranges presented in Table 16.4.1 represent situations in which none of the money spent on imported PAC returns to the U.S. economy and all of the money spent on imported PAC returns to the U.S. economy. The U.S. trade deficit in recent years suggests that between 50% and 75% of the money spent on imported PAC is likely to return, with employment impacts falling within the ranges presented below.

Table 16.4.1 Net National Short-term Change in Employment (1000 Jobs)

Trial Standard Level	2022	2027
TSL 1	-0.01 to 0.06	0.33 to 0.43
TSL 2	-0.11 to 0.21	1.10 to 1.56
TSL 3	-0.31 to 0.34	1.69 to 2.70
TSL 4	-0.27 to 0.52	2.67 to 3.93

For context, the Office of Management of Budget currently assumes that the unemployment rate may decline to 5.4 percent by 2017.[5] The unemployment rate in 2022 is projected to remain close to “full employment.” When an economy is at full employment any effects on net employment are likely to be transitory as workers change jobs, rather than enter or exit longer-term employment.

16.5 LONG-TERM RESULTS

Over the long term DOE expects the energy savings to consumers to increasingly dominate the increase in product costs, resulting in increased aggregate savings to consumers. As a result, DOE expects demand for energy to decline over time and demand for other goods to increase. Because the utility and energy production sectors are relatively capital intensive compared to the consumer goods sector, the net effect will be an increase in labor demand. In

[a] Bureau of Labor Statistics: Labor Force Statistics (Available at http://www.bls.gov/data/#employment).

equilibrium, this should lead to upward pressure on wages and a shift in employment away from utilities and energy producers towards consumer goods. Note that in long-run equilibrium there is no net effect on total employment because wages adjust to bring the labor market into equilibrium. Nonetheless, even to the extent that markets are slow to adjust, DOE anticipates that net labor market impacts will in general be negligible over time due to the small magnitude of the short-term effects presented in Table 16.4.1. The ImSET model projections, assuming no price or wage effects until 2026, are included in the second column of Table 16.4.1.

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CHAPTER 17. REGULATORY IMPACT ANALYSIS

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CHAPTER 17. REGULATORY IMPACT ANALYSIS

17.1 INTRODUCTION

The Administrator of the Office of Information and Regulatory Affairs (OIRA) in the OMB has determined that the regulatory action in this document is a significant regulatory action under section (3)(f) of EO 12866. For such actions, E.O. 12866 requires Federal agencies to provide "an assessment, including the underlying analysis, of costs and benefits of potentially effective and reasonably feasible alternatives to the planned regulation, identified by the agencies or the public (including improving the current regulation and reasonably viable non-regulatory actions), and an explanation why the planned regulatory action is preferable to the identified potential alternatives." 58 FR 51735, 51741.

To conduct this analysis, DOE used an integrated National Impact Analysis (NIA)-RIA model built on a modified[a] version of the NIA model discussed in Chapter 10. DOE identified five non-regulatory policy alternatives that possibly could provide incentives for the same energy efficiency levels as the ones in the selected trial standard levels (TSL) for the portable air conditioners (ACs) that are the subject of this rulemaking. The non-regulatory policy alternatives are listed in Table 17.1.1, which also includes the "no new regulatory action" alternative. DOE evaluated each alternative in terms of its ability to achieve significant energy savings at a reasonable cost, and compared the effectiveness of each to the effectiveness of the selected TSLs for the residential sector.[b]

Table 17.1.1 Non-Regulatory Alternatives to National Standards

No New Regulatory Action
Consumer Rebates
Consumer Tax Credits
Manufacturer Tax Credits
Voluntary Energy Efficiency Targets
Bulk Government Purchases

Sections 17.2 and 17.3 discuss the analysis of five selected policies listed in Table 17.1.1 (excluding the alternative of "No New Regulatory Action"). Section 17.4 presents the results of the policy alternatives.

[a] For this RIA, DOE developed an alternative NIA model where the efficiency distribution in each of the policy cases do not account for any improvement in the market average energy efficiency but for the ones resulting from the market response to each alternative policy.
[b] For this RIA, DOE is analyzing the effects of alternative policies only on the residential sector as shipments of portable ACs to that sector make up majority of total shipments.

17.2 NON-REGULATORY POLICIES

This section describes the method DOE used to analyze the energy savings and cost effectiveness of the non-regulatory policy alternatives for portable ACs. This section also describes the assumptions underlying the analysis.

17.2.1 Methodology

DOE used its integrated NIA-RIA spreadsheet model to calculate the national energy savings (NES) and net present value (NPV) associated with each non-regulatory policy alternative. Chapter 10 of the technical support document (TSD) describes the NIA spreadsheet model. Appendix 17A discusses the NIA-RIA integrated model approach.

DOE quantified the effect of each alternative on the purchase of equipment that meets the efficiency level corresponding to each TSL. After establishing the quantitative assumptions underlying each alternative, DOE appropriately revised inputs to the NIA-RIA spreadsheet model. The primary model inputs revised were market shares of equipment meeting the target efficiency level set for each TSL. The shipments of equipment for any given year reflect a distribution of efficiency levels. DOE assumed, for each TSL, that new energy efficiency standards would affect 100 percent of the shipments of products that did not meet the target levels[c] in the no-new-standards case,[d] whereas the non-regulatory policies would affect a smaller percentage of those shipments. DOE made certain assumptions about the percentage of shipments affected by each alternative policy. DOE used those percentages to calculate the shipment-weighted average energy consumption and costs of portable ACs attributable to each policy alternative.

Increasing the efficiency of a product often increases its average installed cost. However, operating costs generally decrease because energy consumption declines. DOE therefore calculated an NPV for each non-regulatory alternative in the same way it did for the selected standards. In some policy scenarios, increases in total installed cost are mitigated by government rebates or tax credits. Because DOE assumed that consumers would re-pay credits and rebates in some way (such as additional taxes), DOE did not include rebates or tax credits as a consumer benefit when calculating national NPV. DOE’s analysis also excluded any administrative costs for the non-regulatory policies; including such costs would decrease the NPVs slightly.

The following are key measures for evaluating the impact of each alternative.

- National Energy Savings (NES), given in quadrillion Btus (quads), describes the cumulative national energy saved over the lifetime of equipment purchased during the 30-year analysis period starting in the effective date of the policy (2022-2051).
- Net Present Value (NPV), represents the value of net monetary savings in 2016, expressed in 2015$, from equipment purchased during the 30-year analysis period starting in the effective date of the policy (2022-2051). DOE calculated the NPV as the

[c] The target levels refer to the efficiency level set for portable ACs at each TSL.

[d] The no-new-standards case for the NIA is a market-weighted average energy efficiency calculated from units at several efficiency levels.

difference between the present values of installed equipment cost and operating expenditures in the no-new-standards case and the present values of those costs in each policy case. DOE calculated operating expenses (including energy costs) for the life of the product.

17.2.2 Assumptions Regarding Non-Regulatory Policies

The effects of non-regulatory policies are by nature uncertain because they depend on program implementation, marketing efforts, and on consumers' response to a program. Because the projected effects depend on assumptions regarding the rate of consumer participation, they are subject to more uncertainty than are the impacts of mandatory standards, which DOE assumes will be met with full compliance. To increase the robustness of the analysis, DOE conducted a literature review regarding each non-regulatory policy and consulted with recognized experts to gather information on similar incentive programs that have been implemented in the United States. By studying experiences with the various types of programs, DOE sought to make credible assumptions regarding potential market impacts. Section 17.3 presents the sources DOE relied on in developing assumptions about each alternative policy and reports DOE's conclusions as they affected the assumptions that underlie the modeling of each alternative policy.

Each non-regulatory policy that DOE considered would improve the average efficiency of new portable ACs relative to their no-new-standards case efficiency scenario (which involves no new regulatory action). The analysis considered that each alternative policy would induce consumers to purchase units having the same efficiency level as required by standards (the target level), according to the minimum energy efficiency set for each TSL. As opposed to the standards case, however, the policy cases may not lead to 100 percent market penetration of units that meet the target level.

Table 17.1.2 shows the energy efficiency from the technology stipulated for portable ACs at each TSL. The bolded column indicates the proposed TSL.

Table 17.1.1 Energy Efficiency by TSL (CEER)

	TSL 1	**TSL 2**	TSL 3	TSL 4
Portable ACs	5.94	**7.13**	8.46	10.73

DOE assumed that the effects of non-regulatory policies would last from the effective date of standards—2022—through the end of the analysis period, which is 2051.

17.2.3 Policy Interactions

DOE calculated the effects of each non-regulatory policy separately from those of the other policies. In practice, some policies are most effective when implemented in combination, such as voluntary efficiency targets implemented with consumer rebates or tax credits. However, DOE attempted to make conservative assumptions to avoid double-counting policy impacts. The resulting policy impacts are therefore not additive, and the combined effect of several or all policies cannot be inferred from summing their results.

Section 17.4 presents graphs that show the market penetration estimated under each non-regulatory policy for portable ACs.

17.3 NON-REGULATORY POLICY ASSUMPTIONS

The following subsections describe DOE's analysis of the impacts of the five non-regulatory policy alternatives to the standards selected for portable ACs. (Because the alternative of "No New Regulatory Action" has no energy or economic impacts, essentially representing the NIA no-new-standards case, DOE did not perform any additional analysis for that alternative.) DOE developed estimates of the market penetration of more efficient products both with and without each of the non-regulatory policy alternatives.

17.3.1 No New Regulatory Action

The case in which no new regulatory action is taken with regard to the energy efficiency of portable ACs constitutes the no-new-standards case, as described in Chapter 10, National Impact Analysis. The no-new-standards case provides the basis of comparison for all other policies. By definition, no new regulatory action yields zero NES and an NPV of zero dollars.

17.3.2 Consumer Rebates

DOE considered the scenario in which the Federal government would provide financial incentives in the form of rebates to consumers for purchasing energy-efficient equipment. This policy provides a consumer rebate for purchasing portable ACs that operate at the same efficiency as the target level stipulated in each TSL.

17.3.2.1 Methodology

DOE based its evaluation methodology for consumer rebates on a comprehensive study of California's potential for achieving energy efficiency. The study, performed by XENERGY, Inc.,[e] summarized experiences with various utility rebate programs.[1] XENERGY's analytical method utilized graphs, or penetration curves, that estimate the market penetration of a technology based on its benefit/cost (B/C) ratio. DOE consulted with experts and reviewed other methods of estimating the effect of consumer rebate programs on the market penetration of efficient technologies. The other methods, developed after the referenced XENERGY report was published,[2, 3, 4, 5, 6, 7] used different approaches: other economic parameters (e.g., payback period), expert surveys, or model calibration based on specific utility program data rather than multi-utility data. Some models in use by energy efficiency program evaluation experts were so client-specific that generic relationships between economic parameters and consumer response could not be established.[5] DOE decided that the most appropriate available method for this RIA was the XENERGY approach of penetration curves based on B/C ratio, which incorporates lifetime operating cost savings.

XENERGY's model estimates market impacts induced by financial incentives based on the premise that two types of information diffusion drive the adoption of new technologies.

[e] XENERGY is now owned by KEMA, Inc. (www.kema.com)

Internal sources of information encourage consumers to purchase new equipment primarily through word-of-mouth from early adopters. *External sources* affect consumer purchase decisions through marketing efforts and information from outside the consumer group. Appendix 17A contains additional details on internal and external information diffusion.

XENERGY's model equation accounts for the influences of both internal and external sources of information by superimposing the two components. Combining the two mechanisms for information diffusion, XENERGY's model generates a set of penetration (or implementation) curves for a policy measure. XENERGY calibrated the curves based on participation data from utility rebate programs. The curves illustrate the increased penetration (i.e., increased market share) of efficient equipment driven by consumer response to changes in B/C ratio induced by rebate programs. The penetration curves depict various diffusion patterns based on perceived market barriers (from no-barriers to extremely-high-barriers) to consumer purchase of high-efficiency equipment. DOE adjusted the XENERGY former penetration curves based on expert advice founded on more recent utility program experience.[5, 8]

DOE modeled the effects of a consumer rebate policy for portable ACs by determining, for each TSL, the increase in market penetration of equipment meeting the target level relative to their market penetration in the no-new-standards case. It used the interpolation method presented in Blum et al (2011)[9] to create customized penetration curves based on relationships between actual no-new-standards case market penetrations and actual B/C ratios. To inform its estimate of B/C ratios provided by a rebate program DOE performed a thorough nationwide search for existing rebate programs for portable ACs. It searched for data on utility or agency rebates throughout the nation for this equipment, to calibrate the customized penetration curve it developed for the sector covered by this RIA so it can best reflect the market barrier level that consumer rebates for portable ACs would face. Section 17.3.2.2 shows the resulting interpolated curve used in the analysis.

17.3.2.2 Analysis

DOE estimated the effect of increasing the B/C ratio of portable ACs via a rebate that would reduce the increased installed cost of units that meet the target efficiency levels compared to units meeting the baseline efficiency level.[f] During its search for existing rebate programs for portable ACs in the third quarter of 2015 DOE found only one program that offered an incentive for efficient portable ACs.[g] DOE therefore relied on that rebate program to assume a rebate amount that would remain in effect at the same level throughout the forecast period (2022-2051).

DOE first calculated the B/C ratio of a portable AC without a rebate using the difference in total installed costs (C) and lifetime operating cost savings[h] (B) between a unit meeting the target level and a baseline unit. It then calculated the B/C ratio given a rebate for the unit meeting the target efficiency level. Because the rebate reduced the incremental cost, the unit

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[f] The baseline technology is defined in the engineering analysis, Chapter 5, as the technology that represents the basic characteristics of portable ACs. A baseline unit typically is one that just meets current Federal energy conservation standards and provides basic consumer utility.

[g] The Western Iowa Power Cooperative offers a $25 rebate (per unit) for PACs that "meet or exceed Energy Star specification." (http://www.wipco.com/aspx/general/clientpage.aspx?pageid=897&n=1389&n1=1756&n2=1762)

[h] The cash flow of the operating cost savings is discounted to the purchase year using a 7 percent discount rate.

receiving the rebate had a larger B/C ratio. Table 17.3.1 shows the effect of consumer rebates for each TSL on the B/C ratio of portable ACs shipped in the first year of the analysis period.

Table 17.3.1 Benefit/Cost Ratios Without and With Rebates

	TSL 1	**TSL 2**	TSL 3	TSL 4
Portable Air Conditioners				
B/C Ratio Without Rebate	3.4	**2.8**	2.3	2.5
Rebate Amount (2015$)	25.00	**25.00**	25.00	25.00
B/C Ratio With Rebate	28.2	**4.2**	2.8	3.0
Estimated Market Barriers	Low	**Low-Mod**	Mod-High	High

* Low-Mod: Low-to-Moderate market barriers.

DOE used the B/C ratio along with the customized penetration curve shown in Figure 17.3.1 to estimate the percentage of consumers who would purchase portables ACs that meet the target levels both with and without a rebate incentive. The estimated level of market barriers corresponding to the penetration curve DOE calculated to represent the market behavior for portable ACs at the selected TSL are indicated (highlighted) in Table 17.3.1. DOE assumed the estimated market barriers would remain the same over the whole analysis period.

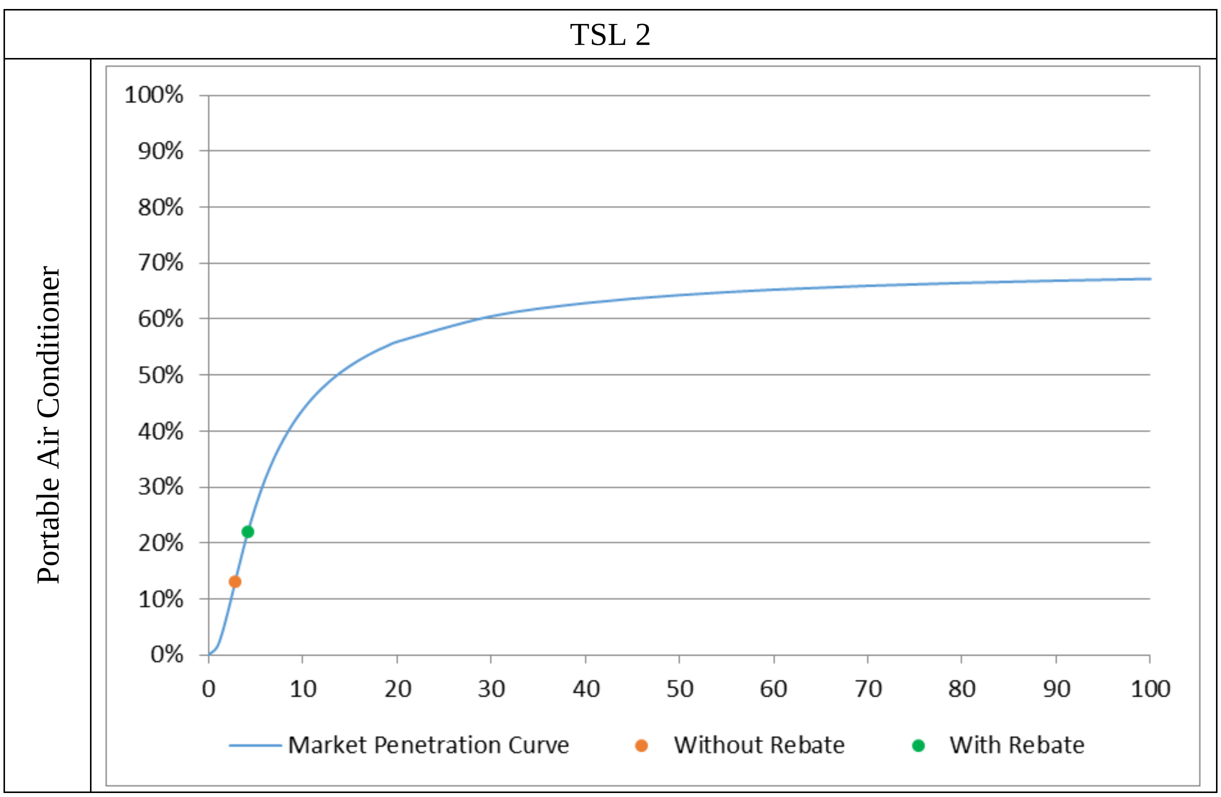

Figure 17.3.1 Market Penetration Curves for Portable Air Conditioners

DOE next estimated the percent increase represented by the change in penetration rate shown on the corresponding penetration curve. It then added this percent increase to the market share of units that meet the target level in the no-new-standards case to obtain the market share of units that meet the target level in the rebate policy case.

Table 17.3.2 summarizes DOE's assumptions for portable ACs regarding the market penetration of products in 2022 that meet the target level at each TSL given a consumer rebate.

Table 17.3.2 Market Penetrations in 2022 Attributable to Consumer Rebates

	TSL 1	**TSL 2**	TSL 3	TSL 4
Portable Air Conditioners				
Base-Case Market Share	47.8%	**13.0%**	2.2%	0.0%
Policy Case Market Share	74.0%	**22.1%**	3.3%	0.6%
Increased Market Share	26.2%	**9.1%**	1.1%	0.6%

DOE used the resulting annual increases in market shares as inputs to represent the rebate policy case scenario in its NIA-RIA model. Appendix 17A shows the annual market share increases due to this policy for the whole forecast period. Section 17.4 presents the resulting market penetration trends for the policy case of consumer rebates for portable ACs.

17.3.3 Consumer Tax Credits

DOE estimated the effects of tax credits on consumer purchases based on its previous analysis of consumer participation in tax credits. DOE supported its approach using data from Oregon State's tax credit program for energy-efficient appliances. DOE also incorporated previous research that disaggregated the effect of rebates and tax credits into a *direct price effect*, which derives from the savings in purchase price, and an *announcement effect*, which is independent of the amount of the incentive.[10, 11] The announcement effect derives from the credibility that a technology receives from being included in an incentive program, as well as changes in product marketing and modifications in markup and pricing. DOE assumed that the rebate and consumer tax credit policies would encompass both direct price effects and announcement effects, and that half the increase in market penetration associated with either policy would be due to the direct price effect and half to the announcement effect.

In estimating the effects of a tax credit on purchases of consumer products that meet new efficiency standards, DOE assumed the amount of the tax credit would be the same as the corresponding rebate amount discussed above.

DOE estimated that fewer consumers would participate in a tax credit program than would take advantage of a rebate. Research has shown that the delay required for a consumer to receive a tax credit, plus the added time and cost in preparing the tax return, make a tax credit incentive less effective than a rebate received at the time of purchase. Based on previous analyses, DOE assumed that only 60 percent of the consumers who would take advantage of a rebate would take advantage of a tax credit.[12]

In preparing its assumptions to estimate the effects of tax credits on consumer purchases of portable ACs, DOE also reviewed other tax credit programs that have been offered at both the Federal and State levels for energy-efficient appliances.

The Energy Policy Act of 2005 (EPACT 2005) included Federal tax credits for consumers who purchase energy-efficient products.[13] Those tax credits were in effect in 2006 and 2007, expired in 2008, were reinstated for 2009–2010 by the American Recovery and Reinvestment Act of 2009 (ARRA), extended by Congress for 2011 with some modifications, and expired at the end of 2011.[14, 15] The American Taxpayer Relief Act of 2012 extended, with some modifications, residential tax credits for air conditioners, heat pumps, furnaces, and water heaters placed in service between January 1, 2012 and December 31, 2013.[16] DOE reviewed Internal Revenue Service data on the numbers of taxpayers who claimed the tax credits during tax years 2006 and 2007. DOE also reviewed data from an earlier Federal energy conservation tax credit program in place in the 1980s. However, DOE did not find data specific enough to portable ACs to warrant adjusting its analysis method for the Consumer Tax Credits policy case. Appendix 17A contains more information on Federal consumer tax credits.

DOE also reviewed its previous analysis of Oregon's tax credits for clothes washers to provide support for its assumptions.[17] In that previous analysis, DOE compared the market shares of ultra-high efficiency (UHE) residential clothes washers in Oregon, which offered both State tax credits and utility rebates, with those in Washington State, which offered only utility rebates during the same period. Based on this analysis, DOE estimated that in Oregon the impact of tax credits was 62 percent of the impact of rebates for UHE clothes washers having equivalent efficiency. This finding supports its original assumption that participation in a tax credit program would be about 60 percent of participation in a rebate program. Additional discussion of State tax credits for Oregon and other states is in Appendix 17A.

DOE applied the assumed 60 percent participation described above to the increase in penetration rates estimated for the rebate policy to estimate penetration rates attributable to consumer tax credits. In doing so, DOE incorporated the assumptions for consumer response to financial incentives from the customized penetration curves it developed for portable ACs (See Figure 17.3.1).

Table 17.3.3 summarizes DOE's assumptions for portable ACs regarding the market penetration of products in 2022 that meet the target level at each TSL given a consumer tax credit.

Table 17.3.3 Market Penetrations in 2022 Attributable to Consumer Tax Credits

	TSL 1	**TSL 2**	TSL 3	TSL 4
Portable Air Conditioners				
Base-Case Market Share	47.8%	**13.0%**	2.2%	0.0%
Policy Case Market Share	63.5%	**18.5%**	2.9%	0.3%
Increased Market Share	15.7%	**5.5%**	0.7%	0.3%

The increased market shares attributable to consumer tax credits shown in Table 17.3.3 were used as inputs in the NIA-RIA model. Appendix 17A shows the annual market share increases due to this policy for the whole forecast period. Section 17.4 presents the resulting market penetration trends for the policy case of consumer tax credits for portable ACs that meet the efficiency level for the selected TSL.

17.3.4 Manufacturer Tax Credits

To analyze the potential effects of a policy that offers tax credits to manufacturers that produce portable ACs that meet the target efficiency level at each TSL, DOE assumed that a manufacturer tax credit would lower the consumer's purchase cost by an amount equivalent to that provided by the consumer rebates or tax credits described above. DOE further assumed that manufacturers would pass on some of their reduced costs to consumers, causing a direct price effect. DOE assumed that no announcement effect would occur, because the program would not be visible to consumers.[i] Because the direct price effect is approximately equivalent to the announcement effect,[10] DOE estimated that a manufacturer tax credit would induce half the number of consumers assumed to take advantage of a consumer tax credit to purchase more efficient products. Thus the assumed participation rate is equal to 30 percent of the number of consumers who would participate in a rebate program.

DOE attempted to investigate manufacturer response to the Energy Efficient Appliance Credits for manufacturers mandated by EPACT 2005.[18] Those manufacturer tax credits have been in effect for dishwashers, clothes washers and refrigerators produced beginning in 2009. DOE was unable to locate data from the Internal Revenue Service or other sources on manufacturer response to the Federal credits. Appendix 17A presents details on Federal manufacturer tax credits.

DOE applied the assumption of 30 percent participation to the increase in penetration rates predicted for the rebate policy to estimate the effects of a manufacturer tax credit policy. In doing so, DOE incorporated the assumptions for consumer response to financial incentives from the customized penetration curves it developed for portable ACs. (See Figure 17.3.1).

Table 17.3.4 summarizes DOE's assumptions for portable ACs regarding the market penetration of products in 2022 that meet the target level at each TSL given a manufacturer tax credit.

Table 17.3.4 Market Penetrations in 2022 Attributable to Manufacturer Tax Credits

	TSL 1	**TSL 2**	TSL 3	TSL 4
Portable Air Conditioners				
Base-Case Market Share	47.8%	**13.0%**	2.2%	0.0%
Policy Case Market Share	55.7%	**15.7%**	2.5%	0.2%
Increased Market Share	7.9%	**2.7%**	0.3%	0.2%

The increased market shares attributable to a manufacturer tax credit shown in Table 17.3.4 were used as inputs in the NIA-RIA model. Appendix 17A shows the annual market share increases due to this policy for the whole forecast period. Section 17.4 presents the resulting market penetration trends for the policy case of manufacturer tax credits for portable ACs.

[i] Note that this is a conservative assumption, since it is possible that manufacturers or utility/agency efficiency programs might promote the models for which manufacturers increase production due to the tax credits, which in turn might induce some announcement effect. However, DOE found no data on such programs on which to base an estimate of the magnitude of this possible announcement effect on consumer behavior.

17.3.5 Voluntary Energy Efficiency Targets

DOE assumed that voluntary energy efficiency targets would lead manufacturers of portable ACs to gradually stop producing units that operate below the efficiency level set for each TSL. DOE assumed that the impetus for phasing out production of low-efficiency units would be a program with impacts similar to those of the ENERGY STAR labeling program conducted by the Environmental Protection Agency (EPA) and DOE in conjunction with industry partners. The ENERGY STAR program specifies the minimum energy efficiencies that various products must have to receive the ENERGY STAR label. ENERGY STAR encourages consumers to purchase efficient products via marketing that promotes consumer label recognition, various incentive programs that adopt the ENERGY STAR specifications, and manufacturers' promotion of their qualifying appliances. ENERGY STAR projects market penetration of compliant appliances and estimates the percentage of sales of compliant appliances that are attributable to the ENERGY STAR program.

Researchers have analyzed the ENERGY STAR program's effects on sales of several consumer products. Program efforts generally involve a combination of information dissemination and utility or agency rebates. The analyses have been based on State-specific data on percentages of shipments of various appliances that meet ENERGY STAR specifications. The analyses generally have concluded that the market penetration of ENERGY STAR-qualifying appliances is higher in regions or States where ancillary promotional programs have been active.[19, 20, 21]

DOE believes that informational incentive programs – like ENERGY STAR, or any other labeling program sponsored by industry or other organizations – are likely to reduce the market barriers to more efficient products over time. During the rebate analysis, when assessing the B/C ratio and market penetration in the no-new-standards case for portable ACs, DOE observed that the level of market barriers for more efficient portable ACs are in the range of moderate to high barriers, depending on the TSL. DOE estimates that voluntary energy efficiency targets could reduce these barriers to lower levels over 10 years. Table 17.3.5 presents the levels of market barriers DOE estimated for portable ACs in the no-new-standards case and in the policy case of voluntary energy efficiency targets. DOE followed the methodology presented by Blum et al (2011)[9] to evaluate the effects that such a reduction in market barriers would have on the market penetration of efficient portable ACs.[j] The methodology relies on interpolated market penetration curves to calculate – given a B/C ratio – how the market penetration of more efficient units increases as the market barrier level to those units decreases.

[j] For the calculation of B/C ratios DOE discounted the cash flow of the operating cost savings to the purchase year using a 7 percent discount rate.

Table 17.3.5 Market Barriers Changes Attributable to Voluntary Energy Efficiency Targets

	No-New-Standards Case	Voluntary Energy Efficiency Targets
TSL 1	Low	No
TSL 2	**Low-Moderate**	**Low**
TSL 3	Moderate-High	Moderate
TSL 4	High	Moderate-High

Table 17.3.6 summarizes DOE's assumptions for portable ACs regarding the market penetration of products in 2022 that meet the target level at each TSL given voluntary energy efficiency targets. Table 17.3.7 expands on Table 17.3.6 to include, for the selected TSL, DOE's assumptions regarding the market penetration of units in selected years.

Table 17.3.6 Market Penetrations in 2022 Attributable to Voluntary Energy Efficiency Targets

	TSL 1	**TSL 2**	TSL 3	TSL 4
Portable Air Conditioners				
Base-Case Market Share	47.8%	**13.0%**	2.2%	0.0%
Policy Case Market Share	50.0%	**19.5%**	2.7%	0.5%
Increased Market Share	2.2%	**6.5%**	0.5%	0.5%

Table 17.3.7 Market Penetrations in Selected Years Attributable to Voluntary Energy Efficiency Targets for TSL 2

	2022	2031	2051
Portable Air Conditioners			
Base-Case Market Share	13.0%	13.0%	23.1%
Policy Case Market Share	19.5%	48.2%	55.5%
Increased Market Share	6.5%	35.2%	32.4%

The increased market shares attributable to voluntary energy efficiency targets shown in Table 17.3.6 were used as inputs in the NIA-RIA model. Appendix 17A shows the annual market share increases due to this policy for the whole forecast period. Section 17.4 presents the resulting market penetration trends for the policy case of voluntary energy efficiency targets for portable ACs that meet the efficiency level for the selected TSL. Because of the decrease in the market barriers level over the first 10 years of the analysis period, the market penetration of more efficient portable ACs significantly increases over that period. For the remaining 20 years of the forecast period the increase in market penetration keeps growing because, even though the market barriers level remains constant (at 2031 level), the increase in energy prices leads to increasing B/C ratios and eventually to higher market penetrations.

17.3.6 Bulk Government Purchases

Bulk government purchases can lead to Federal, State, and local governments purchasing large quantities of products that meet a certain, target efficiency level. Combining the market demands of multiple public sectors can provide a market signal to manufacturers and vendors that some of their largest customers seek products that meet an efficiency target at favorable prices. Such a program also can induce “market pull,” whereby manufacturers and vendors would achieve economies of scale for high efficiency products.

Most of the previous bulk government purchase (procurement) initiatives at the Federal, State, and municipal levels have not tracked data on numbers of purchases or degree of compliance with procurement specifications. In many cases, procurement programs are decentralized, being part of larger State or regional initiatives. DOE based its assumptions regarding the effects of this policy on studies the Federal Energy Management Program (FEMP) performed regarding the savings potential of its procurement specifications for appliances and other products. FEMP, however, does not track purchasing data, because of the complex range of purchasing systems, large number of vendors, and so on. States, counties, and municipalities have demonstrated increasing interest and activity in “green purchasing." Although many of the programs target office equipment, the growing infrastructure for developing and applying efficient purchasing specifications indicates that bulk government purchase programs are feasible.[22, 23]

DOE assumed that government agencies would administer bulk purchasing programs for portable ACs. At the federal level, this type of program could lead to FEMP procurement guidelines for portable ACs, which would refer to the target level of the selected TSL as the minimum efficiency level of portable ACs to be purchased. DOE reviewed its own previous research on the potential for market transformation through bulk government purchases. Its major study analyzed several scenarios based on the assumption that 20 percent of Federal equipment purchases in 2000 already incorporated energy efficiency requirements based on FEMP guidelines. One scenario in the DOE report showed energy efficient purchasing ramping up during 10 years from 20 percent to 80 percent of all Federal purchases.[24] Based on this study, DOE estimated that a bulk government purchase program instituted within a 10-year period would result in at least 80 percent of government-purchased portable ACs meeting the target efficiency level.

DOE assumed that bulk government purchases would affect a subset of housing units for which government agencies purchased or influenced the purchase of portable ACs. According to the 2009 Residential Energy Consumption Survey (RECS 2009), about 7.2 percent of the U.S. households with a room with no more than 1,000 square feet cooled by a room AC with capacity below 14,000 Btu/hr[k] are housing units in public housing authority.[25] DOE therefore estimated that 7.2 percent of the U.S. housing units meeting those criteria constitute the population to which this policy would apply.

[k] These are the same criteria DOE used to select the RECS households that comprise the sample of households used in the LCC analysis of PACs.

DOE estimated that starting in 2022, each year of a bulk government purchase policy would result in an increasing percent of shipments of government-purchased units beyond the no-new-standards case that would meet the target efficiency level. DOE estimated that within 10 years (by 2031) bulk government purchasing programs would result in 80 percent[1] of the market for portable ACs used in publicly owned housing meeting the target level. DOE modeled the bulk government purchase program assuming that the market share for portable ACs achieved in 2031 would be at least maintained throughout the rest of the forecast period.

Table 17.3.8 summarizes DOE's assumptions for portable ACs regarding the market penetration of products in 2022 that meet the target level at each TSL given bulk government purchases.

Table 17.3.8 Market Penetrations in 2022 Attributable to Bulk Government Purchases

	TSL 1	**TSL 2**	TSL 3	TSL 4
Portable Air Conditioners				
Base-Case Market Share	47.8%	**13.0%**	2.2%	0.0%
Policy Case Market Share	48.0%	**13.5%**	2.8%	0.6%
Increased Market Share	0.2%	**0.5%**	0.6%	0.6%

The increased market shares attributable to bulk government purchases shown in Table 17.3.8 were used as inputs in the NIA-RIA model. Appendix 17A shows the annual market share increases due to this policy for the whole forecast period. Section 17.4 presents the resulting market penetration trends for the policy case of bulk government purchases for portable ACs. Market penetrations increase over the first 10 years of the forecast period, and steady for the rest of the analysis period.

17.4 IMPACTS OF NON-REGULATORY ALTERNATIVES

Figure 17.4.1 shows the effects of each non-regulatory policy alternative on the market penetration of more efficient portable ACs. Relative to the no-new-standards case, the alternative policy cases increase the market shares that meet the target level. Recall the selected standards (not shown in the figures) would result in a 100-percent market penetration of products that meet the more efficient technology.

[1] The 80 percent target to be achieved within 10 years may not be reached, as it is constrained by the market share below the target level in the no-new-standards case scenario.

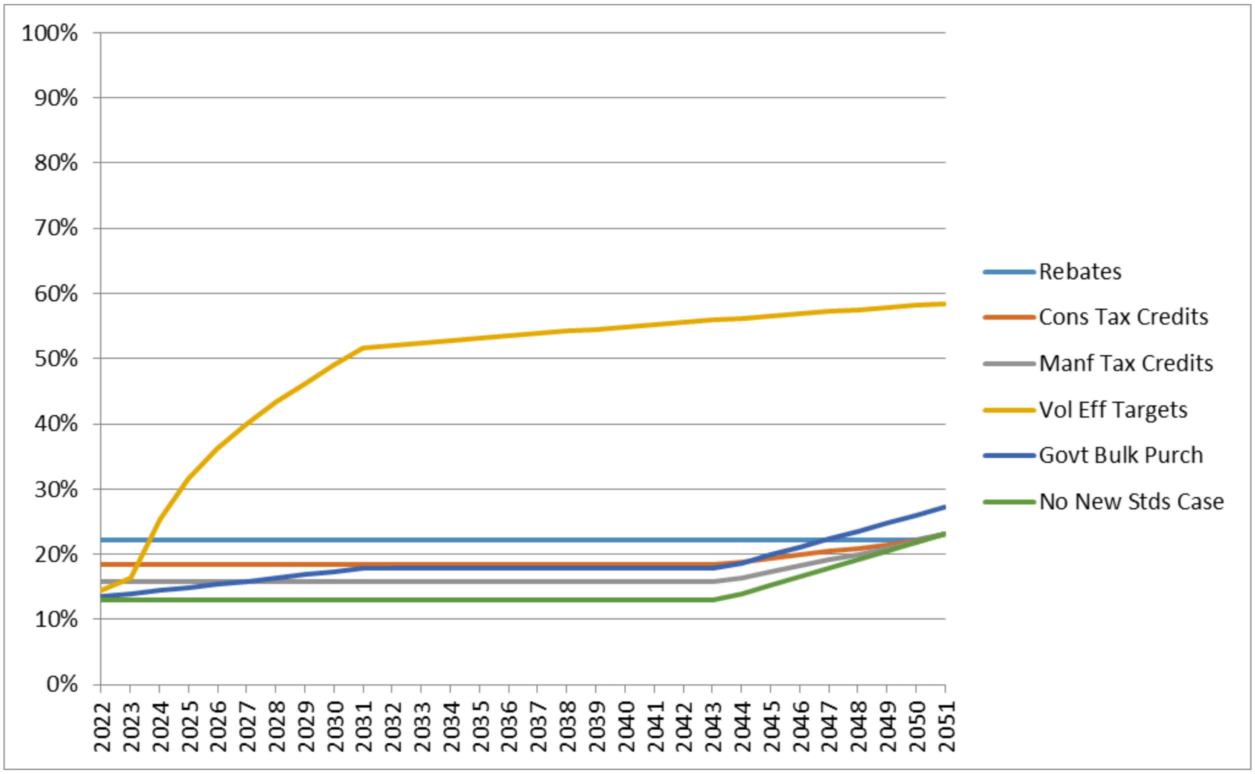

Figure 17.4.1 Market Penetration of Efficient Portable Air Conditioners (TSL 2)

Table 17.4.1 shows the national energy savings and net present value for the five non-regulatory policy alternatives analyzed in detail for portable ACs. The target level for each policy corresponds to the same efficient technology selected for standards in TSL 2. The case in which no regulatory action is taken with regard to portable ACs constitutes the no-new-standards case (or "No New Regulatory Action" scenario), in which NES and NPV are zero by definition. For comparison, the tables include the impacts of the selected standards. Energy savings are given in quadrillion British thermal units (quads) of primary energy savings.[m] The NPVs shown in Table 17.4.1 are based on two discount rates, 7 percent and 3 percent.

The policy with the highest projected cumulative energy savings is consumer rebates, followed by tax credits, and voluntary energy efficiency targets. Bulk government purchasing has the lowest cumulative energy savings. Overall, the energy saving benefits from the alternative policies range from 1.0 percent to 10.8 percent of the benefits from the selected standards, when the latter is calculated as described in footnote ‘a.’

[m] For the alternative policies whose market penetration depends on B/C ratio, the energy savings in Table 17.4.1 correspond to the case where the cash flow of the operating cost savings was discounted to the purchase year using a 7 percent discount rate.

Table 17.4.1 Impacts of Non-Regulatory Policy Alternatives (TSL 2)

Policy Alternative	**Energy Savings*** *quads*		**Net Present Value*** *million 2015$*	
			7% Disc Rate	3% Disc Rate
Consumer Rebates	0.039	(10.8%)**	96.0	232.7
Consumer Tax Credits	0.023	(6.5%)	57.6	139.6
Manufacturer Tax Credits	0.012	(3.2%)	28.8	69.8
Voluntary Energy Efficiency Targets	0.013	(3.5%)	104.5	72.2
Bulk Government Purchases	0.004	(1.0%)	8.3	20.8
Selected Standards***	0.362	(100.0%)	894.3	2,161.2

* For products shipped 2022-2051.
**The percentages show how the energy savings from each policy alternative compare to the primary energy savings from the selected standards (represented in the table as 100%).
*** Calculated as described in footnote 'a.'

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APPENDIX 7A. CORRELATING WEATHER STATION DATA TO SAMPLE BUILDINGS

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APPENDIX 7A. CORRELATING WEATHER STATION DATA TO SAMPLE BUILDINGS

7A.1 INTRODUCTION

The Energy Information Administration's (EIA's) 2009 *Residential Energy Consumption Survey* (RECS 2009)[1] and the EIA's 2012 *Commercial Building Energy Consumption Survey* (CBECS 2012)[2] provide annual data on heating and cooling degree-days for the buildings in their samples, which the U.S. Department of Energy (DOE) utilized for its energy use analysis for portable air conditioners (ACs); (see chapter 7). Neither EIA survey, however, provides data regarding other weather parameters needed for the energy use analysis, such as outdoor design temperature (ODT), monthly (rather than annual) heating degree-days (HDDs) and cooling degree-days (CDD), and average outdoor temperature. DOE uses CDDs to estimate hours of operation for portable ACs and electricity prices weighted to summer months. Monthly energy price data are available for use in the analysis. Monthly energy use is combined with monthly energy prices to determine the monthly operating cost.

7A.2 METHODOLOGY

To derive the additional weather data needed for analyzing the energy use of portable ACs in each building in its sample, DOE assigned a physical location to each RECS household and CBECS building.[a] The method comprised the following steps.

1. DOE assembled monthly weather data from 360 National Oceanic and Atmospheric Administration (NOAA) weather stations that provide heating and cooling degree-days at a base temperature 65 ^{o}F for 2009 (for the RECS sample) and for 2012 (for the CBECS sample).[3] The 2009 and 2012 heating and cooling degree-days match the period used to determine the degree-days in RECS 2009 and in CBECS 2012, respectively. DOE selected only those weather stations for which NOAA provided HDDs and CDDs, which reduced the number of weather stations used in the matching process to 321.
2. DOE obtained ODT data from the 1993 *ASHRAE Handbook.*[4]
3. RECS and CBECS report both HDD and CDD to a base temperature 65 ^{o}F for each building record. DOE assigned each building to one of the 339 weather stations by calculating which weather station (within the appropriate region) was closest based on the best linear least-squares fit of the RECS or CBECS data to the weather data. The following equation calculates the U.S. weather station closest to (or having the minimum distance from) a given RECS or CBECS building.

$$"\,Distance" = \sqrt{(HDD_2 - HDD_1)^2 + (CDD_2 - CDD_1)^2}$$

[a] To maintain survey confidentiality, the EIA slightly altered heating and cooling degree-day values to mask the exact geographic location of each surveyed housing unit and business enterprise.

Where:

HDD_1 = heating degree-days from U.S. weather data,
HDD_2 = heating degree-days from RECS/CBECS data,
CDD_1 = cooling degree-days from U.S. weather data, and
CDD_2 = cooling degree-days from RECS/CBECS data.

7A.3 RESULTS

Table 7A.3.1 shows the results of correlating the NOAA weather data with all RECS and CBECS locations used in DOE's energy analysis. Some U.S. weather station data match with several RECS/CBECS records. The number of RECS or CBECS buildings that were matched to a specific weather station is indicated in the column "Count." Table 7A.3.1 shows the data matches, including the heating ODT for the weather stations, for 321 weather stations.

Table 7A.3.1 Weather Station Data

Station Location		Code	RECS 2009			CBECS 2012			Heating ODT
State	City		HDD	CDD	Count	HDD	CDD	Count	
AK	Anchorage	ANC	10335	2	8	4822	0	0	-18
AK	Bethel	BET	12530	0	1	5906	0	3	-24
AK	Cold Bay	CDB	9668	0	2	-	-	0	10
AK	Cordova	CDV	9511	0	2	4692	0	1	1
AK	Homer	HOM	9817	0	10	4607	0	2	4
AK	Juneau	JNU	8536	6	2	4189	1	1	1
AK	Kenai	ENA	10423	0	1	5339	0	2	-14
AK	Ketchikan	KTN	7359	68	2	3129	4	0	20
AK	King Salmon	AKN	11088	0	1	149	0	0	-19
AK	Kodiak	ADQ	8903	0	1	3996	0	0	13
AK	Sitka	SIT	-	-	-	3330	0	1	-
AK	St Paul Island	SNP	11420	0	4	66	0	0	3
AK	Talkeetna	TKA	-	-	-	5115	3	2	-
AK	Valdez	VWS	7074	23	2	3294	19	1	7
AK	Yakutat	YAK	9295	1	1	4338	0	0	2
AL	Birmingham	BHM	2605	1958	25	968	2247	0	21
AL	Huntsville	HSV	2982	1863	26	1112	2098	0	16
AL	Mobile	MOB	1594	2681	59	599	2709	0	29
AL	Montgomery	MGM	2137	2367	3	726	2601	0	25
AL	Muscle Shoals	MSL	2948	1773	12	-63	-2	0	21
AL	Tuscaloosa	TCL	2349	2136	10	906	2412	0	23

Station Location		Code	RECS 2009			CBECS 2012			Heating ODT
State	City		HDD	CDD	Count	HDD	CDD	Count	
AR	Fayetteville	FYV	3957	1185	48	1512	1798	0	12
AR	Fort Smith	FSM	3174	1906	3	-37	6	0	17
AR	Little Rock	LIT	2946	1943	27	-71	8	0	20
AR	Texarkana	TXK	2573	2006	10	893	2820	2	23
AZ	Douglas	DUG	2160	2204	27	875	2074	0	31
AZ	Flagstaff	FLG	6741	176	2	2450	164	0	4
AZ	Phoenix	PHX	807	4942	26	276	5078	1	34
AZ	Tucson	TUS	1268	3626	85	419	3607	6	32
AZ	Winslow	INW	4233	1395	4	1640	1464	0	10
AZ	Yuma	NYL	671	4757	82	234	4943	0	39
CA	Bakersfield	BFL	1873	2644	177	694	2590	0	32
CA	Blythe	BLH	968	4580	8	370	4639	1	33
CA	Eureka	EKA	5137	2	2	2372	10	0	33
CA	Fresno	FAT	2239	2390	50	658	2657	1	30
CA	Los Angeles	LAX	1294	569	117	-49	0	0	43
CA	Mt Shasta	MHS	5474	433	5	131	0	0	21
CA	Paso Robles	PRB	2676	1095	144	-56	0	0	29
CA	Red Bluff	RBL	2452	2122	70	51	0	0	32
CA	Redding	RDD	2750	2086	63	1052	1991	8	31
CA	Sacramento	SAC	2531	1357	30	887	1338	2	32
CA	San Diego	SAN	1050	813	540	-64	0	0	44
CA	San Francisco	SFO	2614	220	278	-78	0	0	38
CA	Stockton	SCK	2451	1468	122	887	1401	15	30
CO	Alamosa	ALS	8229	49	27	3695	132	13	-16
CO	Colorado Spring	COS	6301	356	90	-	-	0	2
CO	Denver	DEN	5988	541	69	2218	1248	0	1
CO	Eagle	EGE	7593	124	15	2841	344	0	-7
CO	Pueblo	PUB	5427	818	77	2201	1351	0	0
CO	Trinidad	TAD	5323	719	17	2028	1182	0	3
CT	Bridgeport	BDR	5484	669	57	1699	1079	0	9
CT	Hartford	BDL	6072	610	94	2041	962	0	7
DC	Washington	DCA	4124	1427	39	1320	1969	3	17
DE	Wilmington	ILG	4789	1031	14	1656	1378	29	14
FL	Daytona Beach	DAB	753	3321	99	59	-16	0	35

Station Location		Code	RECS 2009			CBECS 2012			Heating ODT
State	City		HDD	CDD	Count	HDD	CDD	Count	
FL	Fort Myers	FMY	294	4151	63	20	-29	0	44
FL	Ft Lauderdale	FLL	118	4839	30	19	-34	0	46
FL	Gainesville	GNV	1181	2789	118	398	2989	0	31
FL	Jacksonville	JAX	1339	2772	60	475	2736	0	32
FL	Key West	EYW	108	5017	11	7	-11	0	57
FL	Melbourne	MLB	526	3718	80	150	3496	0	43
FL	Miami	MIA	109	4914	2	17	4665	8	47
FL	Orlando	MCO	588	3620	103	169	3572	1	38
FL	Pensacola	PNS	1443	2729	44	443	3051	0	29
FL	Tallahassee	TLH	1574	2802	31	540	2956	1	30
FL	Tampa	TPA	496	3876	112	130	3962	10	40
FL	Vero Beach	VRB	477	3604	26	35	-66	0	43
FL	West Palm Beach	PBI	239	4314	169	-26	57	0	45
GA	Albany	ABY	1767	2686	5	656	2792	2	29
GA	Athens	AHN	2882	1903	253	989	1946	0	22
GA	Atlanta	ATL	2813	1838	87	886	2224	0	22
GA	Augusta	AGS	2475	2068	55	933	2142	0	23
GA	Brunswick	SSI	-	-	-	-	-	0	-
GA	Columbus	CSG	2183	2194	2	666	2643	0	24
GA	Macon	MCN	2288	2133	17	834	2283	0	25
GA	Savannah	SAV	1739	2497	21	628	2661	0	27
GA	Waycross	AYS				572	2769	0	
HI	Hilo-Hawaii	ITO	0	3050	14	0	3209	0	62
HI	Honolulu-Oahu	HNL	0	4816	14	0	4540	0	63
HI	Kahului-Maui	OGG	1	3746	21	0	3968	0	61
HI	Lihue-Kauai	LIH	2	3611	5	0	4164	0	62
IA	Burlington	BRL	5687	810	24	2187	1337	0	-3
IA	Cedar Rapids	CID	6977	419	15	65	0	0	-5
IA	Des Moines	DSM	6124	898	33	65	0	0	-5
IA	Dubuque	DBQ	7204	345	1	2670	933	0	-7
IA	Mason City	MCW	7856	338	15	65	0	0	-11
IA	Ottumwa	OTM	6317	588	43	2302	1245	0	-4
IA	Sioux City	SUX	6913	678	75	31	0	0	-7
IA	Waterloo	ALO	7253	448	58	2679	1085	0	-10

Station Location		Code	RECS 2009			CBECS 2012			Heating ODT
State	City		HDD	CDD	Count	HDD	CDD	Count	
ID	Boise	BOI	5592	1199	9	1862	1276	0	10
ID	Burley	BYI	6697	397	1	2334	573	0	2
ID	Idaho Falls	IDA	-	-	-	-147	0	0	-
ID	Lewiston	LWS	5386	1008	3	1799	1051	0	6
ID	Pocatello	PIH	7463	321	17	2531	567	0	-1
IL	Chicago	ORD	6417	585	40	2132	1326	0	0
IL	Moline	MLI	6250	636	35	2335	1210	0	-4
IL	Peoria	PIA	5841	752	62	2142	1377	0	-4
IL	Quincy	UIN	5460	849	12	2041	1581	0	3
IL	Rockford	RFD	6738	433	58	2329	1229	3	-4
IL	Springfield	SPI	5234	933	41	1872	1541	0	2
IN	Evansville	EVV	4397	1283	13	1655	1842	0	9
IN	Fort Wayne	FWA	6077	601	41	-34	0	0	1
IN	Indianapolis	IND	5203	953	22	1990	1523	0	2
IN	South Bend	SBN	6426	545	54	-41	0	0	1
IN	West Lafayette	LAF	5436	826	32	17	0	0	3
KS	Concordia	CNK	5558	1094	18	2017	1643	0	3
KS	Dodge City	DDC	4975	1257	27	-90	0	0	5
KS	Garden City	GCK	5014	1154	31	-122	0	0	4
KS	Goodland	GLD	6016	722	11	2247	1361	0	0
KS	Russell	RSL	5298	1194	46	1957	1861	0	4
KS	Salina	SLN	-	-	-	1772	2063	0	-
KS	Topeka	TOP	4968	1195	9	1768	1979	0	4
KS	Wichita	ICT	4552	1506	68	1562	2309	0	7
KY	Bowling Green	BWG	3808	1407	52	-66	3	0	10
KY	Jackson	JKL	4237	984	15	1619	1311	0	14
KY	Lexington	LEX	4670	1020	40	1786	1345	14	8
KY	Louisville	SDF	4155	1316	29	1496	1940	0	10
KY	Paducah	PAH	4198	1239	39	1639	1681	0	12
LA	Baton Rouge	BTR	1404	2985	24	-59	1	0	29
LA	Lafayette	LFT	1296	3086	3	489	3138	0	30
LA	Lake Charles	LCH	1380	2980	10	-73	31	0	31
LA	Monroe	MLU	2118	2547	11	804	2839	0	25
LA	New Orleans	MSY	1156	3221	35	-31	5	0	33
LA	Shreveport	SHV	-	-	-	752	2953	0	-

Station Location		Code	RECS 2009			CBECS 2012			Heating ODT
State	City		HDD	CDD	Count	HDD	CDD	Count	
MA	Boston	BOS	5694	581	243	1830	903	0	9
MA	Worcester	ORH	6699	370	258	2217	675	0	4
MD	Baltimore	BWI	4745	1088	34	1607	1564	25	13
MD	Salisbury	SBY	4345	1149	19	1252	1850	0	16
ME	Augusta	AUG	7487	276	18	2582	476	0	-3
ME	Bangor	BGR	8098	246	19	2813	384	0	-6
ME	Caribou	CAR	9415	149	13	3197	268	39	-13
ME	Houlton	HUL	9316	178	24	3196	271	12	-13
ME	Portland	PWM	7107	294	108	2359	486	0	-1
MI	Alpena	APN	-	-	-	2794	466	0	-
MI	Detroit	DTW	6224	588	81	2131	1145	0	6
MI	Flint	FNT	7068	328	40	2376	860	0	1
MI	Grand Rapids	GRR	6580	444	35	-3	0	0	5
MI	Houghton Lake	HTL	-	-	-	34	0	0	-
MI	Jackson	JXN	6585	420	11	2403	865	0	5
MI	Lansing	LAN	6830	372	36	2389	928	0	1
MI	Marquette	MQT	-	-	-	-	-	0	-
MI	Muskegon	MKG	6719	371	38	2214	907	0	6
MI	Saginaw	MBS	6960	350	19	2349	856	0	4
MI	Sault St Marie	SSM	-	-	-	-	-	0	-
MI	Traverse City	TVC	7695	253	14	-7	0	0	1
MN	Alexandria	AXN	8922	340	8	3323	709	0	-16
MN	Duluth	DLH	9517	118	10	3464	412	0	-16
MN	Hibbing	HIB	10159	64	4	3966	197	31	-20
MN	Int’l Falls	INL	10648	72	8	227	0	0	-25
MN	Minneapolis	MSP	7613	646	48	2765	1133	0	-12
MN	Rochester	RST	7884	321	9	2716	890	0	-12
MN	Saint Cloud	STC	8704	301	74	219	0	0	-11
MO	Columbia	COU	4999	958	125	1759	1897	10	4
MO	Joplin	JLN	4216	1382	98	1491	2117	9	10
MO	Kansas City	MCI	5084	1093	213	6	0	0	6
MO	Saint Louis	STL	4438	1457	70	-22	8	0	6
MO	Springfield	SGF	4596	1114	180	1643	1769	0	9
MS	Greenwood	GWO	2376	2250	1	1021	2270	0	20
MS	McComb	MCB	1833	2472	34	711	2501	0	26

Station Location		Code	RECS 2009			CBECS 2012			Heating ODT
State	City		HDD	CDD	Count	HDD	CDD	Count	
MS	Tupelo	TUP	2842	1947	20	1081	2212	0	19
MT	Billings	BIL	6948	627	9	2527	971	0	-10
MT	Butte	BTM	-	-	-	3627	124	0	-
MT	Cut Bank	CTB	-	-	-	284	0	0	-
MT	Great Falls	GTF	7941	300	1	179	0	0	-15
MT	Havre	HVR	-	-	-	3358	517	0	-
MT	Helena	HLN	7704	444	1	2894	564	0	-16
MT	Kalispell	FCA	-	-	-	2069	1648	5	-
MT	Lewistown	LWT	-	-	-	3158	330	0	-
MT	Miles City	MLS	7700	716	1	208	0	0	-15
MT	Missoula	MSO	7588	355	2	2771	418	0	-6
NC	Asheville	AVL	4194	768	23	1568	1008	0	14
NC	Cape Hatteras	HAT	-	-	-	15	24	0	-
NC	Charlotte	CLT	3346	1611	71	1187	1772	0	22
NC	Greensboro	GSO	3605	1510	41	1349	1616	0	18
NC	Hickory	HKY	3593	1353	42	1321	1530	0	18
NC	New Bern	EWN	2769	1788	16	-38	-20	0	24
NC	Raleigh Durham	RDU	3164	1865	55	-30	3	0	20
NC	Wilmington	ILM	2521	1937	14	933	1987	0	26
ND	Bismarck	BIS	9130	332	16	3542	601	0	-19
ND	Devil’s Lake	P11	10245	236	8	360	0	0	-21
ND	Fargo	FAR	9304	362	17	3434	797	4	-18
ND	Grand Forks	GFK	9928	269	8	308	0	0	-22
ND	Minot	MOT	9559	314	9	3744	594	9	-20
ND	Williston	ISN	9721	297	8	3760	534	0	-21
NE	Grand Island	GRI	6431	788	26	38	0	0	-3
NE	Lincoln	LNK	6159	912	14	2415	1500	0	-2
NE	Norfolk	OFK	6789	643	4	2599	1386	1	-4
NE	North Platte	LBF	6946	534	14	64	0	0	-4
NE	Omaha	OMA	6288	851	32	2272	1653	0	-3
NE	Scottsbluff	BFF	6689	579	6	2399	1216	0	-3
NE	Valentine	VTN	7279	527	2	2668	1305	0	-8
NH	Concord	CON	7462	325	5	2525	584	0	-3
NH	Lebanon	LEB	7312	371	18	2550	553	0	-3

Station Location		Code	RECS 2009			CBECS 2012			Heating ODT
State	City		HDD	CDD	Count	HDD	CDD	Count	
NJ	Atlantic City	ACY	4693	994	57	1	0	0	13
NJ	Newark	EWR	4790	1021	147	1618	1438	0	14
NM	Albuquerque	ABQ	3823	1435	17	1494	1782	0	16
NM	Carlsbad	CNM	2398	2376	2	994	2541	0	19
NM	Clayton	CAO	4517	1143	31	1610	1455	0	9
NM	Gallup	GUP	6134	442	6	2421	586	0	5
NM	Roswell	ROW	3098	1961	7	1145	2364	0	18
NV	Elko	EKO	6948	450	1	2416	699	0	-2
NV	Ely	ELY	7925	125	4	2614	318	0	-4
NV	Las Vegas	LAS	1882	3818	66	-92	0	0	28
NV	Lovelock	LOL	-	-	-	2173	1226	0	-
NV	Reno	RNO	-	-	-	1657	1277	0	-
NV	Tonopah	TPH	5298	874	5	1913	1029	0	10
NV	Winnemucca	WMC	6236	611	2	2305	759	0	3
NY	Albany	ALB	6644	433	149	2269	797	0	-1
NY	Binghamton	BGM	7067	261	59	2538	544	0	1
NY	Buffalo	BUF	6651	361	54	2171	863	0	6
NY	Glens Falls	GFL	7612	285	26	62	0	0	-5
NY	Massena	MSS	7980	298	2	2804	514	145	-8
NY	New York	LGA	4647	1041	469	19	0	0	15
NY	Rochester	ROC	6765	315	46	2172	786	0	5
NY	Syracuse	SYR	6687	439	23	2116	938	0	2
NY	Utica	UCA	-	-	-	1419	2424	0	-
NY	Watertown	ART	7707	298	11	2448	613	0	-6
OH	Akron Canton	CAK	6131	497	6	-42	0	0	6
OH	Cincinnati	CVG	4950	874	13	1879	1426	0	6
OH	Cleveland	CLE	5833	664	44	2091	1086	0	5
OH	Columbus	CMH	5243	874	32	1915	1424	0	5
OH	Dayton	DAY	5602	732	45	2040	1248	0	4
OH	Findlay	FDY	5901	698	34	2181	1131	0	3
OH	Mansfield	MFD	6214	468	10	2214	949	0	5
OH	Toledo	TOL	6283	592	32	2263	985	0	1
OH	Youngstown	YNG	6239	443	8	2275	748	0	4
OK	Hobart	HBR	3392	2034	1	1263	2714	5	16
OK	McAlester	MLC	3136	1845	6	1121	2563	0	19

Station Location		Code	RECS 2009			CBECS 2012			Heating ODT
State	City		HDD	CDD	Count	HDD	CDD	Count	
OK	Oklahoma City	OKC	3519	1849	37	-40	2	0	13
OK	Tulsa	TUL	3608	1885	24	1246	2717	0	13
OR	Astoria	AST	4871	39	4	2028	25	1	29
OR	Baker	BKE	7529	220	2	2956	197	1	6
OR	Eugene	EUG	4999	331	89	1606	237	0	22
OR	Medford	MFR	-	-	-	1540	963	7	-
OR	Pendleton	PDT	5713	720	6	1955	623	5	5
OR	Portland	PDX	4357	635	32	1488	443	3	23
OR	Redmond	RDM	6737	313	17	2543	233	2	9
OR	Salem	SLE	4660	457	50	1607	316	0	23
PA	Allentown	ABE	5725	622	22	1993	1041	0	9
PA	Altoona	AOO	6109	433	17	2178	823	0	5
PA	Bradford	BFD	-	-	-	2552	353	0	-
PA	Du Bois	DUJ	6753	254	5	-3	0	0	5
PA	Erie	ERI	6183	423	9	2027	889	0	9
PA	Harrisburg	CXY	5097	866	111	1846	1260	0	11
PA	Philadelphia	PHL	4557	1219	46	1509	1592	0	14
PA	Pittsburgh	PIT	5661	617	6	2085	1015	0	5
PA	Williamsport	IPT	5636	644	69	2045	934	0	7
RI	Providence	PVD	5717	579	69	1850	830	0	9
SC	Charleston	CHS	1941	2390	13	706	2447	0	27
SC	Columbia	CAE	2561	2220	19	851	2483	4	24
SC	Florence	FLO	2541	2061	13	820	2305	0	25
SC	Greenville	GSP	3116	1735	42	1059	1811	0	22
SD	Aberdeen	ABR	8872	329	13	3419	765	0	-15
SD	Huron	HON	8070	469	105	3057	1087	6	-14
SD	Pierre	PIR	7738	577	36	2928	1114	0	-10
SD	Rapid City	RAP	7738	362	12	79	0	0	-7
SD	Sioux Falls	FSD	7670	481	42	162	0	0	-11
TN	Bristol	TRI	4267	930	28	1677	1181	0	14
TN	Chattanooga	CHA	3168	1808	35	1148	2016	0	18
TN	Crossville	CSV	4100	940	33	1608	1183	0	15
TN	Jackson	MKL	3379	1597	22	1344	1922	0	16
TN	Knoxville	TYS	3643	1392	91	1365	1705	0	19
TN	Memphis	MEM	2906	2091	3	1024	2617	3	18

Station Location		Code	RECS 2009			CBECS 2012			Heating ODT
State	City		HDD	CDD	Count	HDD	CDD	Count	
TN	Nashville	BNA	3615	1558	37	1302	1979	0	14
TX	Abilene	ABI	2359	2494	217	836	3050	2	20
TX	Alice	ALI	738	4832	23	228	4528	1	34
TX	Amarillo	AMA	4034	1340	33	1355	2012	0	11
TX	Austin	AUS	1722	3214	45	612	3165	0	28
TX	Brownsville	BRO	525	4300	20	80	4822	0	39
TX	College Station	CLL	1404	3476	29	-47	49	0	29
TX	Corpus Christi	CRP	811	4058	8	-87	98	0	35
TX	Dallas-Ft. Worth	DFW	2097	2745	61	-121	26	0	22
TX	Del Rio	DRT	1252	3807	29	-151	22	0	31
TX	El Paso	ELP	2106	2783	43	-171	0	0	24
TX	Galveston	GLS	907	3640	3	257	3950	1	36
TX	Houston	IAH	1267	3410	170	422	3575	1	32
TX	Laredo	LRD	602	5330	1	203	5205	0	36
TX	Lubbock	LBB	3178	1965	10	1199	2322	0	15
TX	Lufkin	LFK	1803	2839	64	609	3231	0	29
TX	McAllen	MFE	393	5387	3	103	5233	0	39
TX	Midland Odessa	MAF	2495	2445	81	-180	0	0	21
TX	San Angelo	SJT	2020	2814	56	-151	16	0	22
TX	San Antonio	SAT	1270	3598	28	-59	31	0	30
TX	Victoria	VCT	1123	3608	35	352	3747	2	32
TX	Waco	ACT	1927	3086	18	739	3241	8	26
TX	Wichita Falls	SPS	2838	2394	14	-57	9	0	18
UT	Cedar City	CDC	6058	645	56	-188	0	0	5
UT	Salt Lake City	SLC	5716	1147	29	-143	0	0	8
VA	Lynchburg	LYH	4433	1003	159	1645	1237	1	16
VA	Norfolk	ORF	3330	1659	41	1102	1845	0	22
VA	Richmond	RIC	3781	1564	47	1329	1737	0	17
VA	Roanoke	ROA	3931	1173	34	1520	1412	0	16
VT	Burlington	BTV	-	-	-	2411	728	0	-
VT	Montpelier	MPV	7998	237	12	2959	289	0	-6
WA	Bellingham	BLI	5568	115	8	2077	49	0	15
WA	Olympia	OLM	5614	178	24	2151	87	0	22

Station Location		Code	RECS 2009			CBECS 2012			Heating ODT
State	City		HDD	CDD	Count	HDD	CDD	Count	
WA	Quillayute	UIL	5869	44	7	2308	28	0	27
WA	Seattle Tacoma	SEA	4879	319	94	-67	0	0	26
WA	Spokane	GEG	6942	599	5	2410	550	0	2
WA	Walla Walla	ALW	5062	1144	12	-199	0	0	7
WA	Yakima	YKM	6204	699	25	2183	717	0	5
WI	Eau Claire	EAU	8208	333	23	48	0	0	-11
WI	Green Bay	GRB	8005	275	55	15	0	0	-9
WI	Lacrosse	LSE	7334	536	16	2684	1091	0	-9
WI	Madison	MSN	7343	368	66	2593	1070	0	-7
WI	Milwaukee	MKE	6816	474	28	2322	1044	0	-4
WI	Wausau	AUW	8337	277	54	2979	730	0	-12
WV	Beckley	BKW	5325	404	16	2031	751	0	4
WV	Charleston	CRW	4443	960	3	1741	1330	0	11
WV	Elkins	EKN	5993	284	3	2392	564	0	6
WV	Huntington	HTS	4557	922	3	1753	1318	0	10
WV	Martinsburg	MRB	5046	854	63	1896	1222	0	10
WV	Morgantown	MG W	4957	836	15	1869	1132	0	8
WV	Parkersburg	PKB	4910	850	19	1916	1214	0	11
WY	Casper	CPR	-	-	-	2712	714	0	-
WY	Cheyenne	CYS	7390	203	11	2687	579	0	-1
WY	Cody	COD	7551	410	2	2722	669	0	-13
WY	Lander	LND	7743	351	1	2760	796	0	-11
WY	Rock Springs	RKS	8204	230	3	28	0	0	-3
WY	Sheridan	SHR	7844	287	2	2948	671	0	-8
WY	Worland	WRL	7757	467	2	2867	926	0	-13

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2 U.S. Department of Energy–Energy Information Administration. *Commercial Buildings Energy Consumption Survey*. 2012. (Last accessed November 3, 2016.) <http://www.eia.gov/consumption/commercial/data/2012/>

3 National Oceanic And Atmospheric Administration. *Degree Days Archives.* 1997-Present. (Last accessed November 3, 2016.) <ftp://ftp.cpc.ncep.noaa.gov/htdocs/products/analysis_monitoring/cdus/degree_days/archives/>

4 American Society for Heating Refrigeration and Air-Conditioning Engineers (ASHRAE). *ASHRAE Handbook: Fundamentals*. 1993.

APPENDIX 7B. ENERGY USE IN COMMERICAL APPLICATIONS

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APPENDIX 7B. ENERGY USE IN COMMERICAL APPLICATIONS

7B.1 INTRODUCTION

This appendix describes the method the U.S. Department of Energy (DOE) used to calculate the energy use of portable air conditioners (ACs) installed in commercial settings. DOE applied data regarding local cooling degree-days to the commercial buildings it sampled from the Energy Information Administration's 2012 *Commercial Buildings Energy Consumption Survey* (CBECS).[1] DOE calculated the annual operating hours for portable ACs in each sampled commercial building by establishing a relationship between cooling degree-days and operating hours for various combinations of building type and building schedule. DOE focused on buildings that have no central air conditioning, as reported in the 2012 CBECS.

7B.2 ANSI/ASHRAE STANDARD FOR THERMAL COMFORT

DOE assumed that a portable AC is operated when outdoor air conditions exceed the comfort zone described by ANSI/ASHRAE Standard 55-2004, *Thermal Environmental Conditions for Human Occupancy* (see Figure 7B.2.1).[2]

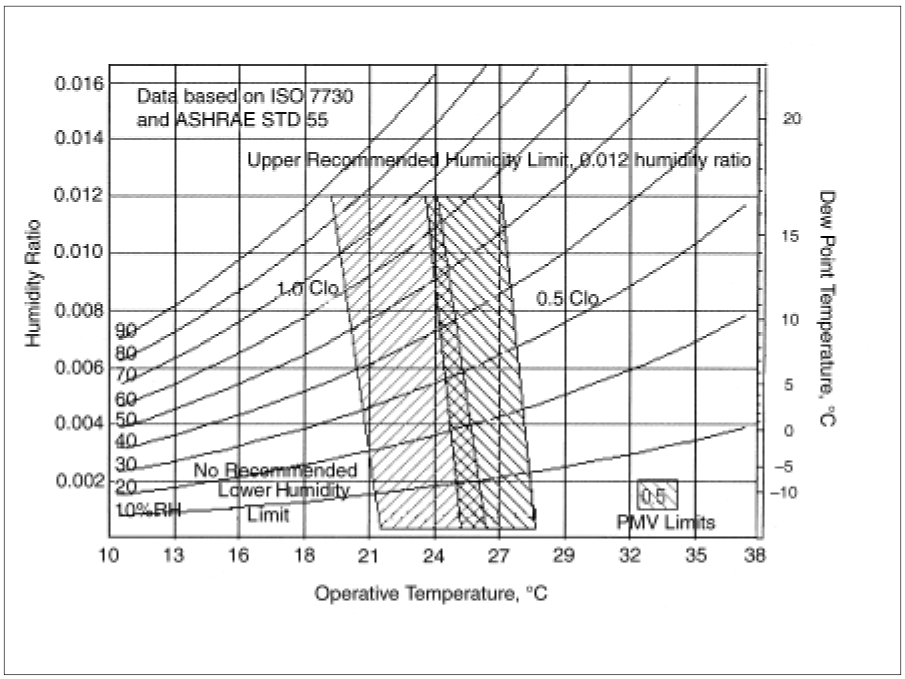

Figure 7B.2.1 ANSI/SHRAE Standard 55-2004: Thermal Environmental Conditions for Human Occupancy

ANSI/ASHRAE Standard 55 is based on the following assumptions.

- Metabolic rates of occupants are 1.1 met (occupants are engaged in near-sedentary physical activity).

- Occupants are wearing 0.5 clo of clothing insulation, a level typical of clothing worn when the outdoor environment is warm.
- Air speeds are not greater than 0.20 m/s (40 ft/min).
- Humidity is at or near the upper recommended limit, and the humidity ratio is 0.012.

The range of operative temperatures presented in Figure 7B.2.1 reflects an assumed 80-percent rate of occupant acceptance. That percentage reflects a 10-percent dissatisfaction criterion for a general (whole-body) thermal comfort index based on a combination of two indexes. Predicted mean vote (PMV) is an index that predicts the mean value of the votes of a large group of persons on a seven-point thermal sensation scale. The predicted percentage of dissatisfied (PPD) index establishes a quantitative prediction of the percentage of people dissatisfied with the thermal environment determined from PMV. The overall index is termed the PMV-PPD index. An additional average 10-percent rate of dissatisfaction may occur from local (partial-body) thermal discomfort. A portable air conditioner is assumed to operate if outdoor conditions exceed the outdoor comfort zone, as defined by a W (humidity ratio) greater than 0.012, or a T (temperature) that exceeds $Tcomf$ for that humidity ratio. $Tcomf$ is given by the following equation.

$$T_{comf} = -117 \times W + 28.25491422$$

where W is the humidity ratio of outdoor conditions for a given hour.

To estimate how often outdoor conditions exceed ANSI/SHRAE Standard 55-2004 (OH55), DOE used the following equation.

$$OH55 = (a \times CDD) + b$$

Where:

$OH55$ =	average annual hours when outdoor air conditions exceed the ASHRAE Standard 55 comfort zone,
CDD =	the number of annual cooling degree-days (65 °F) for a given location, and
a and b =	linear fit parameters.

7B.3 NATIONAL SOLAR RADIATION DATA

To estimate portable air conditioner (AC) operation and energy use in buildings from the CBECS sample, DOE used data on cooling degree-days (CDDs) from the National Solar Radiation Database (NSRDB) for 1991–2005.[3] The 1991–2005 NSRDB, which is an update of the 1961–1990 NSRDB database, is an hourly ground-based database of solar and meteorological fields for 1,454 NSRDB stations. The data, which provide a complete 15-year period of record for 858 sites. The NSRDB stations are divided into three classes (see Figure 7B.3.1).

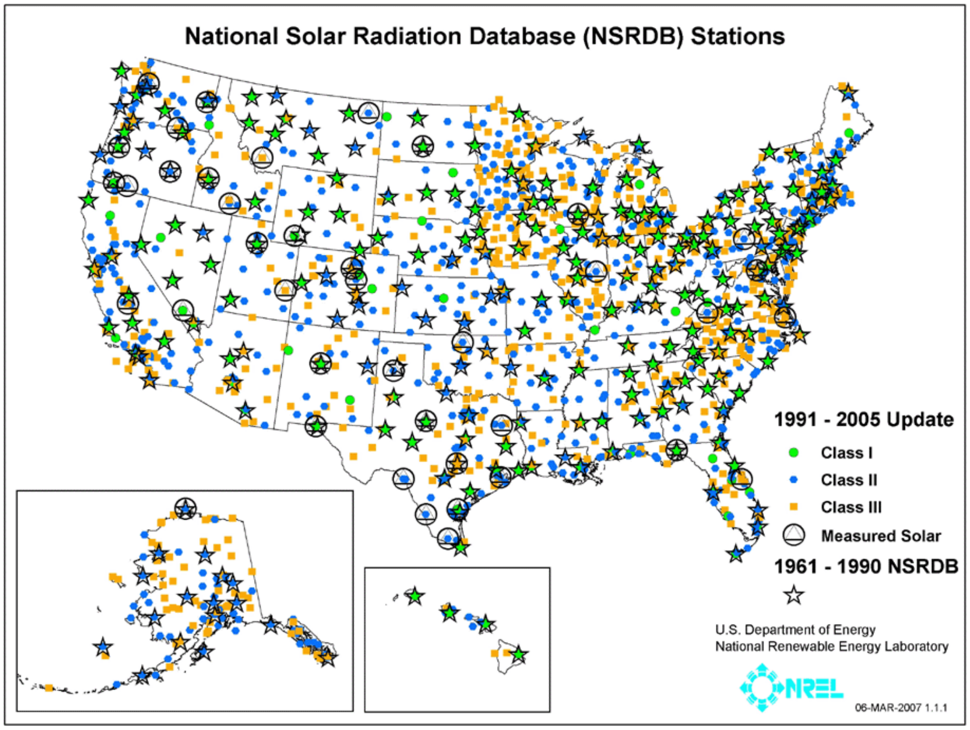

Figure 7B.3.1 National Solar Radiation Database Stations

NSRDB stations are assigned a U.S. Air Force class number as follows:

- Class I stations have a complete period of record for solar and key meteorological fields (all hours for 1991–2005) and have the highest-quality modeled data (221 sites).
- Class II stations have a complete period of record but significant periods of interpolated, filled, or otherwise lower-quality input data for the solar models (637 sites).
- Class III stations have some gaps in the period of record but at least 3 years of data that might be useful for some applications (596 sites).

The NSRDB database has complete fields for measured hourly dry bulb temperature, dew point temperature, relative humidity, and atmospheric pressure for all class I and class II stations. DOE used data from the dry bulb temperature, relative humidity, and atmospheric pressure fields to calculate the humidity ratio for each operating hour for every commercial building in DOE's sample. DOE calculated the humidity ratio (*W*) using procedures from ASHRAE's 2005 *Handbook–Fundamentals.*[a] The process utilizes dry bulb temperature, relative humidity, and

[a] Chapter 6 in the 2005 ASHRAE *Handbook* is entitled *Psychometrics*. Under the section on "Numerical Calculation of Moist Air Properties," Situation 3 describes the process for calculating humidity ratio (*W*) from dry bulb temperature, relative humidity, and pressure.

pressure. The saturation pressure for the dry bulb temperature is calculated using the following equation.

$$\ln(Pws) = \frac{C_8}{T} + C_9 + C_{10} \times T + C_{11} \times T^2 + C_{12} \times T^3 + C_{13} \times \ln(T)$$

Where:

C8 = -5.8002206 E+03,
C9 = 1.3914993 E+00,
C10 = -4.8640239 E-02,
C11 = 4.1764768 E-05,
C12 = -1.4452093 E-08,
C13 = 6.5459673 E+00,
Pws = saturation pressure, Pa, and
T = absolute temperature, K = °C + 273.15

The partial pressure (*Pw*) of the water vapor is the saturation pressure multiplied by the relative humidity:

$$Pw = \varphi \times Pws$$

The humidity ratio, *W*, is defined as the ratio of the mass of water vapor to the mass of dry air contained in a given air sample. The ratio can be calculated from the pressure and the partial pressure of the water vapor as:

$$W = 0.62198 \times \frac{Pw}{(P - Pw)}$$

By comparing the conditions for a given hour in a specific geographic location against the criteria established in ANSI/ASHRAE Standard 55-2004, we can determine whether a portable air conditioner would have operated during that hour. Figure 7B.3.2 shows the 2,281 hours in 1991 that exceeded the comfort zone for Palm Springs, CA.

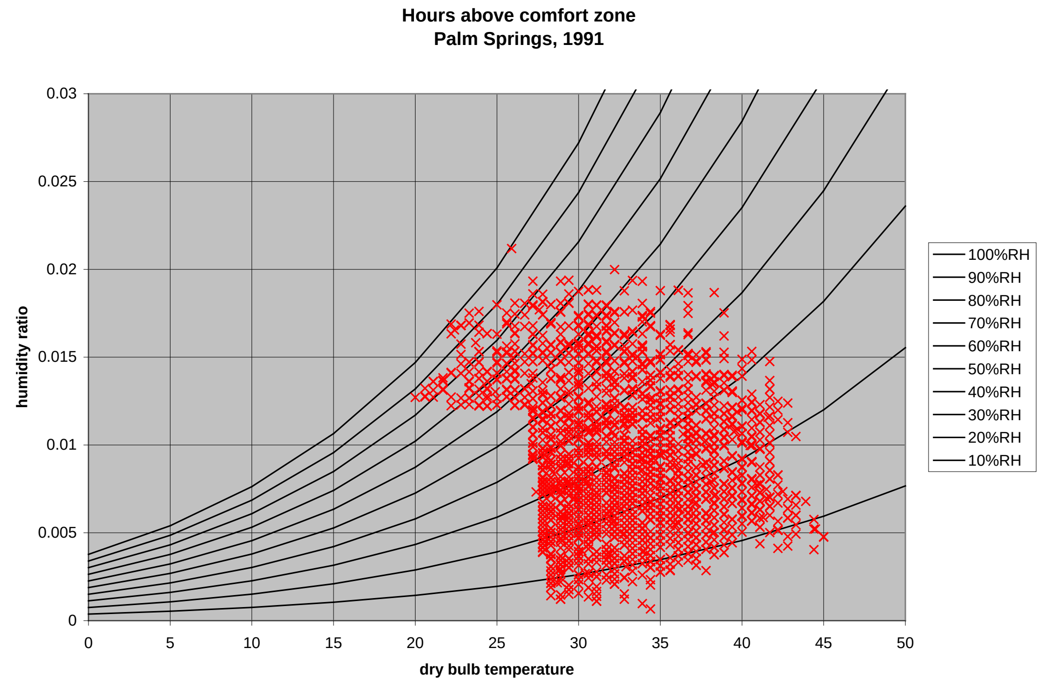

Figure 7B.3.2 Hours that Exceeded ASHRAE Standard 55 Comfort Zone in Palm Springs CA, 1991

Figure 7B.3.3 shows hours that exceeded the ANSI/ASHRAE Standard 55-2004 comfort zone compared to CLDD for 15 years (1991–2005) for all NSRDB class 1 and class II stations.

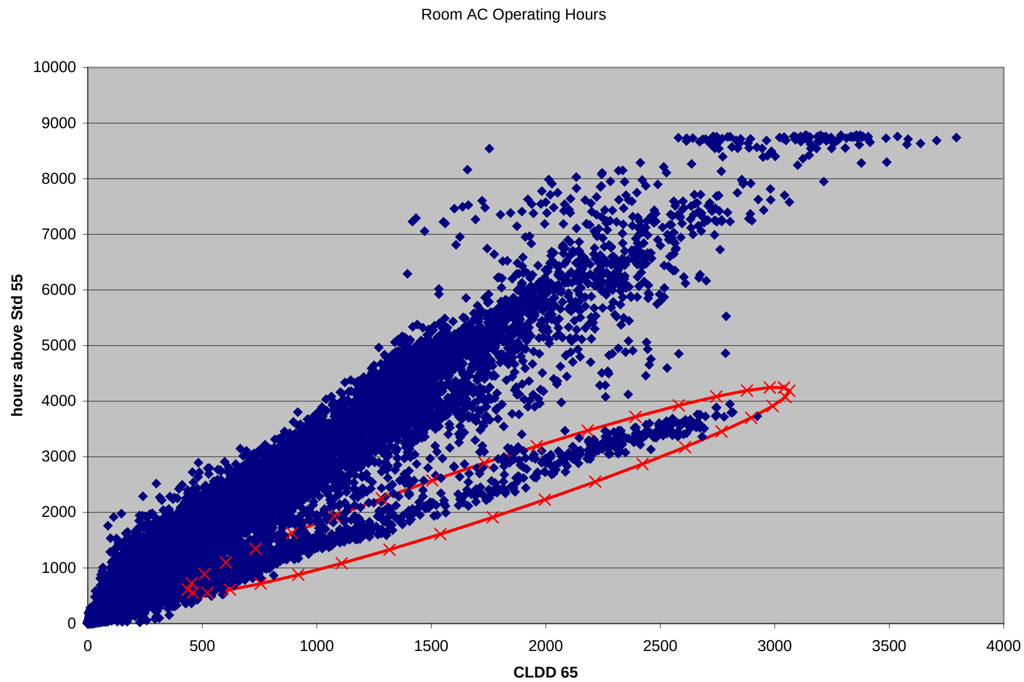

Figure 7B.3.3 Hours that Exceeded ASHRAE Standard 55Comfort Zone Compared to CLDD

The lower branch of data points (outlined in red in Figure 7B.3.3) reflects low-desert locations, where humidity is not a factor that affects comfort. After examining the data, DOE classified the following sites as desert.

Table 7B.3.1 Weather Stations Classified as Desert

Station	State
Davis Monthan Air Force Base	AZ
Deer Valley/Phoenix	AZ
Douglas Bisbee-Douglas Int'l. Airport	AZ
Kingman (AMOS*)	AZ
Luke Air Force Base	AZ
Phoenix Sky Harbor Int'l. Airport	AZ
Scottsdale Muni Airport?	AZ
Tucson Int'l. Airport	AZ
Yuma Int'l. Airport	AZ
Yuma Marine Corps Air Station	AZ
Bakersfield Meadows Field	CA
Blythe Riverside Co Airport	CA
China Lake Naval Air Station	CA
Daggett Barstow-Daggett Airport	CA
Edwards Air Force Base	CA
Imperial	CA
Lancaster Gen. Wm. Fox Field	CA
Needles Airport	CA
Palm Springs Int'l. Airport	CA
Palm Springs Thermal Airport	CA
Palmdale Airport	CA
Twenty-nine Palms	CA
Carlsbad Cavern City Air Terminal	NM
Deming Muni [Airport]	NM
Holloman Air Force Base	NM
Las Cruces Intl [Airport]	NM
Roswell Industrial Air Park	NM
Truth or Consequences Muni [Airport]	NM
Las Vegas Mccarran Int'l. [Airport]	NV
Mercury Desert Rock Airport [SURFRAD†]	NV
Nellis Air Force Base	NV
El Paso Int'l. [Airport] [UT‡]	TX
Saint George (AWOS§)	UT

*AMOS = Automated Meteorological Observing System
† SURFRAD = Surface Radiation Network
‡ UT = University of Texas??
§ AWOS = Automated Weather Observing System

Figure 7B.3.4 shows NSRDB data points highlighting desert and tropical sites. The uppermost points represent data from stations in Hawaii, Guam, and the Caribbean.

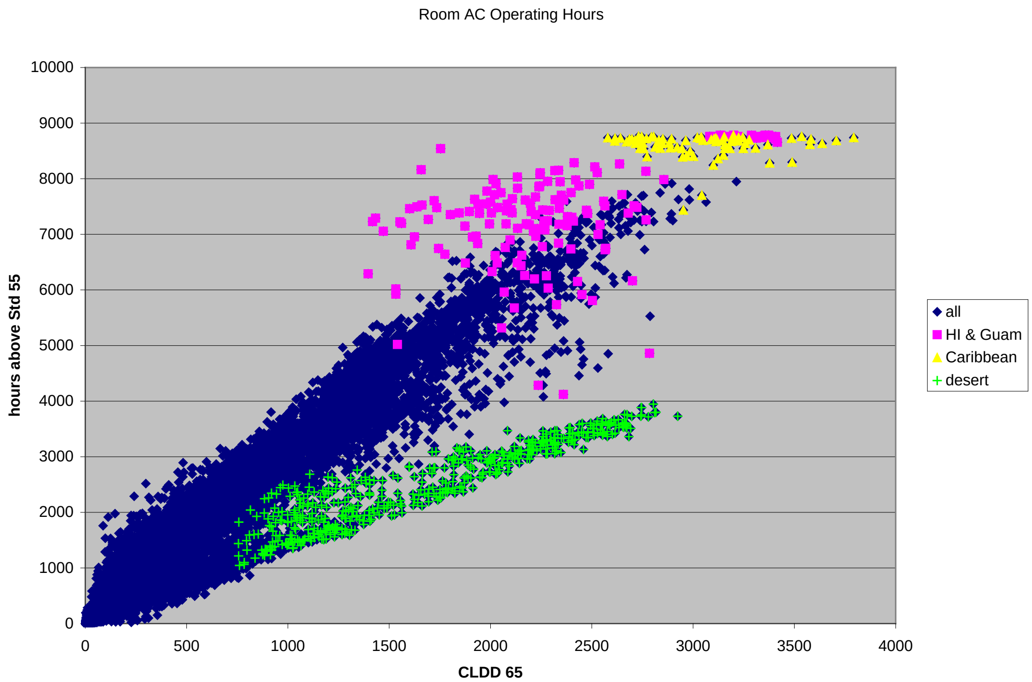

Figure 7B.3.4 Hours that Exceeded ASHRAE Standard 55 Comfort Zone versus CLDD Highlighting Various Regions

7B.4 EQUATIONS AND CALCULATIONS

DOE removed the sites in Hawaii, Guam, and the Caribbean islands from consideration because their conditions of high humidity likely would call for use of a portable dehumidifier rather than a portable AC. After removing the sites in Hawaii, Guam, and the Caribbean islands from DOE's set of data for commercial buildings, DOE performed regressions to predict the hours per year that exceed ASHRAE Standard 55 from the number of cooling degree-days for each year. The data points and regression lines are shown in Figure 7B.4.1 for all hours of the year. The figure reflects 15 years' worth of data from 842 sites in the continental United States.

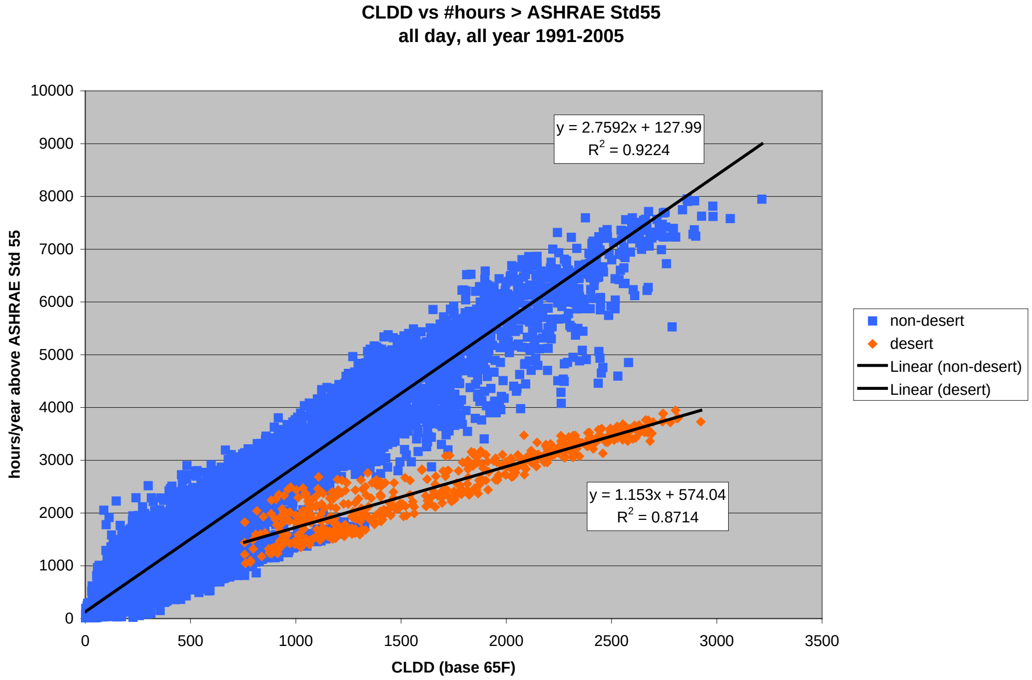

Figure 7B.4.1 Hours that Exceeded ANSI/ASHRAE Standard 55 Comfort Zone as a Function of Cooling Degree-Days, Continental United States

The regression equations used to derive the average annual number of hours when outdoor air conditions exceed ASHRAE Standard 55 comfort zone (OH55) are shown in Table 7B.4.1.

Table 7B.4.1 Regression Equations

Region	Equation	R^2	No. of Sites
Non-desert	OH55 = 2.759 x CLDD + 127.99	0.9224	809
Desert	OH55 = 1.153 x CLDD + 574.04	0.8714	33

The number of annual hours that exceed the ASHRAE Standard 55 comfort zone in a given geographic location will differ depending on building schedule, which refers to the period(s) when a building is open. Thus, DOE performed the regression for various combinations of building type and schedule, yielding somewhat different equations for each combination. The building types included are: assembly, education, food service, office, retail, and warehouse. For each building type, DOE estimated operating hours for building schedules that included: (1) open 24 hours a day and seven days a week; (2) open business hours Monday through Friday; (3) open business hours Monday through Saturday; (4) open business hours Monday through Friday and Sunday; (5) open business hours all week. The building types and schedule abbreviations are shown in Table 7B.4.2 and Table 7B.4.3. DOE assumed that if the occupancy rate was greater than 20 percent of full occupancy, a portable AC would operate when outdoor air conditions exceeded the ASHRAE standard 55 comfort zone.

Table 7B.4.2 Building Types and Abbreviations

Building Type	Abbreviation
Assembly	ASM
Education	EDU
Food service	FDS
Lodging	LOD
Medical	MED
Office	OFF
Outdoor	OUT
Retail	RET
Warehouse	WHS

Table 7B.4.3 Building Schedules and Abbreviations

Building Schedule	Abbreviation
24 hours per day, 7 days per week	247
Business hours, Monday–Friday	M-F
Business hours, Monday–Friday and Saturday and Sunday	ALL

The equations for predicting the hours per year a portable AC would operate for various commercial building types and schedules for non-desert locations are shown in Table 7B.4.4.

Table 7B.4.4 Equations for Portable AC Operating Hours by Building Type and Schedule, Non-Desert Locations

Building Type	Times Open	Equation	R^2
ALL	247	ROH55 = 2.759 x CLDD + 127.99	0.9224
OUT	M_F	ROH55 = 1.974 x CLDD + 93.29	0.9458
OUT	ALL	ROH55 = 2.759 x CLDD + 127.99	0.9430
ASM	M_F	ROH55 = 0.751 x CLDD + 119.67	0.9458
ASM	ALL	ROH55 = 1.396 x CLDD + 169.18	0.9430
EDU	M_F	ROH55 = 1.001 x CLDD + 117.11	0.9412
EDU	ALL	ROH55 = 1.398 x CLDD + 163.52	0.9424
FDS	M_F	ROH55 = 1.243 x CLDD + 112.91	0.9354
FDS	ALL	ROH55 = 1.510 x CLDD + 166.44	0.9408
LOD	M_F	ROH55 = 1.471 x CLDD + 17.11	0.9428
LOD	ALL	ROH55 = 2.206 x CLDD + 40.94	0.9408
MED	M_F	ROH55 = 1.001 x CLDD + 128.06	0.9428
MED	ALL	ROH55 = 1.151 x CLDD + 148.72	0.9408
OFF	M_F	ROH55 = 0.918 x CLDD + 119.76	0.9428
OFF	ALL	ROH55 = 1.510 x CLDD + 166.44	0.9408
RET	M_F	ROH55 = 0.751 x CLDD + 119.67	0.9458
RET	ALL	ROH55 = 1.281 x CLDD + 170.57	0.9450
WHS	M_F	ROH55 = 0.836 x CLDD + 109.17	0.9422
WHS	ALL	ROH55 = 1.514 x CLDD + 178.06	0.9419

The top row (grayed) of the table pertains to any building type that operate on a 24/7 schedule, because the occupancy rate will exceed 20 percent at all times. The analysis does not account for differences in building operation schedules on holidays.

The equations for predicting the hours per year a portable AC would operate for various building types and schedules for desert locations are shown in Table 7B.4.5.

Table 7B.4.5 Equations for Portable AC Operating Hour by Building Type and Schedule, Desert Locations

Building Type	Times Open	Equation	R^2
ALL	247	ROH55 = 1.153 x CLDD + 574.04	0.9224
OUT	M_F	ROH55 = 1.974 x CLDD + 93.29	0.8353
OUT	ALL	ROH55 = 2.759 x CLDD + 127.99	0.8925
ASM	M_F	ROH55 = 0.289 x CLDD + 546.12	0.8353
ASM	ALL	ROH55 = 0.600 x CLDD + 721.20	0.8925
EDU	M_F	ROH55 = 0.409 x CLDD + 532.56	0.8723
EDU	ALL	ROH55 = 0.572 x CLDD + 741.06	0.8794
FDS	M_F	ROH55 = 0.553 x CLDD + 449.33	0.8914
FDS	ALL	ROH55 = 0.663 x CLDD + 690.02	0.8985
LOD	M_F	ROH55 = 0.642 x CLDD + 40.06	0.8260
LOD	ALL	ROH55 = 0.951 x CLDD + 157.74	0.8985
MED	M_F	ROH55 = 0.402 x CLDD + 603.12	0.8260
MED	ALL	ROH55 = 0.458 x CLDD + 706.19	0.8985
OFF	M_F	ROH55 = 0.353 x CLDD + 573.23	0.8260
OFF	ALL	ROH55 = 0.663 x CLDD + 690.02	0.8985
RET	M_F	ROH55 = 0.289 x CLDD + 546.12	0.8353
RET	ALL	ROH55 = 0.534 x CLDD + 749.00	0.8813
WHS	M_F	ROH55 = 0.317 x CLDD + 524.97	0.8087
WHS	ALL	ROH55 = 0.612 x CLDD + 837.58	0.8682

To estimate the operating hours for portable ACs in each building in the CBECS 2012 sample that has a portable AC, DOE identified the building type and schedule using information provided by CBECS, then applied the appropriate equation (non-desert or desert) combined with the number of cooling degree-days for the location of the building. DOE adjusted the results by applying a scaling factor to account for the difference between the number of building operating hours that were assumed when deriving the equations and the actual building operating hours reported by CBECS 2012. Table 7B.4.6 shows the CBECS building codes matched to the building types in the regression equations.

Table 7B.4.6 CBECS 2012 Building Codes Matched to Building Types in Portable AC Equations

CBECS 2012 PBA Code*	Definition	Building Type Match	CBECS 2012 Buildings with Portable ACs %
1	Vacant	Not Applicable	
2	Office	OFF	17.8
4	Laboratory	MED	0.3
5	Nonrefrigerated warehouse	WHS	10.1
6	Food sales	RET	2.5
7	Public order and safety	OFF	2.3
8	Outpatient health care	MED	0.7
11	Refrigerated warehouse	WHS	0.0
12	Religious worship	ASM	7.1
13	Public assembly	ASM	4.0
14	Education	EDU	7.2
15	Food service	FDS	7.22.2
16	Inpatient health care	MED	0.2
17	Nursing	MED	1.0
18	Lodging	LOD	6.1
23	Strip shopping mall	RET	0.0
24	Enclosed mall	RET	0.0
25	Retail other than mall	RET	10.3
26	Service	RET	21.9
91	Other	OFF	1.4

* PBA = Principal building activity.

The approach described here provides a best guess of the operating hours for a portable AC in a particular CBECS building. Operating hours are affected by some factors not included in the analysis, however, such as interior heat gains from equipment or people and solar gains. To develop a distribution of the number of operating hours for each sample building, DOE added an error band to the value derived using the regression equation. The error band includes values that are ±10 percent from the regression line for the appropriate building type and schedule combination.

The operating hours for portable ACs in commercial buildings were estimated based on the cooling climate in 2012. To match the 118-year average CDD values, DOE decreased the operating hours estimated for commercial applications by 18 percent on average.

REFERENCES

1 U.S. Department of Energy–Energy Information Administration. *Commercial Buildings Energy Consumption Survey*. 2012. (Last accessed November 3, 2016.) <http://www.eia.gov/consumption/commercial/data/2012/>

2 American National Standards Institute and American Society of Heating, Refrigeration, and Air-Conditioning Engineers, Inc. *ANSI/ASHRAE 55-2004 Thermal Environmental Conditions for Human Occupancy*. 2004.

3 National Renewable Energy Laboratory. *National Solar Radiation Database: 1991–2005 Update: User's Manual.* May 2007. Technical Report NREL/TP-581-41364. (Last accessed November 3, 2016.) <http://www.nrel.gov/docs/fy07osti/41364.pdf>

APPENDIX 8A. USER INSTRUCTIONS FOR LIFE-CYCLE COST AND PAYBACK PERIOD SPREADSHEETS

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APPENDIX 8A. USER INSTRUCTIONS FOR LIFE-CYCLE COST AND PAYBACK PERIOD SPREADSHEETS

8A.1 DEFINITIONS

The interested reader can examine, reproduce, and adjust detailed results of the U.S. Department of Energy's (DOE's) life-cycle cost (LCC) and payback period (PBP) analysis for portable air conditioners by using Microsoft Excel spreadsheets available on DOE's website at http://www1.eere.energy.gov/buildings/appliance_standards/residential/dehumidifiers.html.

The latest version of the spreadsheet workbook was tested using Microsoft Excel 2010. The LCC workbook for residential and commercial portable air conditioners (ACs) comprises the following worksheets.

Summary This worksheet contains summary results for the full LCC analysis of 10,000 consumers for the residential and commercial sectors.

LCC for Indiv. Consumer This worksheet contains the calculations and results for a single consumer (*i.e.*, a purchaser of a computer system). Users can choose consumer characteristics with a series of drop-down menus and fillable cells. Characteristics include:

- Sector (residential or commercial).
- Geographical location.
- Hours of operation spent in cooling, fan-only mode, and standby mode (total ≤8,760).
- Lifetime (1 to 30 years).
- Discount rate (0% to 100%).
- Sales tax (0% to 100%).
- Average electricity price in 2014.
- Marginal electricity price in 2014.
- AEO electricity price trend (reference, high, or low).
- EL for Selected Household for LCC savings (0 through 4).
- Price learning (true or false).
- Purchaser index (which enables the user to select a purchaser from the purchaser sample used in the LCC analysist).

LCC and LCC savings results for the selected parameters are displayed below the inputs box.

Consumer Samples	This worksheets contain the samples of 10,000 consumers for the residential and commercial. DOE uses these samples to derive results for the analysis.The residential sample is based on households that reported having room or window/wall air conditioners in the RECS 2009 survey (12,083 housing units surveyed). The commercial sample is based on commercial/institutional buildings that reported having room or window/wall air conditioners in the CBECS 2012 survey (6,720 buildings surveyed). The purchaser samples for each sector identifies the parameters exported to the LCC and PBP analysis, including (1) geographic location (a determinant of electricity price and sales tax); (2) lifetime; (3) number of operating hours for cooling (fan operating and stand-by mode); and (4) discount rate. During a simulation, DOE uses those characteristics to determine the analysis parameters.
Efficiency Distribution	This worksheet provides (1) market shares of ELs in the no-new-standards case; (2) percent of purchasers by geographic location for commercial and residential sectors; and (3) distribution of portable ACs by residential and commercial sectors.
Engineering Analysis	This worksheet contains data from the engineering analysis used in this LCC and PBP analysis.
Markups	This worksheet contains the markups used in this analysis.
Price Learning	This worksheet contains price learning curve factors to project future product prices.
Lifetime	This worksheet presents the average lifetime, in years, of portable ACs for both residential and commercial applications (10.5 years for both). Includes the Weibull parameters used for the survival function, and a graph of the Weibull retirement function for portable ACs.
Discount Rates	This worksheet presents data used to develop average real discount rates and a distribution of discount rates for residential and commercial purchases. Rates are for the various types of debt and equity used to purchase products installed in homes and businesses. Appendix 8E gives a detailed description of DOE's development of discount rates.
Electricity Prices	This worksheet contains the average and marginal electricity prices used to calculate operating costs in the LCC analysis.

Electricity Price Trends	This worksheet shows the price trends used to estimate electricity price in the LCC analysis.
Sales Tax	This worksheet contains projected tax rates in 2022.

8A.2 BASIC INSTRUCTIONS

Basic instructions for operating the LCC spreadsheet are provided here.

1. After downloading the LCC spreadsheet file from DOE's website, use Microsoft Excel to open it. At the bottom of the workbook, click on the tab for the sheet labeled *LCC for Indiv. Consumer*.
2. Use Excel's "View/Zoom" command in the top menu bar to change the size of the display so that it fits your monitor.
3. Use the graphical interface in the spreadsheet to choose parameters or enter data. You can change the default choices for the inputs listed under "Inputs." To change a default input, select the desired value from the drop-down choices by the input box or enter the number manually where applicable.
4. After you have selected the desired parameters, the spreadsheet will automatically generate updated LCC results based on chosen inputs. Results are provided under "LCC Calculations for an Individual Consumer."

APPENDIX 8B. UNCERTAINTY AND VARIABILITY IN LCC ANALYSIS

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APPENDIX 8B. UNCERTAINTY AND VARIABILITY IN LCC ANALYSIS

8B.1 INTRODUCTION

Analysis of energy conservation standards involves calculations of impacts, for example, the impact of a standard on consumer life-cycle cost (LCC). In order to perform the calculation, the analyst must first: 1) specify the equation or model that will be used; 2) define the quantities in the equation; and 3) provide numerical values for each quantity. In the simplest case, the equation is unambiguous (contains all relevant quantities and no others), each quantity has a single numerical value, and the calculation results in a single value. However, unambiguity and precision are rarely the case. In almost all cases, the model and/or the numerical values for each quantity in the model are not completely known (i.e., there is uncertainty) or the model and/or the numerical values for each quantity in the model depend upon other conditions (i.e., there is variability).

Thorough analysis involves accounting for uncertainty and variability. While the simplest analysis involves a single numerical value for each quantity in a calculation, arguments can arise about what the appropriate value is for each quantity. Explicit analysis of uncertainty and variability is intended to provide more complete information to the decision-making process.

8B.2 UNCERTAINTY

When making observations of past events or speculating about the future, imperfect knowledge is the rule rather than the exception. For example, the energy actually consumed by a particular appliance type (such as the average U.S. water heater, direct heating equipment, or pool heater) is not directly recorded, but rather estimated based upon available information. Even direct laboratory measurements have some margin of error. When estimating numerical values expected for quantities at some future date, the exact outcome is rarely known in advance.

8B.3 VARIABILITY

Variability means that different applications or situations produce different numerical values when calculating a quantity. Specifying an exact value for a quantity may be difficult because the value depends on something else. For example, water heater energy consumption depends upon the specific circumstances and behaviors of the occupants (e.g., number of persons, length and temperature of showers, etc.). Variability makes specifying an appropriate population value more difficult in as much as any one value may not be representative of the entire population. Surveys can be helpful here, and analysis of surveys can relate the variable of interest (e.g., hours of use) to other variables that are better known or easier to forecast (e.g., persons per household).

8B.4 APPROACHES TO UNCERTAINTY AND VARIABILITY

This section describes two approaches to uncertainty and variability: (1) scenario analysis and (2) probability analysis.

Scenario analysis uses a single numerical value for each quantity in a calculation, then changes one (or more) of the numerical values and repeats the calculation. A number of calculations are done, which provide some indication of the extent to which the result depends upon the assumptions. For example, the life-cycle cost of an appliance could be calculated for energy rates of 2, 8, and 14¢ per kWh.

The advantages of scenario analysis are that each calculation is simple; a range of estimates is used and crossover points can be identified. (An example of a crossover point is the energy rate above which the life-cycle cost is reduced, holding all other inputs constant. That is, the crossover point is the energy rate at which the consumer achieves savings in operating expense that more than compensate for the increased purchase expense.) The disadvantage of scenario analysis is that there is no information about the likelihood of each scenario.

Probability analysis considers the probabilities within a range of values. For quantities with variability (e.g., electricity rates in different households), surveys can be used to generate a frequency distribution of numerical values (e.g., the number of households with electricity rates at particular levels) to estimate the probability of each value. For quantities with uncertainty, statistical or subjective measures can be used to provide probabilities (e.g., manufacturing cost to improve energy efficiency to some level may be estimated to be $10 ± $3).

The major disadvantage of the probability approach is that it requires more information, namely information about the shapes and magnitudes of the variability and uncertainty of each quantity. The advantage of the probability approach is that it provides greater information about the outcome of the calculations, that is, it provides the probability that the outcome will be in a particular range.

Scenario and probability analysis provide some indication of the robustness of the policy given the uncertainties and variability. A policy is robust when the impacts are acceptable over a wide range of possible conditions.

8B.5 PROBABILITY ANALYSIS AND THE USE OF MONTE CARLO SIMULATION

To quantify the uncertainty and variability that exist in inputs to the engineering, LCC, and payback period (PBP) analyses, DOE used Monte Carlo simulation and probability distributions to conduct probability analyses.

Simulation refers to any analytical method meant to imitate a real-life system, especially when other analyses are too mathematically complex or too difficult to reproduce. Without the aid of simulation, a model will only reveal a single outcome, generally the most likely or average scenario. Probabilistic risk analysis uses both a spreadsheet model and simulation to automatically analyze the effect of varying inputs on outputs of the modeled system. One type of simulation is Monte Carlo simulation, which randomly generates values for uncertain variables again and again to simulate a model. Monte Carlo simulation was named for Monte Carlo, Monaco, where the primary attractions are casinos containing games of chance. Games of chance, such as roulette wheels, dice, and slot machines, exhibit random behavior. The random behavior in games of chance is similar to how Monte Carlo simulation selects variable values at random to simulate a model. When you roll a die, you know that a 1, 2, 3, 4, 5, or 6 will come up, but you do not know which for any particular roll. It is the same with the variables that have a known range of values but an uncertain value for any particular time or event (e.g., equipment lifetime, discount rate, and installation cost).

For each uncertain variable (one that has a range of possible values), possible values are defined with a probability distribution. The type of distribution selected is based on the conditions surrounding that variable. Probability distribution types include:

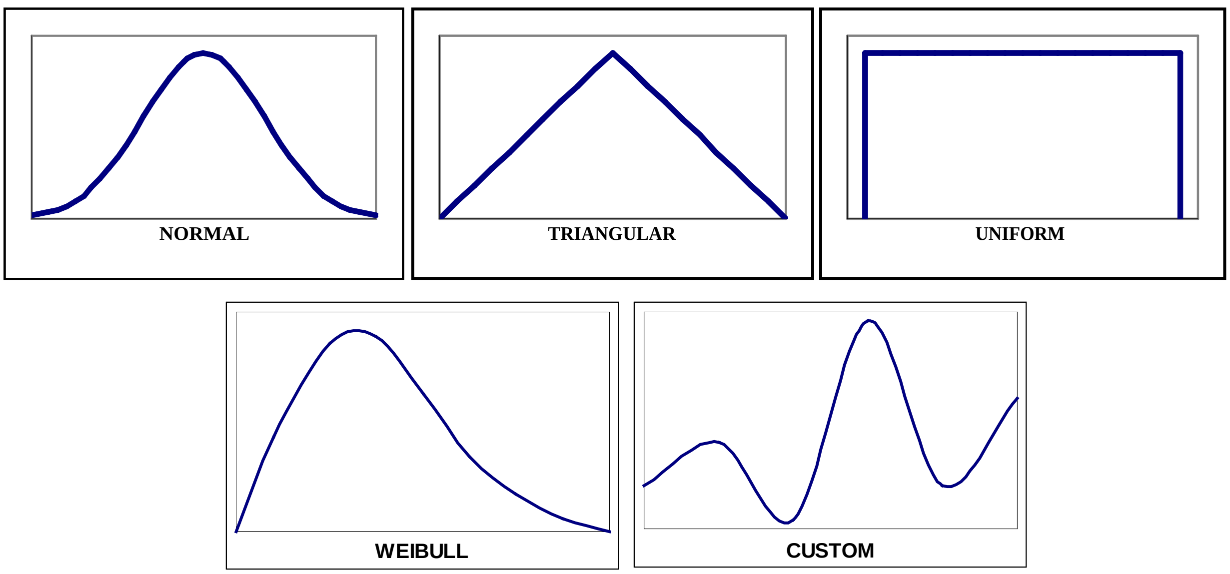

Figure 8B.5.1 Normal, Triangular, Uniform, Weibull, and Custom Probability Distributions

During a simulation, multiple scenarios of a model are calculated by repeatedly sampling values from the probability distributions for the uncertain variables and using those values for the cell. Monte Carlo simulations can consist of as many trials (or scenarios) as desired—hundreds or even thousands. During a single trial, the simulation randomly selects a value from the defined possibilities (the range and shape of the probability distribution) for each uncertain variable and then recalculates the LCC and PBP for that trial.

APPENDIX 8C. ELECTRICITY PRICES

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APPENDIX 8C. ELECTRICITY PRICES

8C.1 INTRODUCTION

The following sections discuss DOE's general methodology to derive electricity prices for the residential and commercial sectors. DOE used marginal and average electricity prices in the computer systems life-cycle cost (LCC) and payback period (PBP) NOPR analyses. Marginal electricity prices are used to calculate the operating cost savings to consumers who purchase and operate a more efficacious appliance. The electricity savings are estimated as the difference between the electricity use in the reference case and at standards efficiency level cases. For a consumer using more efficacious equipment, total household electricity use and therefore the total electricity bill is reduced in the standards case. The value of the electricity savings is defined by the *marginal price, i.e.*, the cost of a unit increment or decrement in energy use relative to the consumer's bill in the reference case. If the utility bill were simply a commodity cost times the amount consumed, then the marginal and average price would be identical. However, utility tariffs can have complex structures, so in general the marginal price differs from the average price and may be higher or lower. For this reason, DOE uses utility tariff information to independently estimate marginal and average prices. Two examples are presented below to illustrate how marginal prices depend on the tariff structure.

Example 1: in this example the tariff is defined by a fixed charge F and a commodity charge A. Let E be the electricity use in the reference case, and ΔE the decremented electricity use in the standards case.

The total utility bill B (neglecting taxes) is

$$B = F + (A \times E)$$

Eq. 8C.1

The average price p is defined as the ratio of the total bill to total usage:

$$p = \frac{B}{E} = \frac{F}{E} + A$$

Eq. 8C.2

The marginal price is defined by considering an increment dE to total usage (dE may be negative), and calculating the ratio of the change in the bill dB to the change E:

$$\Delta B = F + [A \times (E + \Delta E)] - [F + (A \times E)] = A \times \Delta E$$
$$m = \frac{\Delta B}{\Delta E} = A$$

Eq. 8C.3

For the simple tariff defined above $m < p$ as long as the fixed charge F is not zero.

Example 2: in this example the tariff is defined by a fixed charge F and two commodity charges A_1 and A_2. Charge A_1 applies for all electricity use up to E_1, while charge A_2 applies for any usage over E_1. This is an example of a tiered rate structure. In general A_2 may be larger or smaller than A_1, although most utilities use increasing tiers with $A_2 > A_1$. For a tariff of this type, the marginal price is either A_1 or A_2, depending on whether the household energy use is more or less than E_1 in the reference case. For $E < E_1$ the average price is

$$P = \frac{[F + (A_1 \times E)]}{E}$$

Eq. 8C.4

which is higher than the marginal price A_1. However for $E \geq E_1$

$$P = \frac{\{F + (A_1 \times E_1) + [A_2 \times (E - E_1)]\}}{E}$$

Eq. 8C.5

and it is impossible to say in general whether the average price is higher or lower than the marginal price without knowing the precise values of all parameters. This relatively simple case illustrates that, for a given tariff, both the average and marginal prices depend on the level of consumption in the reference case.

8C.2 DATA SOURCES

DOE has reviewed several data sources related to electricity pricing for use in its consumer impacts analyses. The available data sets, along with features such as the size of the sample, temporal and spatial resolution of the data, and coverage of different market segments are summarized in Table 8C.2.1. The five publicly available sources that have been reviewed are

1. The Energy Information Agency (EIA) form 861: annual data on revenues, sales and consumer counts by sector for all utilities in the U. S.
2. The EIA form 826: monthly data on revenues, sales and consumer counts by sector for a subset of utilities in the U. S.
3. The RECS and CBECS building energy use surveys performed by the EIA. These include, for some survey years, monthly utility bills and consumption.
4. Edison Electric Institute "Typical Bills and Average Rates" biannual reports, which provide the total utility bills for specific consumptions levels for most of the investor-owned utilities (IOU's) in the U. S.
5. Utility tariffs are public information and are generally available on the internet. The Tariff Analysis Project (TAP) at LBNL has compiled a database of residential and non-residential sectors, for about 100 utilities.

Table 8C.2.1 Summary of Data Sources for Electricity Price Information

Sector	Data Source	Resolution			Sample		Time Resolution				TOU
		Time	Geographic	Customer Type	Size	Control	Annual	Seasonal	Annual	Seasonal	
Res	EIA 861	annual	by utility	none	complete	n/a	estimate	no	no	no	no
C&I	EIA 861	annual	by utility	none	complete	n/a	estimate	no	no	no	no
Res	EIA 826	monthly	by utility	none	medium	adequate	estimate	estimate	estimate	estimate	no
C&I	EIA 826	monthly	by utility	none	medium	adequate	estimate	estimate	no	no	no
Res	Bill data (RECS)	multi-year	by region	high	large	good	yes	yes	estimate	estimate	no
C&I	Bill data (CBECS)	multi-year	by region	high	large	good	yes	yes	no	no	no
Res	EEI Typical Bills	bi-annual	by utility	3 types	small	poor	yes	yes	estimate	estimate	no
C&I	EEI Typical Bills	bi-annual	by utility	9 types	small	poor	yes	yes	no	no	no
Res	Tariffs	multi-year	by region	high	small	good	yes	yes	yes	yes	yes
C&I	Tariffs	multi-year	by region	high	small	good	yes	yes	yes	yes	yes

The EIA 861 data are often used to estimate average prices by defining the price as the ratio of total revenues to total sales. This is equivalent to calculating a consumption-weighted average bill across all consumers for a given utility and sector. This approach doesn't allow for the fact that the price depends on the consumer's baseline electricity use. In addition, non-residential tariffs generally define the utility bill as a function of both consumption and demand, so datasets that include only electricity consumption cannot account for how the demand affects price.

The EIA 826 data can be used to estimate a monthly average price in the same way as the EIA 861. The EIA826 data can also be used to estimate a marginal price by plotting the revenues vs. sales for each month and calculating the slope of this relationship. Seasonal values can be estimated by segregating the data into summer and winter months. The slope is a single number that represents the marginal revenue per additional unit of electricity sold for the utility. As with the EIA 861 data, this approach doesn't allow for any distinction between consumer segments or account for the role that electricity demand plays in determining prices.

The monthly utility bill data compiled with RECS and CBECS can be used to calculate both average prices and an approximate marginal price for each building in the sample. The marginal price is estimated by plotting the total bill vs. consumption for each billing period and estimating the slope of this relationship. For residential prices this is a useful approach as residential tariffs generally consist of a fixed charge plus tiered rates, which can be captured in a simple regression. For the non-residential sector however this approach is problematic, primarily because it is not possible to explicitly account for the effect of demand charges. Moreover, CBECS data have not included complete billing information since 1995.

The Edison Electric Institute publishes a "Typical Bills and Average Rates" report for summer and winter each year.[1] The data in these reports consist of the total consumer bill at a set of fixed usage levels for most of the major investor-owned utilities (IOU's) in the country. The commercial and industrial usage levels specify both the electricity consumption (E) and the peak electricity demand (D). Usage levels are summarized in Table 8C.2.2. The Edison Electric Institute (EEI) data can be used to estimate average prices for each of the typical bills, which helps to distinguish the effect of baseline energy use on the price. The EEI data also provide some ability to estimate the impact at the margin of changes in electricity consumption, as bills are provided with several levels of consumption for a fixed level of demand. The effect of demand can be evaluated to some extent with these data, by comparing bills for customers with the similar consumption but different demand levels, but the information provided is qualitative rather than quantitative.

The "Tariff Analysis Project" (TAP) database and calculation tools developed at LBNL[2,3] have also been used in some DOE rulemakings.[4] The TAP database consists of a complete set of residential and non-residential tariffs for approximately 100 utilities. The information in the tariffs is stored in a set of normalized data tables whose structure represents the most common tariff structures.[2] The tariff database is the only electricity price dataset that allows the marginal value of changes in electricity demand and consumption to be separately estimated for the non-residential sector, and that can explicitly model time-of-use rate structures. Hence, it allows for the computation of exact marginal prices, assuming the consumer baseline energy use, and appropriate decrements to both consumption and demand are known. However, this database is infrequently updated.

For this analysis, DOE used the EEI Typical Bills and Rates reports for 2014, as these provide the most up-to-date information. This allows separate calculation of rates for summer and winter. The EEI data were supplemented as needed with information from EIA and the TAP database. DOE's calculation methods for the residential and non-residential sectors are described in the next section

Table 8C.2.2 Consumption and Demand Levels Included in the EEI Typical Bills and Rates Reports

Index	Sector	Consumption (E)	Demand (D)	Load Factor (L)
1	residential	500	0	n/a
2	residential	750	0	n/a
3	residential	1,000	0	n/a
4	commercial	375	3	0.171
5	commercial	1,500	3	0.685
6	commercial	10,000	40	0.343
7	commercial	14,000	40	0.480
8	commercial	150,000	500	0.411
9	commercial	180,000	500	0.493
10	industrial	15,000	75	0.274
11	industrial	30,000	75	0.548
12	industrial	50,000	75	0.913
13	industrial	200,000	1,000	0.274
14	industrial	400,000	1,000	0.548
15	industrial	650,000	1,000	0.890
16	industrial	15,000,000	50,000	0.411
17	industrial	25,000,000	50,000	0.685
18	industrial	32,500,000	50,000	0.890

8C.3 RESIDENTIAL SECTOR

DOE used the EEI typical bills to calculate an average and a marginal price for each utility, consumption level and season. The average price is equal to the total bill divided by the consumption:

$$p_i = \frac{B_i}{E_i}$$

Eq. 8C.6

where:

i is the index of the typical bill from Table 8C.2.1,
B_i is the bill,
E_i is the electricity consumption, and
p_i is the average price.

The marginal price was determined by comparing the bills at two different consumption levels:

$$m_{ij} = \frac{(B_i - B_j)}{(E_i - E_j)}$$

Eq. 8C.7

DOE used m_{32} as the marginal price for consumers with baseline energy use above E_2 = 750 kWh/month, and m_{21} as the marginal price for consumers with baseline energy use below E_2. DOE used p_1 as the average price for consumers with baseline consumption below E_1, p_3 as the price for consumers whose baseline is above E_3, and p_2 for those in between. DOE created regional weighted-average values for p_i and m_{ij} by using the utility consumer counts to weight the contribution of each utility in a region. The regions used are census division/large state as used in the RECS data. The consumer counts were taken from the most recent available EIA 861 data (in this case 2012).

The EEI data do not contain information about publicly-owned utilities (POUs). DOE used the EIA data to account for the possibility that prices for POUs might differ systematically from those for IOUs. To begin with, an estimated average price p' for each utility and sector was calculated as the ratio of revenues to sales. Next, two regional weighted averages of p' were calculated, one based on all utilities (p'_{all}), and one based on only IOUs (p'_{IOU}). DOE then defined an adjustment factor for each region and sector as the ratio p'_{all}/p'_{IOU}. This adjustment factor, (shown in Table 8C.3.1 for all sectors) was applied to the prices calculated from the EEI data.

The result of this analysis is a set of average and marginal prices that vary by region and by baseline electricity consumption. DOE assigned an average and a marginal price to each of the households in the RECS 2009 database based on its location and average monthly energy use. The regional prices used for the residential sector, incorporating the adjustment factor, are provided in Table 8C.3.2.

Table 8C.3.1 Adjustment Factors by Region and Sector

Region	Commercial	Industrial	Residential
1. New England	1.002	0.988	0.994
2. Middle Atlantic	1.002	1.003	0.997
3. East North Central	1.008	1.042	1.001
4. West North Central	1.045	1.198	1.012
5. South Atlantic	1.044	1.016	1.006
6. East South Central	1.080	1.028	1.024
7. West South Central	1.056	1.021	1.016
8. Mountain	0.982	1.066	0.994
9. Pacific	0.857	0.820	0.855
10. New York	1.006	0.960	0.999
11. Florida	1.052	0.984	1.020
12. Texas	1.022	1.180	0.963
13. California	0.966	1.033	0.968

Table 8C.3.2 Residential Sector Electricity Prices by Region

Region	Summer Prices (cents/kWh)					Winter Prices (cents/kWh)				
	p_1	p_2	p_3	m_{21}	m_{32}	p_1	p_2	p_3	m_{21}	m_{32}
1. New England	18.4	17.8	17.5	16.6	16.8	18.7	18.1	17.8	16.8	17.1
2. Middle Atlantic	15.3	15.1	15.1	14.6	15.0	15.0	14.5	14.3	13.7	13.7
3. East North Central	14.0	13.5	13.2	12.6	12.3	13.3	12.7	12.3	11.6	10.9
4. West North Central	13.5	12.8	12.5	11.6	11.6	12.1	11.4	10.7	9.8	8.9
5. South Atlantic	12.7	12.1	12.0	11.1	11.7	12.4	11.7	11.3	10.4	10.0
6. East South Central	12.9	12.0	11.5	10.1	10.1	12.5	11.5	10.8	9.5	8.9
7. West South Central	11.1	10.9	10.6	10.4	9.7	10.3	9.7	9.2	8.7	7.5
8. Mountain	12.3	12.2	12.2	12.1	12.1	11.9	11.4	11.2	10.4	10.5
9. Pacific	14.5	14.2	14.0	13.4	13.6	14.5	14.1	13.9	13.3	13.5
10. New York	21.6	20.5	20.0	18.3	18.3	27.0	25.8	25.1	23.3	23.3
11. Florida	11.9	11.3	11.0	10.0	10.0	11.8	11.1	10.8	9.9	9.9
12. Texas	12.4	11.9	11.7	11.0	11.0	11.1	10.6	10.4	9.7	9.6
13. California	17.5	22.9	26.1	33.7	35.6	16.7	21.7	24.7	31.8	33.7

8C.4 NON-RESIDENTIAL SECTOR

Electricity tariffs for non-residential consumers can be very complex, with the principal difference from residential rates being the incorporation of demand charges. The presence of demand charges means that two consumers with the same monthly electricity consumption may have very different bills, depending on their peak demand. Utilities use a broad range of pricing schemes for demand,[2] so the simplest way to characterize the effect of demand charges at the margin is to use an empirical marginal price, defined below.

While the EIA and EEI data make a distinction between the commercial and industrial sectors, utility tariffs typically refer only to consumer usage characteristics (small, medium or large power, high load factor, *etc.*). Hence, the commercial/industrial distinction is somewhat ill-defined in real tariff data. In this analysis DOE uses the commercial and the industrial bills with index ≤ 15 to represent the non-residential sector consisting of commercial buildings and the type of light industry that would typically take place in buildings. The EEI bills for industrial with index ≥ 16 are used to represent heavy industry.

The average prices p_i are calculated using the same method as for the residential sector, with p_i equal to the ratio of the bill to the electricity consumption. Average prices depend on the demand and consumption values that define the bill. Analysis of the data show that prices are also sensitive to the billing-period load factor L. The load factor is defined as the ratio to the average hourly energy use to the peak demand for the billing period:

$$L = (\frac{E}{D}) \times (\frac{1}{H})$$

Eq. 8C.8

where:

$\boldsymbol{H}$ = the number of hours in the average monthly billing period (8,760/12).

Values for L for each commercial and industrial bill are included in Table 8C.2.2. Sensitivity of the average price to demand, consumption and load factor is illustrated in Table 8C.4.1 which provides the national weighted-average (across all utilities in the EEI data) values of pi for summer and winter. The data are sorted on the value of the summer average price. The right-most column defines a bin for the load factor, with L < 0.4 assigned to bin 1, 0.4 ≤ L ≤ 0.6 to bin 2, and L > 0.6 in bin 3. While the ordering of the prices is generally consistent with large users at the low end and small users at the high end, it is most closely tied to the ordering of the load factors. This is especially significant for the mid-range of consumption. The point here is that it can be misleading to assign prices based only on customer size as measured by either consumption or demand; the load factor is an equally important determinant of price.

Table 8C.4.1 Average Price for the US for each Bill Type, Sorted by Summer Price

Sector	Consumption (E)	Demand (D)	Load Factor (L)	Index	Summer	Winter	L-bin
ind	32,500,000	50000	0.890	18	7.32	6.63	3
ind	25,000,000	50000	0.685	17	7.91	7.08	3
ind	650,000	1000	0.890	15	8.47	7.42	3
ind	50,000	75	0.913	12	9.31	8.23	3
ind	15,000,000	50000	0.411	16	9.52	8.34	2
ind	400,000	1000	0.548	14	10.09	8.62	2
ind	30,000	75	0.548	11	10.80	9.40	2
com	180,000	500	0.493	9	11.46	10.37	2
com	14,000	40	0.480	7	12.21	11.13	2
com	150,000	500	0.411	8	12.33	11.02	2
ind	200,000	1000	0.274	13	13.69	11.28	1
com	10,000	40	0.343	6	13.74	12.32	1
ind	15,000	75	0.274	10	14.00	11.88	1
com	1,500	3	0.685	5	14.38	13.24	3
com	375	3	0.171	4	18.14	16.92	1

Marginal prices are defined using the approach developed for the TAP data.[2,4] In this approach, independent marginal consumption and marginal demand prices are defined based on the change in the bill induced by independently changing either one or the other variable. The marginal consumption price (also called the marginal energy price) is defined as:

$$e = \frac{[B(E + \Delta E, D) - B(E, D)]}{\Delta E}$$

Eq. 8C.9

where:

B is the bill expressed as a function of E and D,
E is the electricity consumption,
D is the electricity demand,
ΔE is the increment to electricity consumption (which may be negative), and
e is the marginal energy price or marginal consumption price.

Similarly, a marginal demand price d is defined by:

$$d = \frac{[B(E, D + \Delta D) - B(E, D)]}{\Delta D}$$

Eq. 8C.10

where:

ΔD is the increment to electricity demand (which may be negative), and
d is the marginal demand price.

Typically an energy conservation measure will alter both the consumption and demand. This affects the price through a variable called the marginal load factor λ. The equation for λ is:

$$\lambda = (\frac{\Delta E}{\Delta D}) \times (\frac{1}{H})$$

Eq. 8C.11

where:

H = the number of hours in the average monthly billing period (8,760/12).

The marginal load factor λ is a dimensionless number is analogous to the billing period load factor L, it measures the ratio of the average hourly decrement to the peak demand decrement. The ratio of these two is partly determined by the degree to which the load decrement is coincident with the overall building load shape. For on-off loads such as lighting, the marginal load factor is equal to the fraction of total hours that the load is on. For flat loads such as refrigeration, λ is close to one, while for strongly peaking loads like air conditioning λ is likely to be in the range 0.15-0.5.

The values of e and d are determined by the tariff and the baseline consumer data (E, D), but λ is a variable in the marginal price equation. The empirically-determined marginal price, defined as the change in the bill induced by the joint increment ($E + \Delta E$, $D + \Delta D$),[2] can be written as a function of λ [a] as

$$m = e + [\left(\frac{d}{H}\right) \times \left(\frac{1}{\lambda}\right)]$$

Eq. 8C.12

The value d/H has the same units as e (dollars per kWh). With this definition, the change in the bill is equal to $m \times \Delta E$, which accords with the usual definition of a marginal price. When the demand charges are zero, this marginal price is equal to the energy-only marginal price. The minimum value of λ is $1/H$, and the maximum value is 1. In real applications λ is unlikely to fall below 0.1.[3]

The EEI data allow estimation of marginal energy prices based on the equation

[a] The equation for m is equivalent to setting $m \times \Delta E = (e \times \Delta E) + (d \times \Delta D)$.

$$e_{ij} = \frac{B_i - B_j}{E_i - E_j}$$

Eq. 8C.13
Eq. 8C.13

for pairs of indices (i, j) corresponding to constant demand and varying energy ((i, j) = (4,5), (6,7), (8,9), (10,11), (11,12), *etc.*). As the EEI data do not allow the marginal demand price d to be estimated directly, DOE used previous analyses of commercial tariffs to estimate the marginal demand price by region.[4] The marginal demand prices estimated based on earlier data were scaled to 2014 using AEO current and historical price indices.

If data about building baseline energy use is available, then in principle prices can be assigned based on the typical bill the building most closely resembles. However, when these data are not available a method must be used to average across the typical bills to get a single regional value from the EEI data for the average prices (p) and marginal energy prices (e). For this analysis, DOE used the CBECS building samples used for the tariff work[4] to estimate the relative weight of buildings that should be assigned to the different consumption tiers represented in the EEI data. For averaging across bill types, DOE excluded very low and very high load factors as not representative of real buildings. Consumption tiers were defined using mid-points between the values used for the typical bills, as shown in Table 8C.4.2. For example, any building with monthly consumption between 22,000 kWh and 105,000 kWh was assigned to the bill with index=11. In creating the tiers, DOE mixed the commercial and industrial bills because, as noted above, these distinctions are typically not used in the utility tariffs.

Table 8C.4.2 Definition of Consumption Tiers for Averaging Across Bill Types

Tier	E_min	E_max	Index	Sector
1	0	7,750	5	com
2	7,750	22,000	7	com
3	22,000	105,000	11	ind
4	105,000	290,000	9	com
5	290,000	7,700,000	14	ind
6	7,700,000	20,000,000	15	ind
7	20,000,000	ω	16	ind

Once the average across bill types is complete, for each region a summer and winter average price, marginal energy price and marginal demand price can be calculated. For a given value of the marginal load factor, the empirical marginal price can also be defined. For the commercial sector, as the only location data available in CBECS are census divisions, DOE used these to define the regions. The Mountain and Pacific census divisions (8 and 9) were further subdivided into north and south based on the CBECS climate zone. Region 8.1 includes CBECS climate zone 1, and subdivision 8.2 all other climate zones. Subdivision 9.1 includes CBECS climate zones 1, 2 and 3, while subdivision 9.2 includes climate zones 4 and 5. The state assignments are 8.1 = (MT, ID, WY), 8.2 = (NV, UT, CO, AZ, NM), 9.1 = (WA ,OR), and 9.2 = CA.

The results of the analysis are presented in Table 8C.4.3. The table includes the marginal price calculated for $\lambda = 0.5$, which is a reasonable mid-range value for many end-uses.

Table 8C.4.3 Non-Residential Sector Prices by Region

Region	Average Price (*p*) cents/kwh		Marginal Energy Price (*e*) cents/kwh		Marginal Demand Price (*d*) $/kWh		Marginal Price (*m*) with $\lambda = 0.5$	
	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter
1_NE	15.36	16.03	12.61	13.54	15.73	11.29	16.92	16.63
2_Mid-Atl	13.88	14.46	10.86	12.12	12.79	13.27	14.36	15.75
3_ENC	11.28	10.51	9.28	8.54	12.05	10.30	12.58	11.36
4_WNC	10.71	8.82	8.56	7.04	5.61	4.58	10.09	8.30
5_S-Atl	10.18	9.88	7.78	7.46	6.84	6.42	9.65	9.22
6_ESC	11.38	10.81	9.28	8.77	6.37	5.65	11.03	10.32
7_WSC	9.58	8.29	7.72	6.60	4.43	3.10	8.93	7.45
8.1_Mtn_N	9.46	8.80	7.72	7.21	3.65	3.73	8.72	8.23
8.2_Mtn_S	10.95	9.72	7.61	6.70	7.48	7.50	9.66	8.75
9.1_Pac_N	9.39	9.41	7.85	7.82	2.19	2.16	8.44	8.42
9.2_Pac_S	21.11	13.32	13.99	10.20	8.84	4.02	16.41	11.30

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APPENDIX 8D. LIFETIME DISTRIBUTIONS

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APPENDIX 8D. LIFETIME DISTRIBUTIONS

8D.1 INTRODUCTION

In order to perform a life-cycle cost analysis, the U.S. Department of Energy (DOE) characterized the lifetime of portable air conditioners (ACs) being considered for new energy efficiency standards. DOE characterized portable ACs lifetimes using a Weibull probability distribution encompassing lifetime estimates from minimum to maximum, as described in chapter 8, section 8.2.5. The Weibull distribution is recommended for evaluating lifetime data, because it can be shaped to match low, most likely (or average), or high values. The probability of exceeding the high value is contained in the long tail of the Weibull distribution.[1, 2]

8D.2 DERIVATION OF WEIBULL DISTRIBUTION PARAMETERS

Weibull distributions utilize data to assign low, average, and high values to a random variable that has unknown distribution parameters. DOE applied Weibull distributions to product lifetime data for portable ACs to derive low, average, and high lifetime values, along with a percentile containing a high value. A similar approach is described in a technical note to the Crystal Ball software, which uses a most likely value in place of an average value.[3] The Weibull distribution can be defined as:

$$f(x) = \frac{\beta}{\alpha}\left(\frac{x-L}{\alpha}\right)^{\beta-1} \exp^{-\left(\frac{x-L}{\alpha}\right)^{\beta}}$$

Where:

L = location,
α = scale, and
β = shape.

The cumulative distribution therefore is:

$$F(x) = 1 - \exp^{-\left(\frac{x-L}{\alpha}\right)^{\beta}}$$

Weibull distribution parameters are specified as follows.

1. The output deviates must be greater than the expert opinion of low value.
2. The average, X_{avg}, must be equal to the average value from the available data.
3. The high value, xb, must correspond to some particular percentile point (such as 95 percent or 90 percent).

The values for the parameters in the equations were determined using the approach outlined in Crystal Ball's technical note.[3] Crystal Ball can be used to check a solution by specifying a Weibull distribution that has the calculated parameters (location, scale, and shape) in an assumption cell, then generating a forecast that equals that assumption. The forecast histogram and statistics will confirm whether the Weibull distribution matches the desired shape.

8D.3 LIFETIME DISTRIBUTION FOR PORTABLE AIR CONDITIONERS

Table 8D.3.1 shows the average, minimum, and maximum lifetimes plus maximum percentile values used to determine the Weibull distribution parameters α and β for portable ACs. DOE estimated that the maximum lifetime percentile for portable ACs was 99 percent.

Table 8D.3.1 Distribution Parameters for Portable ACs

Value				Weibull Parameters	
Minimum ***years***	**Average** ***years***	**Maximum** ***years***	**Maximum Percentile %**	**Alpha** ***scale***	**Beta** ***shape***
1	10.47	20	99	10.66	2.64

Figure 8D.3.1 shows the Weibull distribution for the lifetime of portable ACs. The lifetime distribution is based on the retirement function, which indicates the number of portable ACs that fail and are retired in each year of their life. DOE used an average lifetime of 10.47 years in its analyses.

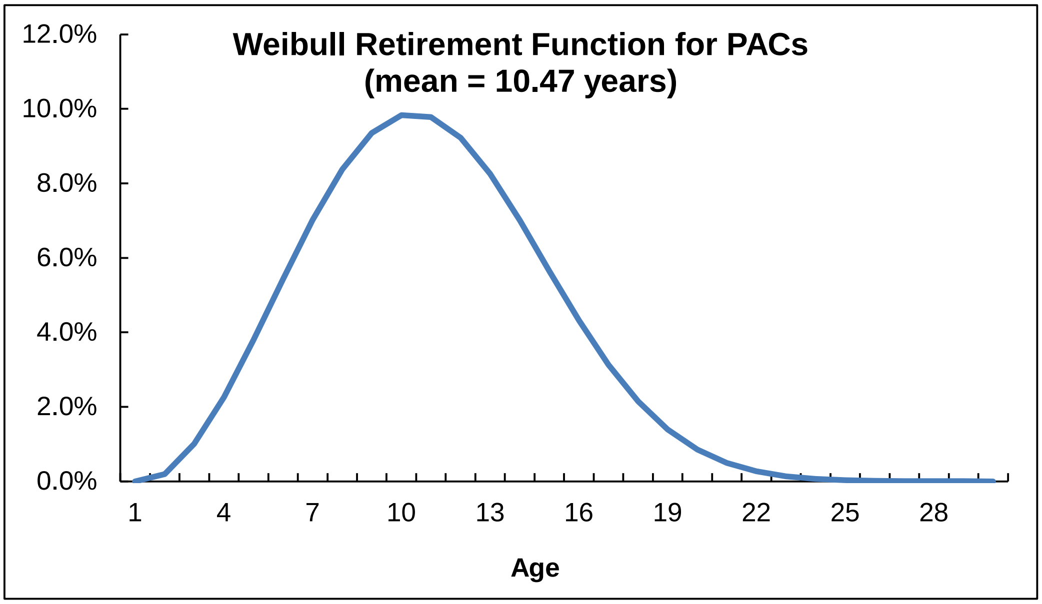

Figure 8D.3.1 Percent of Portable ACs Retiring each Year

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APPENDIX 8E. DISTRIBUTIONS USED FOR DISCOUNT RATES

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APPENDIX 8E. DISTRIBUTIONS USED FOR DISCOUNT RATES

8E.1 INTRODUCTION

The Department of Energy (DOE) estimated discount rate distributions by customer type: commercial and consumer (*i.e.* non-commercial residential end user). This appendix describes the distributions used.

8E.2 DISTRIBUTIONS USED FOR CONSUMER DISCOUNT RATES

The Department of Energy (DOE) derived consumer discount rates for the life-cycle cost (LCC) analysis using data on interest or return rates for various types of debt and equity to calculate a real effective discount rate for each household in the Federal Reserve Board's *Survey of Consumer Finances (SCF)* in 1995, 1998, 2001, 2004, 2007, 2010, and 2013.[1] To account for variation among households in rates for each of the types, DOE sampled a rate for each household in its building sample from a distribution of discount rates for each of six income groups. This appendix describes the distributions used.

8E.2.1 Distribution of Rates for Debt Classes

Figure 8E.2.1 through Figure 8E.2.6 show the distribution of real interest rates for different types of household debt. The data source for the interest rates for mortgages, home equity loans, credit cards, installment loans, other residence loans, and other lines of credit is the Federal Reserve Board's *SCF* in 1995, 1998, 2001, 2004, 2007, 2010 and 2013. DOE adjusted the nominal rates to real rates using the annual inflation rate in each year.

Using the appropriate *SCF* data for each year, DOE adjusted the nominal mortgage interest rate and the nominal home equity loan interest rate for each relevant household in the *SCF* for mortgage tax deduction and inflation. In cases where the effective interest rate is equal to or below the inflation rate (resulting in a negative real interest rate), DOE set the real effective interest rate to zero.

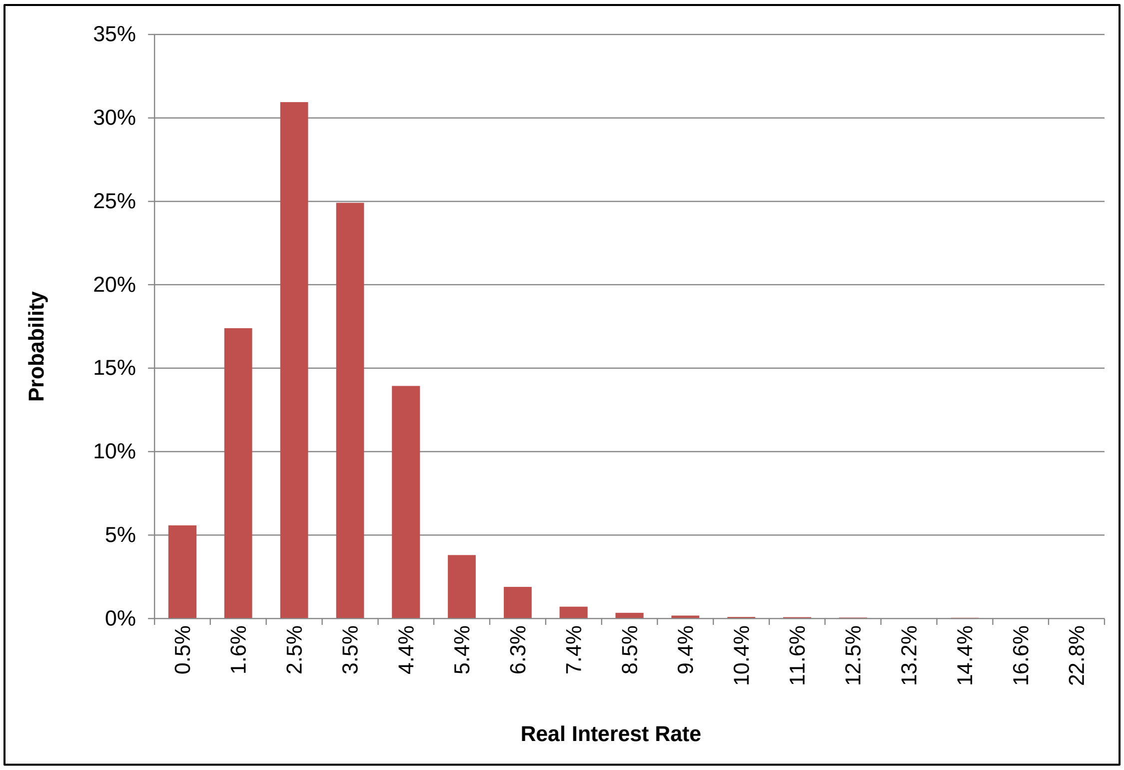

Figure 8E.2.1 Distribution of Mortgage Interest Rates

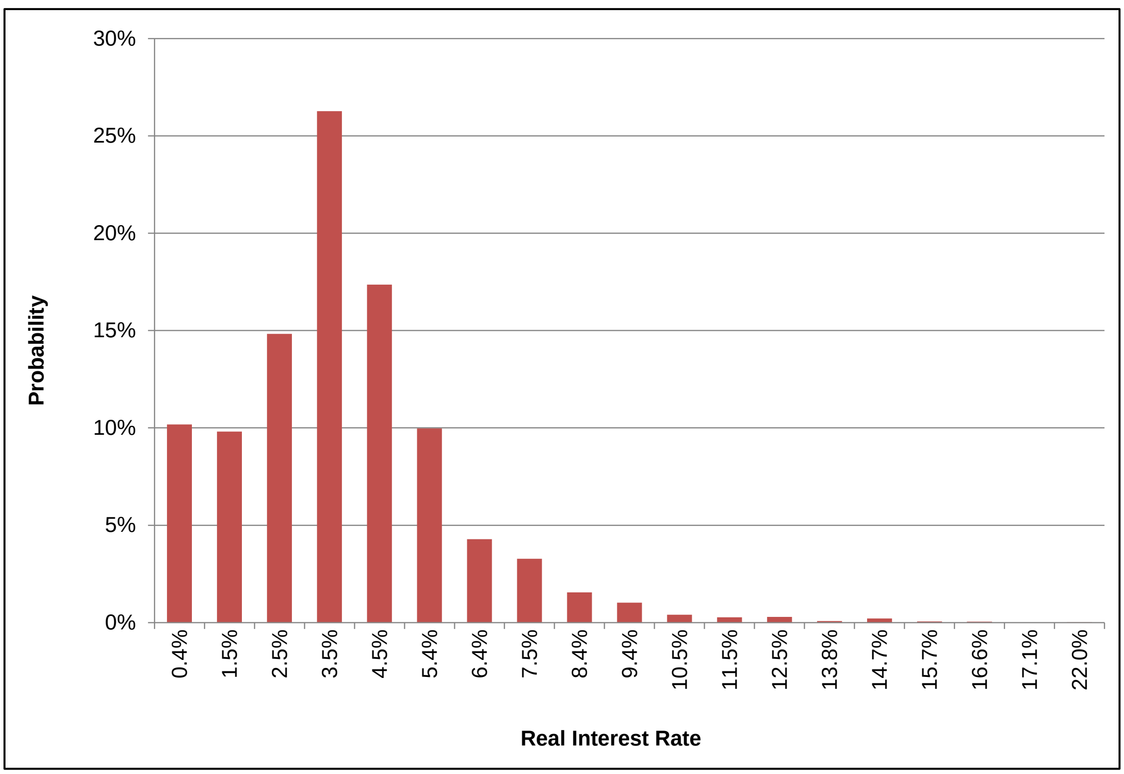

Figure 8E.2.2 Distribution of Home Equity Loan Interest Rates

Figure 8E.2.3 Distribution of Credit Card Interest Rates

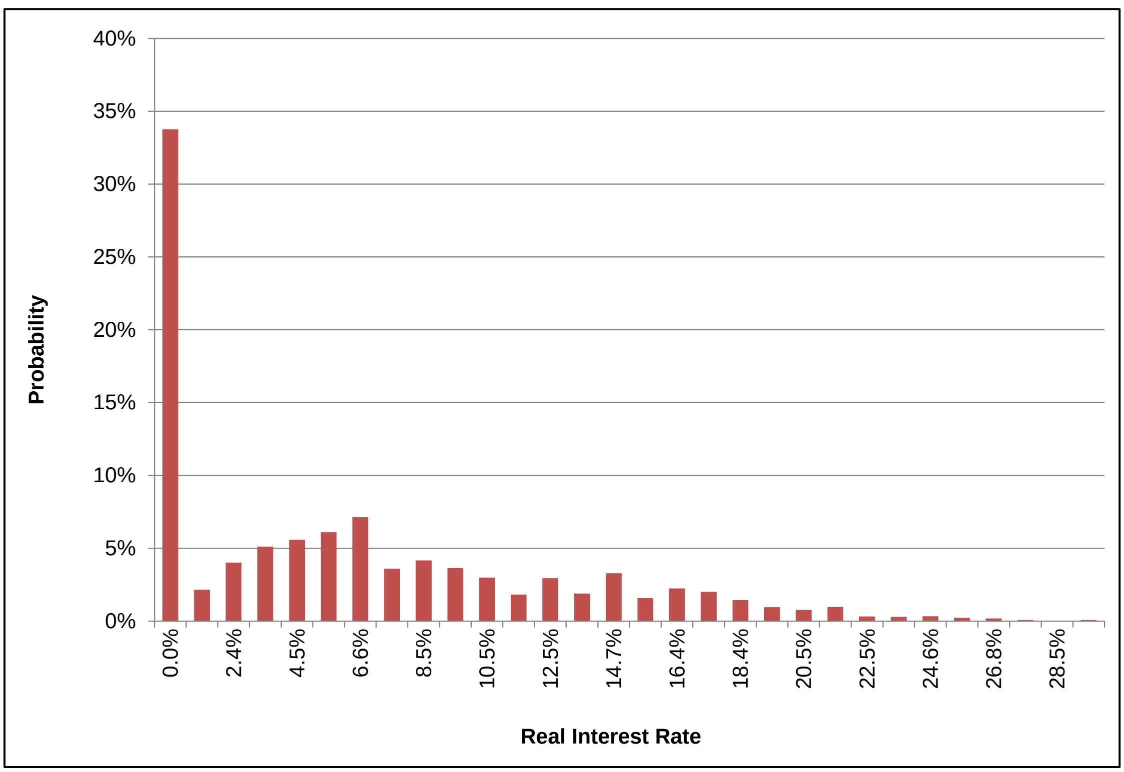

Figure 8E.2.4 Distribution of Installment Loan Interest Rates

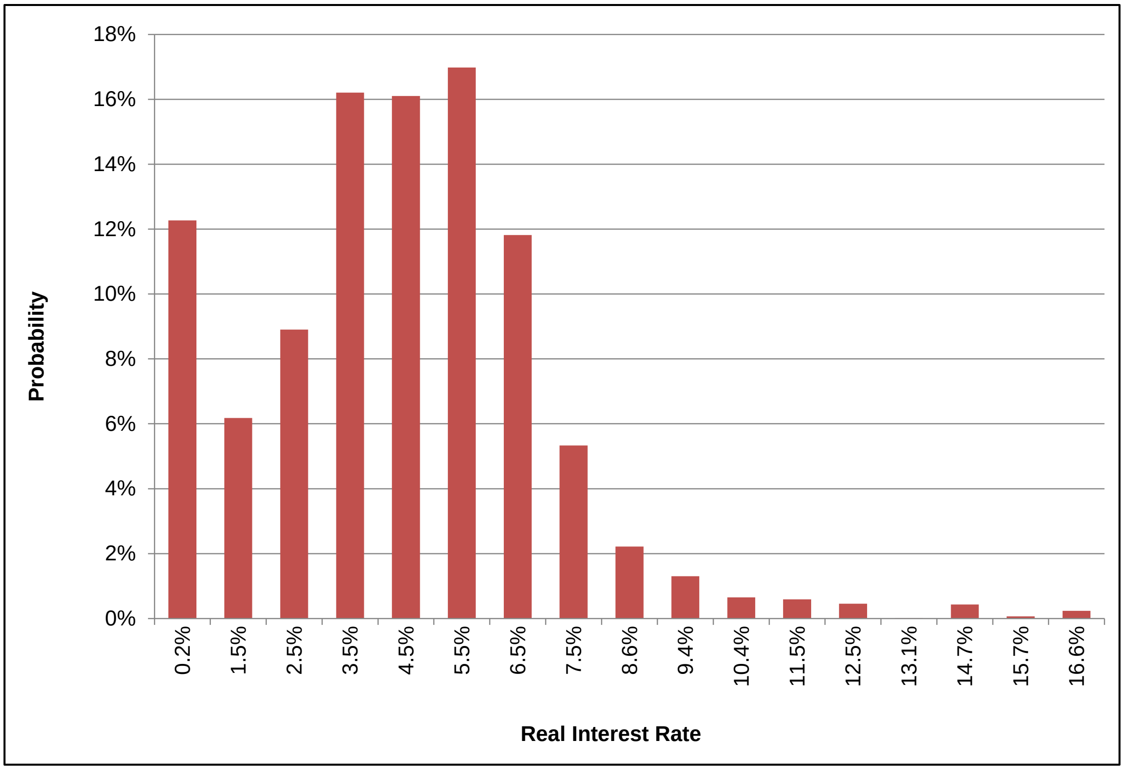

Figure 8E.2.5 Distribution of Other Residence Loan Interest Rates

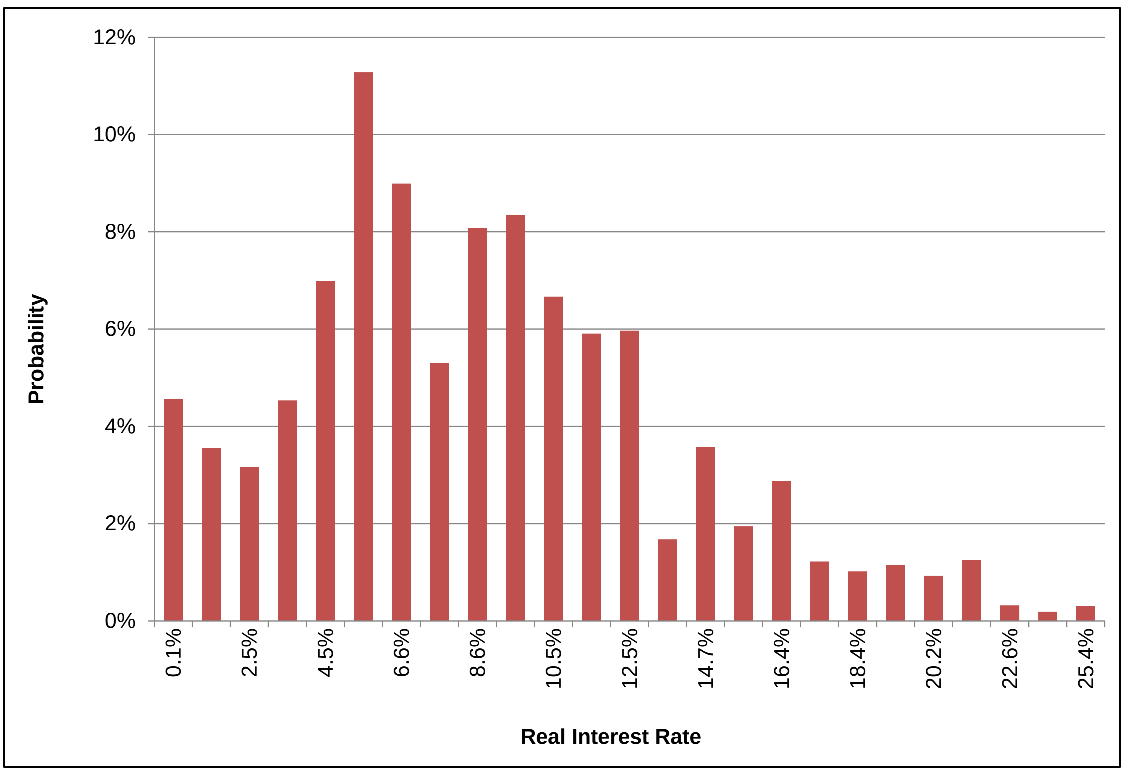

Figure 8E.2.6 Distribution of Other Lines of Credit Loan Interest Rates

8E.2.2 Distribution of Rates for Equity Classes

Figure 8E.2.7 through Figure 8E.2.12 show the distribution of real interest rates for different types of equity. Data for equity classes are not available from the Federal Reserve Board's *SCF*, so DOE derived data for these classes from national-level historical data (1986-2014). The interest rates associated with certificates of deposit (CDs),[2] savings bonds,[3] and AAA corporate bonds[4] are from Federal Reserve Board time-series data. DOE assumed rates on checking accounts to be zero. Rates on savings and money market accounts are from Cost of Savings Index data.[5] The rates for stocks are the annual returns on the Standard and Poor's (S&P) 500.[6] The mutual fund rates are a weighted average of the stock rates (two-thirds weight) and the bond rates (one-third weight) in each year. DOE adjusted the nominal rates to real rates using the annual inflation rate in each year.

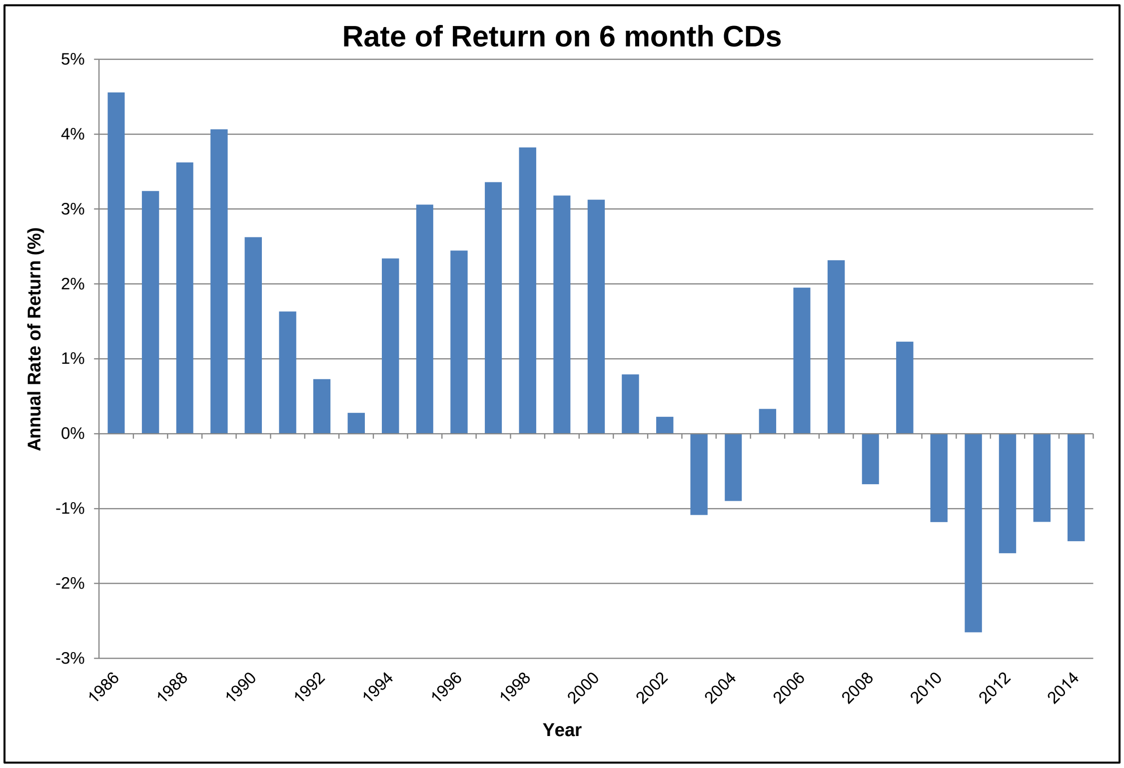

Figure 8E.2.7 Distribution of Annual Rate of Return on CDs

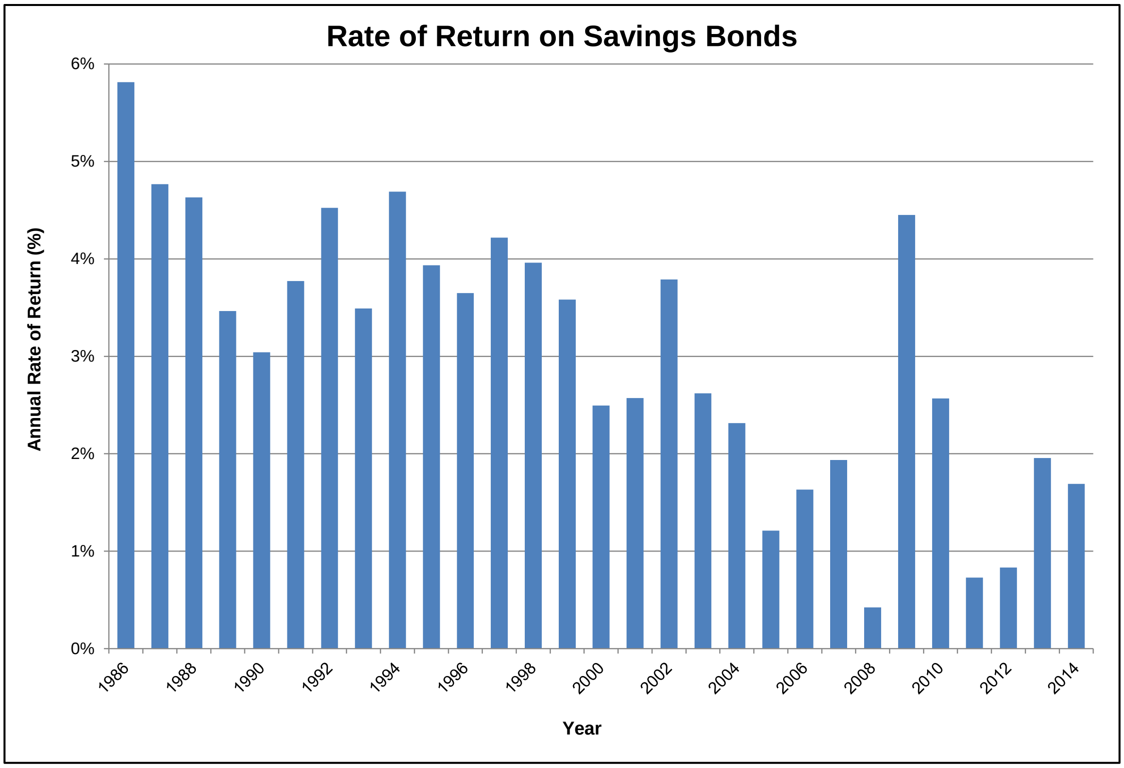

Figure 8E.2.8 Distribution of Annual Rate of Return on Savings Bonds

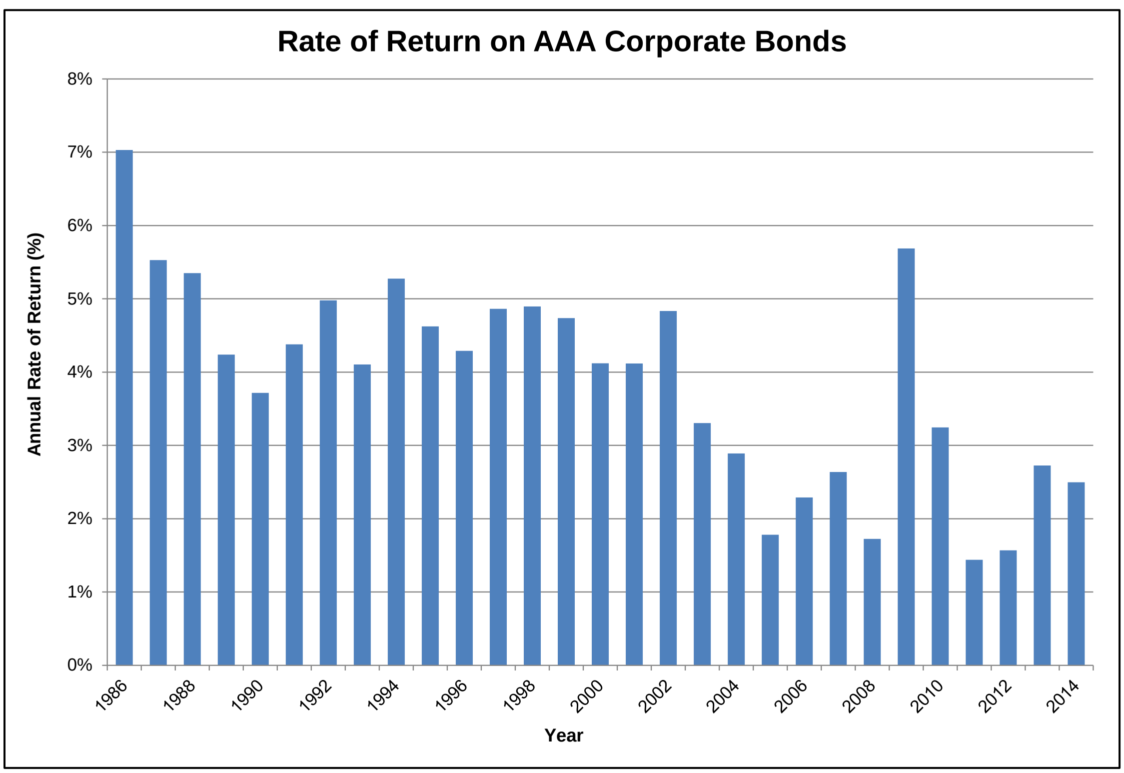

Figure 8E.2.9 Distribution of Annual Rate of Return on Corporate AAA Bonds

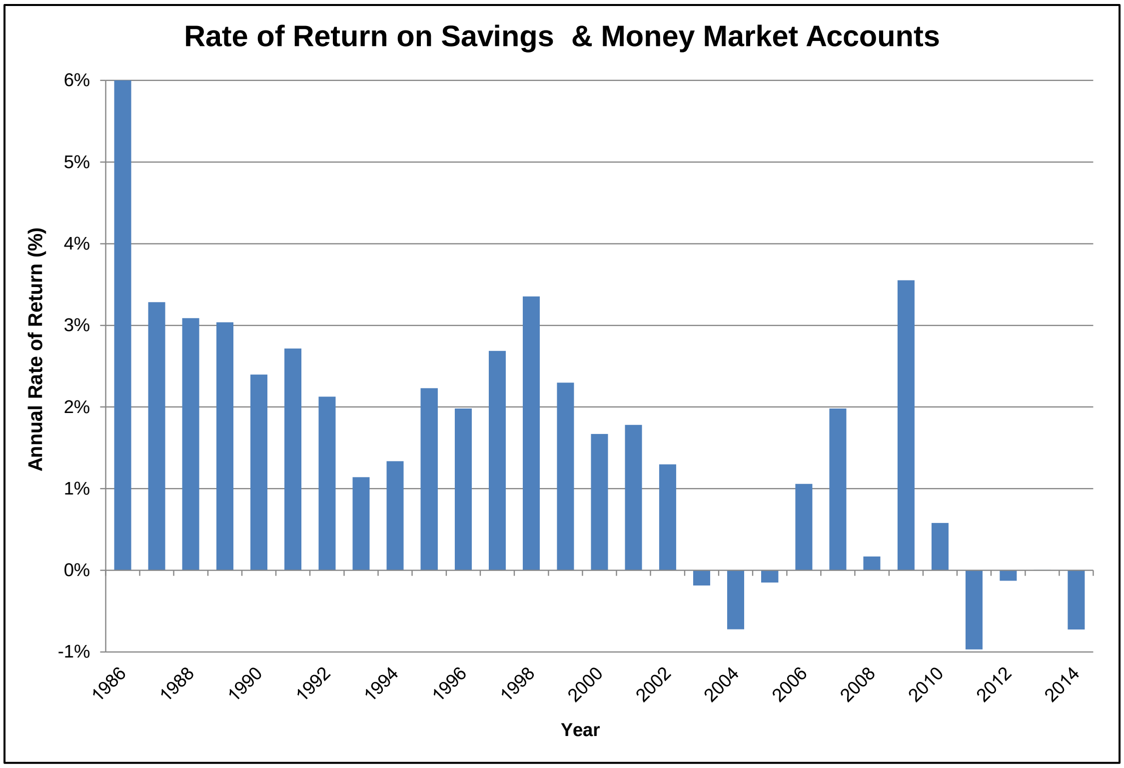

Figure 8E.2.10 Distribution of Annual Rate of Savings Accounts

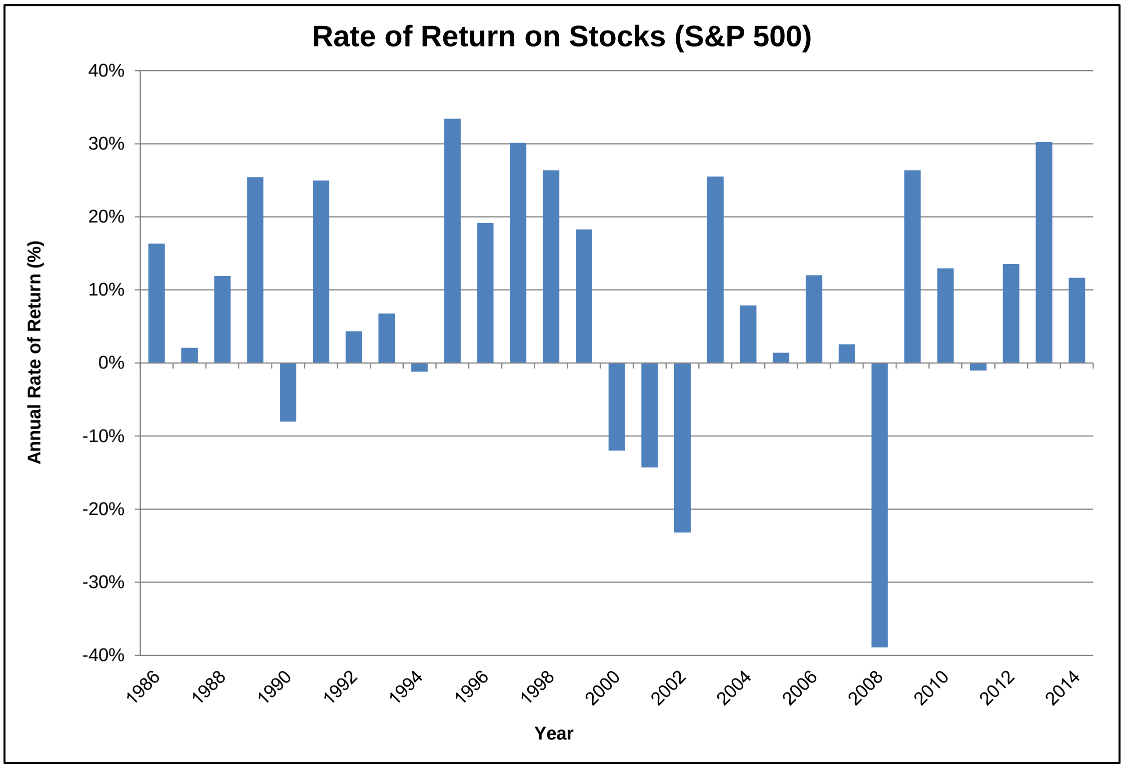

Figure 8E.2.11 Distribution of Annual Rate of Return on S&P 500

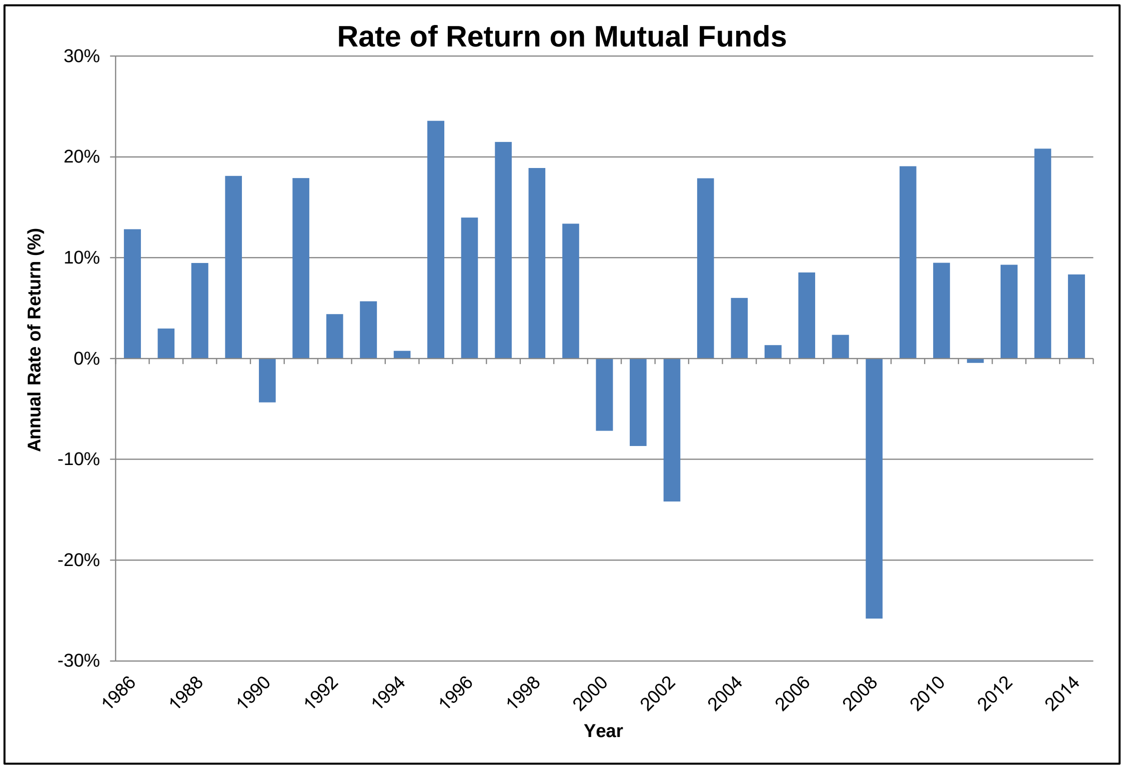

Figure 8E.2.12 Distribution of Annual Rate of Return on Mutual Funds

8E.2.3 Distribution of Real Effective Discount Rates by Income Group

Figure 8E.2.13 and Table 8E.2.1 present the distributions of real discount rates for each income group.

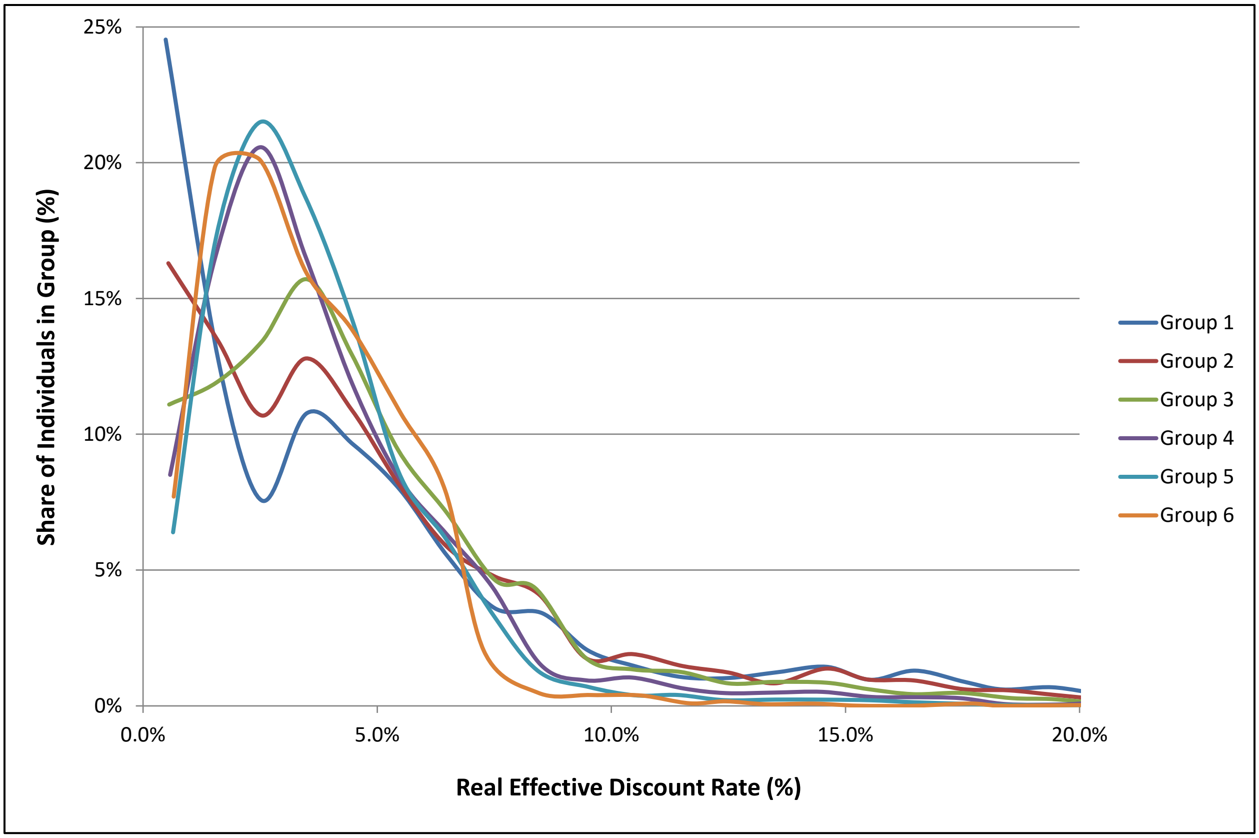

Figure 8E.2.13 Distribution of Real Discount Rates by Income Group

Table 8E.2.1 Distribution of Real Discount Rates by Income Group

DR Bin	Income Group 1 (1-20 percentile)		Income Group 2 (21-40 percentile)		Income Group 3 (41-60 percentile)		Income Group 4 (61-80 percentile)		Income Group 5 (81-90 percentile)		Income Group 6 (90-99 percentile)	
	rate	weight	rate	weight	rate	weight	rate	weight	rate	weight	rate	weight
0-1	0.4%	0.248	0.5%	0.167	0.5%	0.114	0.6%	0.090	0.6%	0.069	0.6%	0.081
1-2	1.5%	0.125	1.5%	0.136	1.5%	0.123	1.5%	0.167	1.5%	0.177	1.5%	0.211
2-3	2.5%	0.078	2.5%	0.106	2.5%	0.134	2.5%	0.209	2.5%	0.217	2.5%	0.206
3-4	3.5%	0.104	3.5%	0.128	3.5%	0.158	3.5%	0.166	3.5%	0.193	3.5%	0.175
4-5	4.5%	0.099	4.5%	0.109	4.5%	0.130	4.5%	0.124	4.5%	0.144	4.5%	0.142
5-6	5.5%	0.080	5.5%	0.085	5.5%	0.096	5.5%	0.087	5.5%	0.087	5.5%	0.111
6-7	6.5%	0.056	6.5%	0.058	6.5%	0.071	6.5%	0.058	6.5%	0.055	6.4%	0.050
7-8	7.5%	0.036	7.5%	0.053	7.5%	0.054	7.4%	0.033	7.4%	0.021	7.4%	0.006
8-9	8.5%	0.033	8.4%	0.029	8.5%	0.027	8.5%	0.014	8.5%	0.011	8.5%	0.005
9-10	9.5%	0.016	9.5%	0.018	9.5%	0.017	9.5%	0.009	9.5%	0.007	9.5%	0.004
10-11	10.5%	0.015	10.5%	0.019	10.5%	0.013	10.4%	0.010	10.5%	0.004	10.6%	0.004
11-12	11.5%	0.010	11.5%	0.014	11.5%	0.012	11.6%	0.007	11.4%	0.004	11.6%	0.001
12-13	12.5%	0.010	12.5%	0.012	12.5%	0.008	12.4%	0.004	12.4%	0.002	12.5%	0.002
13-14	13.5%	0.012	13.5%	0.008	13.5%	0.009	13.5%	0.005	13.5%	0.002	13.4%	0.001
14-15	14.6%	0.014	14.6%	0.014	14.6%	0.009	14.5%	0.005	14.6%	0.002	14.4%	0.001
15-16	15.5%	0.010	15.5%	0.010	15.5%	0.006	15.5%	0.003	15.5%	0.002	15.2%	0.000
16-17	16.5%	0.013	16.5%	0.009	16.4%	0.004	16.5%	0.003	16.4%	0.001	16.4%	0.000
17-18	17.5%	0.009	17.5%	0.006	17.5%	0.005	17.5%	0.003	17.6%	0.001	17.6%	0.001
18-19	18.4%	0.006	18.5%	0.006	18.5%	0.003	18.4%	0.001	18.2%	0.000	18.3%	0.000
19-20	19.4%	0.007	19.4%	0.004	19.4%	0.002	19.6%	0.001	19.7%	0.000	19.3%	0.000
20-21	20.6%	0.004	20.4%	0.003	20.4%	0.001	20.3%	0.001	20.5%	0.000	20.3%	0.000
21-22	21.4%	0.005	21.3%	0.002	21.4%	0.001	21.4%	0.001	21.0%	0.000	21.4%	0.000
22-23	22.4%	0.002	22.4%	0.001	22.6%	0.001	22.6%	0.000	22.8%	0.000	22.3%	0.000
23-24	23.5%	0.001	23.4%	0.001	23.5%	0.001	23.0%	0.000	23.0%	0.000	23.9%	0.000
24-25	24.6%	0.001	24.4%	0.000	24.6%	0.000	24.1%	0.000	24.3%	0.000	0.0%	0.000
25-26	25.4%	0.001	25.4%	0.001	25.4%	0.001	25.0%	0.000	25.0%	0.000	0.0%	0.000
26-27	26.4%	0.001	26.4%	0.000	26.3%	0.000	26.0%	0.000	26.0%	0.000	0.0%	0.000
27-28	27.5%	0.000	27.6%	0.000	27.5%	0.000	27.1%	0.000	27.1%	0.000	0.0%	0.000
28-29	28.1%	0.001	28.1%	0.000	0.0%	0.000	0.0%	0.000	0.0%	0.000	0.0%	0.000
29-23	29.9%	0.000	29.3%	0.000	0.0%	0.000	0.0%	0.000	0.0%	0.000	0.0%	0.000
>30	70.1%	0.001	162.1%	0.002	33.7%	0.000	53.3%	0.000	0.0%	0.000	0.0%	0.000

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APPENDIX 8F. LCC SENSITIVY ANALYSES

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APPENDIX 8F. LCC SENSITIVY ANALYSES

8F.1 INTRODUCTION

In addition to its reference scenario presented in chapter 8 of this final rule TSD, DOE performed a number of sensitivity scenarios. DOE performed the following sensitivity analyses:

- Assuming portable ACs are in cooling mode for 50 percent of the time that room ACs are in cooling mode. (LCC and NIA only)
- Assuming a geographic distribution of consumers matching a figure in an appendix provided by the Association of Home Appliance Manufacturers (AHAM) in comments to the NOPR. [a] (LCC and NIA only)
- Eliminating the room size threshold criterion of 1000 square feet used to define the residential consumer sample. (LCC and NIA only)
- Using the Annual Energy Outlook 2016[1] (hereafter, AEO 2016) High Growth, No Clean Power plan scenario for electricity price trends.
- Using the AEO 2016 Low Growth, No Clean Power Plant scenario for electricity price trends.

The LCC results for the described scenarios are presented in the section below.

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[a] Available at: 2016-09-26 Comment response to the published Notice of Proposed Rulemaking (NOPR) and announcement of public meeting; Reopening of public comment period, https://www.regulations.gov/docketBrowser?rpp=25&so=DESC&sb=commentDueDate&po=0&dct=PS&D=EERE-2013-BT-STD-0033

8F.2 RESULTS

8F.2.1 Reduced Cooling-Mode Hours

Table 8F.2.1 LCC Results for Reduced Cooling-Mode Hours Sensitivity Analysis

EL	EER	CEER	Average Costs *2015$*				Simple Payback *years*	Average Lifetime *years*
			Installed Cost	First Year's Operating Cost	Lifetime Operating Cost	LCC		
0	5.35	5.08	559	69	560	1,119	--	10.5
1	6.05	5.94	588	62	502	1,090	4.3	10.5
2	7.15	7.13	635	53	433	1,068	5.1	10.5
3	8.48	8.46	700	45	368	1,068	6.3	10.5
4	10.75	10.73	733	37	300	1,033	5.8	10.5

Note: The average LCC, LCC savings, and simple PBP for each efficiency level are calculated assuming that all consumers use products having that EL. This assumption allows the results for each efficiency level to be compared under the same conditions.

Table 8F.2.2 LCC Savings Results for Reduced Cooling-Mode Hours Sensitivity Analysis

Efficiency Level	EER	CEER	Life-Cycle Cost Savings	
			% of Consumers Who Experience Net Cost	Average Savings* *2015$*
1	6.05	5.94	16	29
2	7.15	7.13	42	35
3	8.48	8.46	57	30
4	10.75	10.73	52	64

* The calculation excludes households with zero LCC savings (no impact).

Further results of the reduced hours sensitivity analysis can be found in appendices 10E.

8F.2.2 AHAM Consumer Geographic Distribution

AHAM commented that DOE's consumer samples based on room ACs does not geographically match results AHAM obtained through an online survey. Although DOE has not received the full survey results, DOE conducted a sensitivity analysis using data points estimated from AHAM's Figure 6 in Appendix B of their comments. DOE reweighted the residential and commercial sample such that 24 percent of the sample was from the Northeast, 13 percent from the Midwest, 29 percent from the South, and 34 percent from the West.

Table 8F.2.3 LCC Results for AHAM Consumer Geographic Distribution Sensitivity Analysis

EL	EER	CEER	Average Costs *2015$*				Simple Payback *years*	Average Lifetime *years*
			Installed Cost	First Year's Operating Cost	Lifetime Operating Cost	LCC		
0	5.35	5.08	559	142	1,149	1,708	--	10.5
1	6.05	5.94	588	127	1,025	1,613	1.9	10.5
2	7.15	7.13	635	108	877	1,513	2.4	10.5
3	8.48	8.46	700	91	739	1,439	2.9	10.5
4	10.75	10.73	733	73	592	1,325	2.6	10.5

Note: The average LCC, LCC savings, and simple PBP for each efficiency level are calculated assuming that all consumers use products having that EL. This assumption allows the results for each efficiency level to be compared under the same conditions.

Table 8F.2.4 LCC Savings Results AHAM Consumer Geographic Distribution Sensitivity Analysis

Efficiency Level	EER	CEER	Life-Cycle Cost Savings	
			% of Consumers Who Experience Net Cost	Average Savings* *2015$*
1	6.05	5.94	8	94
2	7.15	7.13	23	142
3	8.48	8.46	33	196
4	10.75	10.73	29	307

* The calculation excludes households with zero LCC savings (no impact).

8F.2.3 No Room-size Threshold for Residential Consumer Sample

Table 8F.2.5 LCC Results for Reduced Cooling-Mode Hours Sensitivity Analysis

EL	EER	CEER	Average Costs *2015$*				Simple Payback *years*	Average Lifetime *years*
			Installed Cost	First Year's Operating Cost	Lifetime Operating Cost	LCC		
0	5.35	5.08	559	134	1,098	1,657	--	10.5
1	6.05	5.94	588	120	986	1,574	2.2	10.5
2	7.15	7.13	635	104	852	1,487	2.7	10.5
3	8.48	8.46	700	88	726	1,427	3.3	10.5
4	10.75	10.73	733	72	593	1,325	3.0	10.5

Note: The average LCC, LCC savings, and simple PBP for each efficiency level are calculated assuming that all consumers use products having that EL. This assumption allows the results for each efficiency level to be compared under the same conditions.

Table 8F.2.6 LCC Savings Results for Reduced Cooling-Mode Hours Sensitivity Analysis

Efficiency Level	EER	CEER	Life-Cycle Cost Savings	
			% of Consumers Who Experience Net Cost	Average Savings* *2015$*
1	6.05	5.94	9	83
2	7.15	7.13	25	124
3	8.48	8.46	36	168
4	10.75	10.73	33	265

* The calculation excludes households with zero LCC savings (no impact).

8F.2.4 AEO 2016 High-Growth Scenario

Table 8F.2.7 LCC Results for AEO 2016 High-Growth Scenario

EL	EER	CEER	Average Costs *2015$*				Simple Payback *years*	Average Lifetime *years*
			Installed Cost	First Year's Operating Cost	Lifetime Operating Cost	LCC		
0	5.35	5.08	559	135	1,089	1,648	--	10.5
1	6.05	5.94	588	121	977	1,565	2.2	10.5
2	7.15	7.13	635	104	844	1,479	2.7	10.5
3	8.48	8.46	700	89	719	1,419	3.3	10.5
4	10.75	10.73	733	72	586	1,319	3.0	10.5

Note: The average LCC, LCC savings, and simple PBP for each efficiency level are calculated assuming that all consumers use products having that EL. This assumption allows the results for each efficiency level to be compared under the same conditions.

Table 8F.2.8 LCC Savings Results for AEO 2016 High-Growth Scenario

Efficiency Level	EER	CEER	Life-Cycle Cost Savings	
			% of Consumers Who Experience Net Cost	Average Savings* *2015$*
1	6.05	5.94	8	82
2	7.15	7.13	25	123
3	8.48	8.46	35	166
4	10.75	10.73	32	263

* The calculation excludes households with zero LCC savings (no impact).

8F.2.5 AEO 2016 Low-Growth Scenario

Table 8F.2.9 LCC Results for AEO 2016 Low-Growth Scenario

EL	EER	CEER	Average Costs *2015$*				Simple Payback *years*	Average Lifetime *years*
			Installed Cost	First Year's Operating Cost	Lifetime Operating Cost	LCC		
0	5.35	5.08	559	137	1,119	1,678	--	10.5
1	6.05	5.94	588	123	1,004	1,592	2.1	10.5
2	7.15	7.13	635	106	867	1,502	2.6	10.5
3	8.48	8.46	700	91	739	1,439	3.2	10.5
4	10.75	10.73	733	74	602	1,335	2.9	10.5

Note: The average LCC, LCC savings, and simple PBP for each efficiency level are calculated assuming that all consumers use products having that EL. This assumption allows the results for each efficiency level to be compared under the same conditions.

Table 8F.2.10 LCC Savings Results for AEO 2016 Low-Growth Scenario

Efficiency Level	EER	CEER	Life-Cycle Cost Savings	
			% of Consumers Who Experience Net Cost	Average Savings* *2015$*
1	6.05	5.94	8	85
2	7.15	7.13	24	127
3	8.48	8.46	35	174
4	10.75	10.73	31	274

* The calculation excludes households with zero LCC savings (no impact).

REFERENCES

1 U.S. Department of Energy-Energy Information Administration, *Annual Energy Outlook 2015 with Projections to 2040*, 2015. Washington, DC. <http://www.eia.gov/forecasts/aeo/>

APPENDIX 10A. USER INSTRUCTIONS FOR NATIONAL IMPACT ANALYSIS SPREADSHEET MODEL

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APPENDIX 10A. USER INSTRUCTIONS FOR NATIONAL IMPACT ANALYSIS SPREADSHEET MODEL

10A.1 USER INSTRUCTIONS

The results obtained in this analysis can be examined and reproduced using the Microsoft Excel® spreadsheets accessible on the Internet from the Department of Energy's (DOE's) residential portable AC rulemaking http://energy.gov/eere/buildings/appliance-and-equipment-standards-program. From that page, follow the links to the final rule phase of the rulemaking and then to the analytical tools.

10A.2 STARTUP

The national impact analysis (NIA) spreadsheets enable the user to perform an NIA for portable air conditions (ACs). DOE assumes that the user has access to a PC that has a hardware configuration capable of running Windows 2010 or later. To use the NIA spreadsheets, Microsoft Excel 2010 or later must be installed in the Windows operating system.

10A.3 DESCRIPTIONS OF NATIONAL IMPACT ANALYSIS WORKSHEETS

The NIA spreadsheet performs calculations to project the change in national energy use and net present value of financial impacts produced by potential energy conservation standards for portable ACs. The energy use and associated costs for a given standard level are determined by calculating (1) shipments under that standard and (2) energy use and costs for all portable ACs shipped under that standard. The differences between conditions under a given standards case and the no-new-standards case can be compared and the overall energy savings and net present values determined. The NIA spreadsheet worksheets are described below.

Worksheet	Description
Input and Summary	This sheet enables the user to stipulate inputs under "User Inputs." It also contains a summary table, "National Impact Summary," for the selected efficiency level. The sheet provides the incremental total installed prices associated with the standard levels being evaluated for portable ACs. This sheet also contains efficiency-weighted average energy use and the total installed product price for portable ACs under the no-new-standards case and standards cases.
Efficiency Distribution	This sheet contains the no-new-standards case and standards-case efficiency trends for portable ACs.
Historical Shipment	This sheet contains historical data regarding sales of portable ACs and estimated sales of portable ACs.
No-New-Stds	This sheet estimates shipments of portable ACs. The sheet starts

Case Shipments	with the stock accounting of the product and uses the appropriate survival function to calculate the surviving stock. The sheet then calculates saturation rate of the product each year, yielding total shipments of portable ACs during the analysis period.
Res_No-New-Stds Case	This sheet calculates the energy consumption and operating costs for portable ACs used in the residential sector under the no-new-standards case.
Res_Stds Case	This sheet estimates shipments to the residential sector for a given standards case by accounting for price elasticity of demand. It also calculates the energy and cost savings associated with a given standard. The energy and cost savings in a given year are the difference between the no-new-standards case and the standards-case energy use and costs in that year.
Comm_No-New-Stds Case	This sheet calculates the energy consumption and operating costs for portable ACs used in the commercial sector under the no-new-standards case.
Comm_Stds Case	This sheet estimates shipments to the commercial sector for a given standards case by accounting for price elasticity of demand. It also calculates the energy and cost savings associated with a given standard. The energy and cost savings in a given year are the difference between the no-new-standards case and the standards-case energy use and costs in that year.
Housing Projection	This sheet includes a projection of total housing stocks for residential buildings based on *Annual Energy Outlook 2016* (AEO 2016).
Electricity Prices	This worksheet contains projected average and marginal residential and commercial electricity prices for the three economic growth scenarios in AEO 2016.
Learning Rate	This sheet includes multipliers to adjust the manufacturer's cost throughout the analysis period based on a learning curve.
FFC Factor	The sheet contains the site-to-power plant and full-fuel-cycle conversion factors used to calculate the primary and full-fuel-cycle energy savings, respectively.
Lifetime	This sheet contains the lifetime and retirement function for portable ACs.

10A.4 BASIC INSTRUCTIONS

Basic instructions for operating the NIA spreadsheets are as follows.

1. After downloading the NIA spreadsheet file from DOE's website, use Microsoft Excel to open it. Click "Enable Macro" when prompted. At the bottom of the workbook, click on the tab for the worksheet *Input and Summary.*
2. Use Excel's "View/Zoom" command in the top menu bar to change the size of the display so that it fits your monitor.

3. Use the graphical interface in the worksheet to choose parameters or enter data. You can change the default choices for some of the inputs. To change a default input, select the desired value from the drop-down choices by the input box or enter the number manually where appropriate.The input parameters are as follows.
    A. Discount Rate. To change the value, which is set to 3 percent, click on cell D5 and change the value to 7 percent.
    B. Trial Standards Level. To change the level, click on the drop-down arrow to select TSL 1, 2, 3, or 4.
    C. Relative Price Elasticity. To change the applicable elasticity, use the drop-down arrow to select the desired value. To stipulate no impact or set the relative price elasticity to - 0.45.
    D. Economic Growth. To change the growth scenario, use the drop-down arrow to select the desired AEO growth case (Reference, Low, or High).
    E. Learning Sensitivity. To change the value, use the drop-down arrow to select the desired learning-curve level (Default, High, or Low).
    F. Annual Energy Consumption (AEU) Sensitivity. To change the annual energy consumption scenario, use the drop-down arrow to select the desired AEU values. (Default, 50% of operating hours).
    G. Current Year. To change the year, which is set to 2016, click on cell D6 and change the year.

After you have selected the desired parameters, the spreadsheet will automatically generate updated NIA results based on the new simulation. Results are reported in the “National Impact Summary” table to the right of the “User Inputs” box.

APPENDIX 10B. FULL-FUEL-CYCLE ANALYSIS

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APPENDIX 10B. FULL-FUEL-CYCLE ANALYSIS

10B.1 INTRODUCTION

This appendix summarizes the methods the U.S. Department of Energy (DOE) used to calculate the estimated full-fuel-cycle (FFC) energy savings from potential energy conservation standards. The FFC measure includes point-of-use (site) energy; the energy losses associated with generation, transmission, and distribution of electricity; and the energy consumed in extracting, processing, and transporting or distributing primary fuels. DOE's method of analysis previously encompassed only site energy and the energy lost through generation, transmission, and distribution of electricity. In 2011 DOE announced its intention, based on recommendations from the National Academy of Sciences, to use FFC measures of energy use and emissions when analyzing proposed energy conservation standards.[1] This appendix summarizes the methods DOE used to incorporate impacts of the full fuel cycle into the analysis.

In the national energy savings calculation, DOE estimates the site, primary and full-fuel-cycle (FFC) energy consumption for each standard level, for each year in the analysis period. DOE defines these quantities as follows:

- Site energy consumption is the physical quantity of fossil fuels or electricity consumed at the site where the end-use service is provided.[a] The site energy consumption is used to calculate the energy cost input to the NPV calculation.
- Primary energy consumption is defined by converting the site fuel use from physical units, for example cubic feet for natural gas, or kWh for electricity, to common energy units (million Btu or mmBtu). For electricity the conversion factor is a marginal heat rate that incorporates losses in generation, transmission and distribution, and depends on the sector, end use and year.
- The full-fuel-cycle (FFC) energy use is equal to the primary energy use plus the energy consumed "upstream" of the site in the extraction, processing and distribution of fuels. The FFC energy use was calculated by applying a fuel-specific FFC energy multiplier to the primary energy use.

For electricity from the grid, site energy is measured in terawatt-hours (TWh). The primary energy of a unit of grid electricity is equal to the heat content of the fuels used to generate that electricity, including transmission and distribution losses.[b] DOE typically measures the primary energy associated with the power sector in quads (quadrillion Btu). Both primary fuels and electricity are used in upstream activities. The treatment of electricity in full-fuel-cycle analysis must distinguish between electricity generated by fossil fuels and electricity generated from renewable sources (wind, solar, and hydro). For the former, the upstream fuel cycle relates

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[a] For fossil fuels, this is the site of combustion of the fuel.
[b] For electricity sources like nuclear energy and renewable energy, the primary energy is calculated using the convention described below.

to the fuel consumed at the power plant. There is no upstream component for the latter, because no fuel *per se* is used.

10B.2 HEAT RATES

DOE uses heat rates to convert site electricity savings in TWh to primary energy savings in quads. The heat rates are developed as a function of the sector, end-use and year of the analysis period. For this analysis DOE uses output of the DOE/Energy Information Administration (EIA)'s National Energy Modeling System (NEMS).[2] EIA uses the NEMS model to produce the *Annual Energy Outlook* (*AEO*). DOE's approach uses the most recently available edition, in this case *AEO2016*.[3] The *AEO* publication includes a reference case and a series of side cases incorporating different economic and policy scenarios. DOE's heat rate calculation methods depend on the scenarios available with the current AEO publication. When the data allow it, DOE calculates marginal heat rates as the ratio of the change in fuel consumption to the change in generation for each fossil fuel type, where the change is defined as the difference between the reference case and the side case. The marginal approach relies on the availability of side cases where the primary difference from the reference case is a reduction in demand for electricity, with relatively little change in the fuel mix and the economic and demographic drivers of electricity use. This approach was used with the *AEO2014* and *AEO2015*, and is documented in the appendices to rules published in that time frame. The marginal methodology, and the conditions under which it applies, are also discussed in Coughlin (2014).[4]

The side cases published with *AEO2016* do not allow for calculation of marginal heat rates, so DOE based its calculation of heat rates on grid-average data. DOE calculated heat rates in four steps:

1. DOE defined fuel-specific grid-average heat rates, as the ratio of primary energy consumed per unit of electricity generated for coal, natural gas and petroleum-based fuels. For renewable and nuclear generation, DOE adopted the EIA convention of assigning a constant heat rate of 10.5 Btu/Wh to nuclear power and 9.5 Btu/Wh to electricity from renewable sources. DOE calculated these heat rates for each of five geographic regions. The five regions consist of aggregations of the NERC reliability regions, which also map to aggregations of the NEMS Electricity Market Module regions as follows: region 1 consists of NERC regions NPCC and RFC, region 2 contains the SERC and FRCC regions, region 3 is MRO, region 4 ERCOT plus SPP, and region 5 is WECC. The fuel specific heat rates by region are shown in Figure 10B.2.1.

2. For each sector and end-use, DOE calculated regional weights based on the fraction of electricity consumption for that end-use in each of the five regions. DOE based this calculation on the AEO projection of end-use electricity consumption by census division, and a table matrix provided with the NEMS code that breaks down sectoral electricity use by both EMM region and census division. This calculation provides regional weights that vary by sector, end-use and year.

3. Within each region, DOE calculated the fraction of generation allocated to each fuel type based on AEO projections of generation by EMM region, for the major fuel types: coal, natural gas, nuclear, oil, and renewables. This grid-average calculation shows that

approximately 15-20% of generation is allocated to nuclear. The grid-average calculation is being used as an approximation to the marginal calculation, and all DOE's previous marginal calculations have shown that within NEMS nuclear power is never on the margin (*i.e.* total nuclear power generation is constant across all scenarios). To be consistent with previous marginal analyses, DOE zeroed out the nuclear portion of the generation fraction and redistributed the nuclear share proportionally across the other fuel types. The result is a set of factors defining the fraction of generation by fuel type for marginal reductions in demand that vary by region and year.

4. DOE multiplied the regional end-use weights by the product of the fraction of generation by fuel type and the fuel specific heat rates in each region, and summed over all regions and fuel types, to define a heat rate for each sector/end-use. This calculation also includes the transmission and distribution losses. In equation form:

$$h(u,y) = (1 + TDLoss)*\sum_{r,f} w(u,r)\, G(r,f,y)\, H(r,f,y)$$

Where:

TDLoss = the fraction of total generation that is lost in transmission and distribution, equal to 0.07037
u = an index representing the sector/end-use (e.g. commercial cooling)
r = the region
y = the analysis year
f = the fuel type
w(u,r) = the regional weight
H(r,f,y) = the fuel-specific heat rate plotted in Figure 10B.2.1
G(r,f,y) = the fraction of generation provided by fuel type *f* in region *r* and year *y*
h(u,y) = the end-use specific marginal heat rate

The sector/end-use specific heat rates are shown in Table 10B.2.1. These heat rates convert site electricity to primary energy in quads; i.e., the units used in the table are quads per TWh.

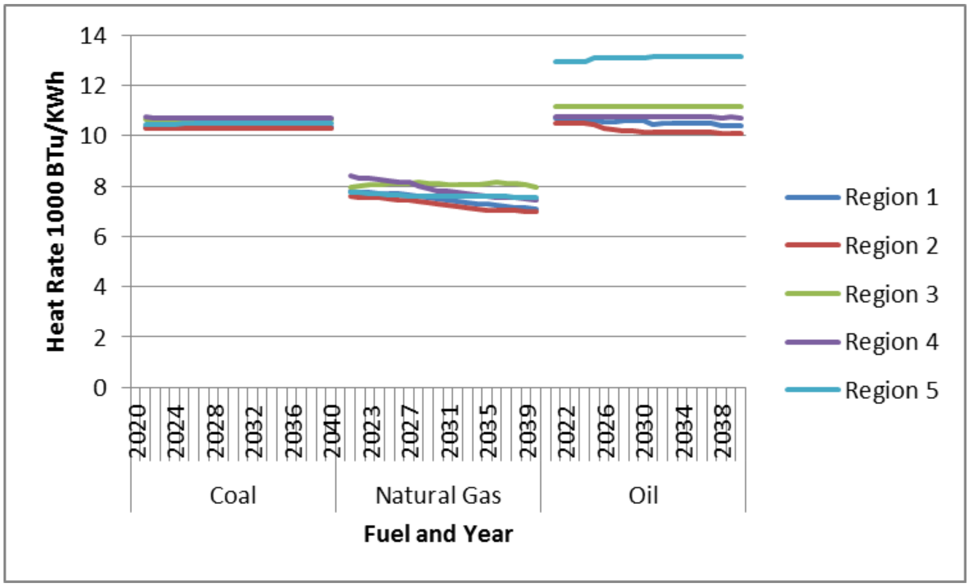

Figure 10B.2.1 Fuel Specific Heat Rates by Region

Table 10B.2.1 Electric Power Heat Rates (quads/TWh) by Sector and End-Use

	2021	2025	2030	2035	2040
Commercial Sector					
cooking	9.995E-03	9.908E-03	9.744E-03	9.599E-03	9.453E-03
lighting	1.002E-02	9.930E-03	9.775E-03	9.644E-03	9.503E-03
office equipment (non-pc)	1.003E-02	9.938E-03	9.792E-03	9.678E-03	9.543E-03
office equipment (pc)	1.001E-02	9.924E-03	9.772E-03	9.643E-03	9.500E-03
other uses	1.003E-02	9.939E-03	9.784E-03	9.655E-03	9.513E-03
refrigeration	1.002E-02	9.936E-03	9.778E-03	9.641E-03	9.495E-03
space cooling	1.001E-02	9.919E-03	9.750E-03	9.607E-03	9.468E-03
space heating	1.005E-02	9.972E-03	9.825E-03	9.701E-03	9.559E-03
ventilation	1.002E-02	9.933E-03	9.775E-03	9.640E-03	9.494E-03
water heating	1.000E-02	9.916E-03	9.757E-03	9.620E-03	9.480E-03
Industrial Sector					
all uses	1.006E-02	9.977E-03	9.826E-03	9.699E-03	9.560E-03
Residential Sector					
ceiling fans	1.003E-02	9.947E-03	9.789E-03	9.652E-03	9.501E-03
clothes dryers	1.000E-02	9.916E-03	9.759E-03	9.622E-03	9.487E-03
cooking	1.001E-02	9.919E-03	9.765E-03	9.633E-03	9.498E-03
electronics	1.002E-02	9.928E-03	9.778E-03	9.654E-03	9.516E-03
freezers	1.003E-02	9.949E-03	9.797E-03	9.667E-03	9.530E-03
furnace fans	1.006E-02	9.979E-03	9.834E-03	9.714E-03	9.560E-03
lighting	1.002E-02	9.931E-03	9.781E-03	9.659E-03	9.525E-03
other uses	1.001E-02	9.924E-03	9.764E-03	9.623E-03	9.486E-03
refrigeration	1.002E-02	9.936E-03	9.788E-03	9.668E-03	9.533E-03
space cooling	9.996E-03	9.907E-03	9.741E-03	9.597E-03	9.465E-03
space heating	9.996E-03	9.912E-03	9.756E-03	9.615E-03	9.478E-03
water heating	9.979E-03	9.895E-03	9.734E-03	9.589E-03	9.451E-03

10B.3 FFC METHODOLOGY

The methods used to calculate FFC energy use are summarized here. The mathematical approach to determining FCC is discussed in Coughlin (2012).[5] Details related to the modeling of the fuel production chain are presented in Coughlin (2013).[6]

When all energy quantities are normalized to the same units, FFC energy use can be represented as the product of the primary energy use and an FFC multiplier. Mathematically the FFC multiplier is a function of a set of parameters that represent the energy intensity and material losses at each stage of energy production. Those parameters depend only on physical data, so the calculations require no assumptions about prices or other economic factors. Although the parameter values may differ by geographic region, this analysis utilizes national averages.

The fuel cycle parameters are defined as follows.

- a_x is the quantity of fuel *x* burned per unit of electricity produced for grid electricity. The calculation of a_x includes a factor to account for losses incurred through the transmission and distribution systems.

- b_y is the amount of grid electricity used in producing fuel *y*, in MWh per physical unit of fuel *y*.

- c_{xy} is the amount of fuel *x* consumed in producing one unit of fuel *y*.

- q_x is the heat content of fuel *x* (MBtu/physical unit).

All the parameters are calculated as functions of an annual time step; hence, when evaluating the effects of potential new standards, a time series of annual values is used to estimate the FFC energy and emissions savings in each year of the analysis period and cumulatively.

The FFC multiplier is denoted μ (mu). A separate multiplier is calculated for each fuel used on site. Also calculated is a multiplier for electricity that reflects the fuel mix used in its generation. The multipliers are dimensionless numbers applied to primary energy savings to obtain the FFC energy savings. The upstream component of the energy savings is proportional to (μ-1). The fuel type is denoted by a subscript on the multiplier μ.

The method for performing the full-fuel-cycle analysis utilizes data and projections published in the *AEO 2016*.[3] Table 10B.3.1 summarizes the data used as inputs to the calculation of various parameters. The column titled "AEO Table" gives the name of the table that provided the reference data.

Table 10B.3.1 Dependence of FFC Parameters on *AEO* Inputs

Parameter(s)	Fuel(s)	*AEO* Table	Variables
q_x	All	Conversion factors	MMBtu per physical unit
a_x	All	Electricity supply, disposition, prices, and emissions Energy consumption by sector and source	Generation by fuel type Electric energy consumption by the power sector
b_c, c_{nc}, c_{pc}	Coal	Coal production by region and type	Coal production by type and sulfur content
b_p, c_{np}, c_{pp}	Petroleum	Refining industry energy consumption Liquid fuels supply and disposition International liquids supply and disposition Oil and gas supply	Refining-only energy use Crude supply by source Crude oil imports Domestic crude oil production
c_{nn}	Natural gas	Oil and gas supply Natural gas supply, disposition, and prices	U.S. dry gas production Pipeline, lease, and plant fuel
z_x	All	Electricity supply, disposition, prices, and emissions	Power sector emissions

The *AEO 2016* does not provide all the information needed to estimate total energy use in the fuel production chain. Coughlin (2013) describes the additional data sources needed to complete the analysis. The time dependence in the FFC multipliers, however, arises exclusively from variables taken from the *AEO*.

10B.4 ENERGY MULTIPLIERS FOR THE FULL FUEL CYCLE

FFC energy multipliers for selected years are presented in Table 10B.4.1. The 2040 value was held constant for the analysis period beyond 2040, which is the last year in the *AEO 2016* projection. The multiplier for electricity reflects the shares of various primary fuels in total electricity generation throughout the forecast period.

Table 10B.4.1 Energy Multipliers for the Full Fuel Cycle (Based on *AEO 2016*)

	2021	2025	2030	2035	2040
Electricity	1.041	1.043	1.045	1.044	1.045
Natural gas	1.108	1.106	1.104	1.105	1.106
Petroleum fuels	1.171	1.171	1.172	1.173	1.174

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APPENDIX 10C. NATIONAL NET PRESENT VALUE OF CONSUMER BENEFITS USING ALTERNATIVE PRODUCT PRICE FORECASTS

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APPENDIX 10C. NATIONAL NET PRESENT VALUE OF CONSUMER BENEFITS USING ALTERNATIVE PRODUCT PRICE FORECASTS

10C.1 INTRODUCTION

The net present value (NPV) results presented in chapter 10 are based on projections of future prices derived from historical Producer Price Index (PPI) data obtained from the Bureau of Labor Statistics (BLS). DOE collected PPI data on “small electric household appliances, except fans” for 1983–2015 to project future prices of portable air conditioners (ACs). To investigate the effect of different product price trends on the consumer NPV for the energy efficiency standards considered for portable ACs, DOE evaluated two alternatives, a low and a high price decline scenario. The following sections describe the methods DOE used to derive the two alternative price trends and the NPV results for all three scenarios.

10C.2 ALTERNATIVE PRICE TREND SCENARIOS

DOE obtained historical PPI data for “small electric household appliances, except fans” as a proxy for portable ACs. DOE understands that the PPI series encompasses a range of products unconnected to portable ACs, but it is the most disaggregated price series that includes portable ACs. DOE obtained the PPI data for 1983–2015 from the BLS.[a] DOE assumed that prices of all portable AC product classes will continue to show the same trend as for 1983–2015. DOE developed the low price decline scenario based on an exponential fit to the PPI data from the more limited period of 1998–2015. The high price decline scenario is based on the projection for the “furniture and appliances” industry series in the Energy Information Administration's *Annual Energy Outlook 2016* (AEO 2016).[1]

10C.2.1 Low Price Decline Scenario

For the low price decline scenario, DOE used the BLS' inflation-adjusted PPI for small electric household appliances spanning 1998–2015 to fit an exponential model having *year* as the explanatory variable. The PPI during that period shows a shallower downward trend than does the longer PPI series starting in 1983 and ending in 2014. The exponential fit based on the shorter period of historical PPI represents the low price decline scenario for projecting future prices. In this case, the exponential function takes the form of:

$$Y = a \cdot e^{bX}$$

where Y is the PPI for small electric household appliances, X is the time variable, a is the constant, and b is the slope parameter of the time variable.

The PPI data reflect nominal prices, adjusted for changes in product quality. DOE developed an inflation-adjusted (deflated) price index for small electric household appliances by

[a] PPI series ID: PCU33521033521014 http://www.bls.gov/ppi/

dividing the PPI series by the chained price index for the gross domestic product. Figure 10C.2.1 presents the nominal and inflation-adjusted PPI trends for small electric household appliances from 1998 to 2015.

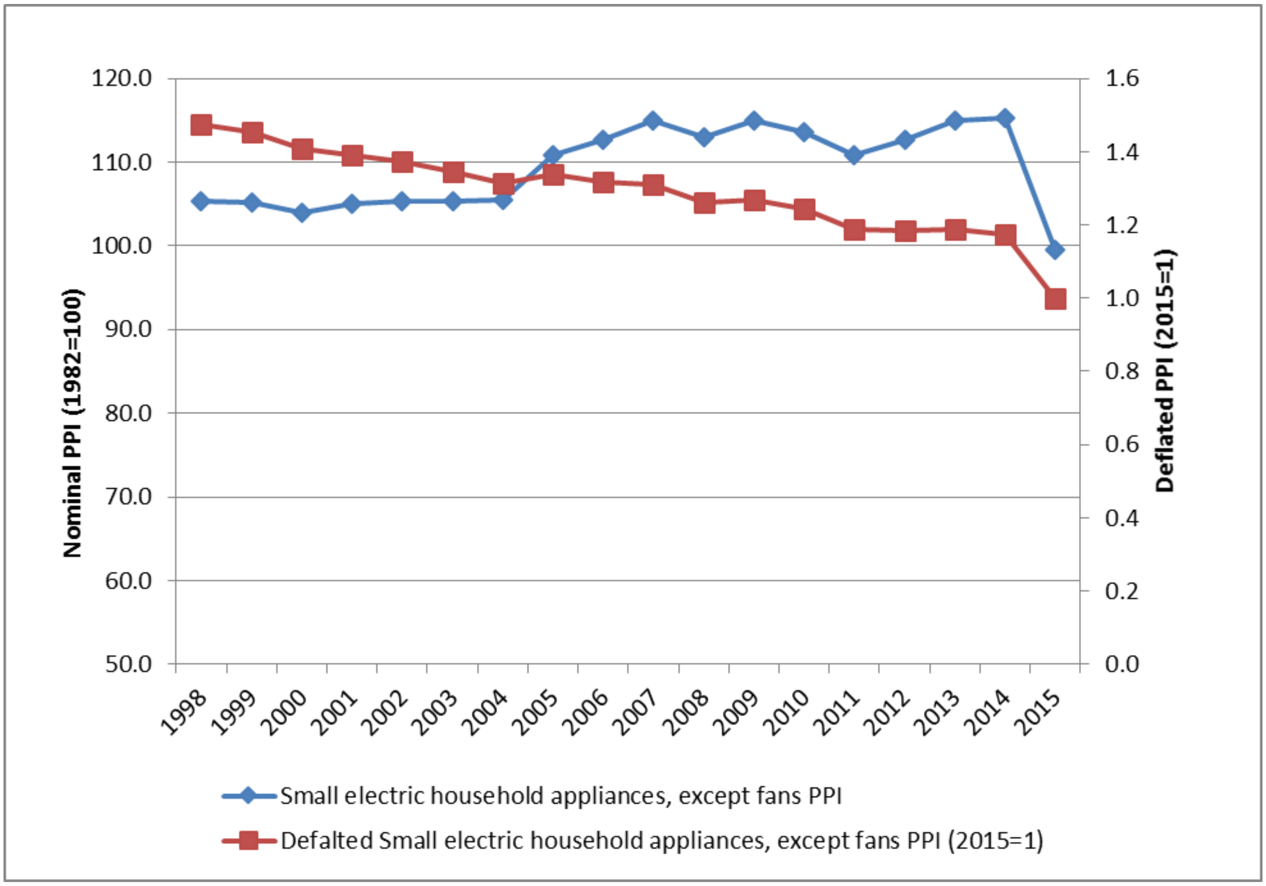

Figure 10C.2.1 Nominal and Deflated PPI Series for Small Electric Household Appliances, 1998–2015

To estimate the exponential parameters, a least-square fit was performed on the inflation-adjusted (deflated) price index versus year from 1998 to 2015. Figure 10C.2.2 shows the results.

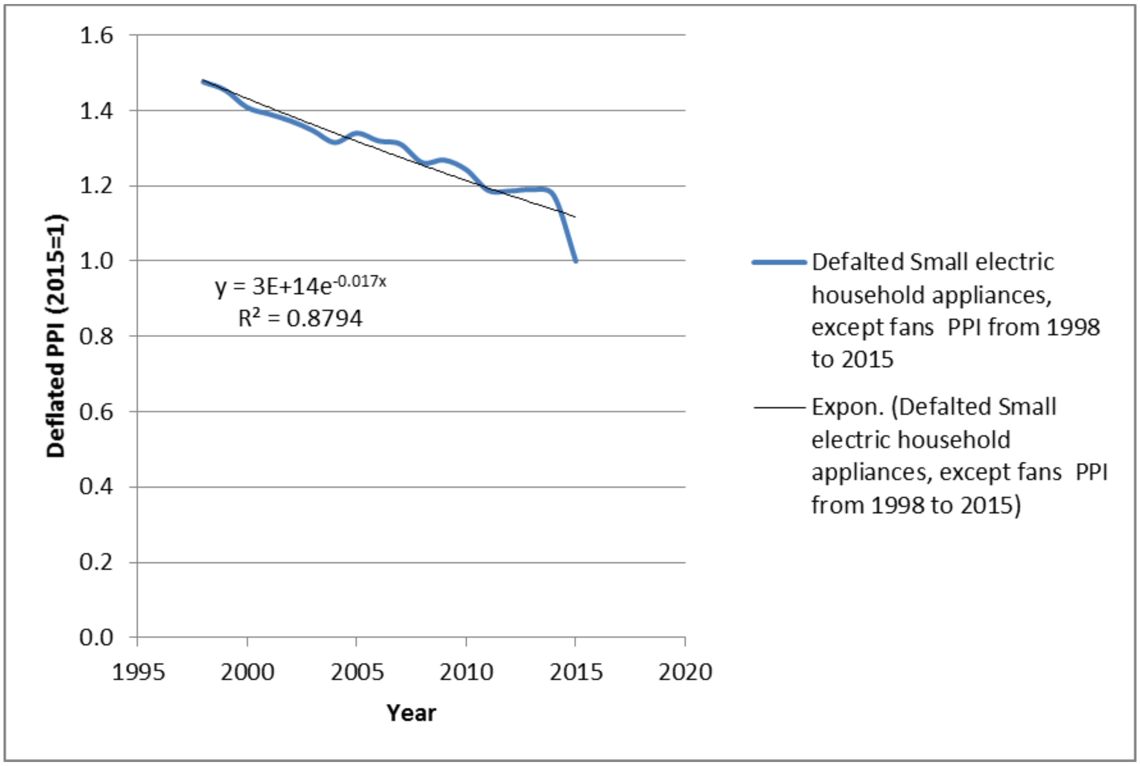

Figure 10C.2.2 Deflated PPI with Exponential Fit for Small Electric Household Appliances, 1998–2015

The regression performed as an exponential trend line fit results in an R-square of 0.88, which indicates a reasonable fit to the data. The final estimated exponential function is:

$$Y = 3.0756 \times 10^{14} \cdot e^{(-0.0165)X}$$

DOE then derived a price factor index for the low price decline scenario, renormalized with 2013 equal to 1, to project product prices in each future year in the analysis period. The index value in a given year is a function of the exponential parameter and *year*.

10C.2.2 High Price Decline Scenario

DOE also examined a forecast based on the "deflator—furniture and appliances" that the AEO 2016 included out to 2040. AEO 2016 offers the most current price trend projections DOE could acquire. The index also represents the most disaggregated category that includes portable ACs. To develop an inflation-adjusted index, DOE normalized the index using the AEO 2016 "chained price index—gross domestic product," with 2013 equal to 1. To extend the price index beyond 2040, DOE used the average annual price growth rate for 2031–2040.

10C.3 SUMMARY

Table 10C.3.1 presents the average annual rates of change for the product price index under the default, high, and low price scenarios. Figure 10C.3.1 shows the resulting price factor indexes (price trends) for portable ACs.

Table 10C.3.1 Price Trend Scenarios

Scenario	Price Trend	Average Annual Rate of Change %
Default	Exponential fit using PPI for small electric household appliances (1983–2015)	-1.96
High price decline	AEO 2016 “chained price index—furniture and appliances”	-2.82
Low price decline	Exponential fit using PPI for small electric household appliances (1998–2015)	-1.64

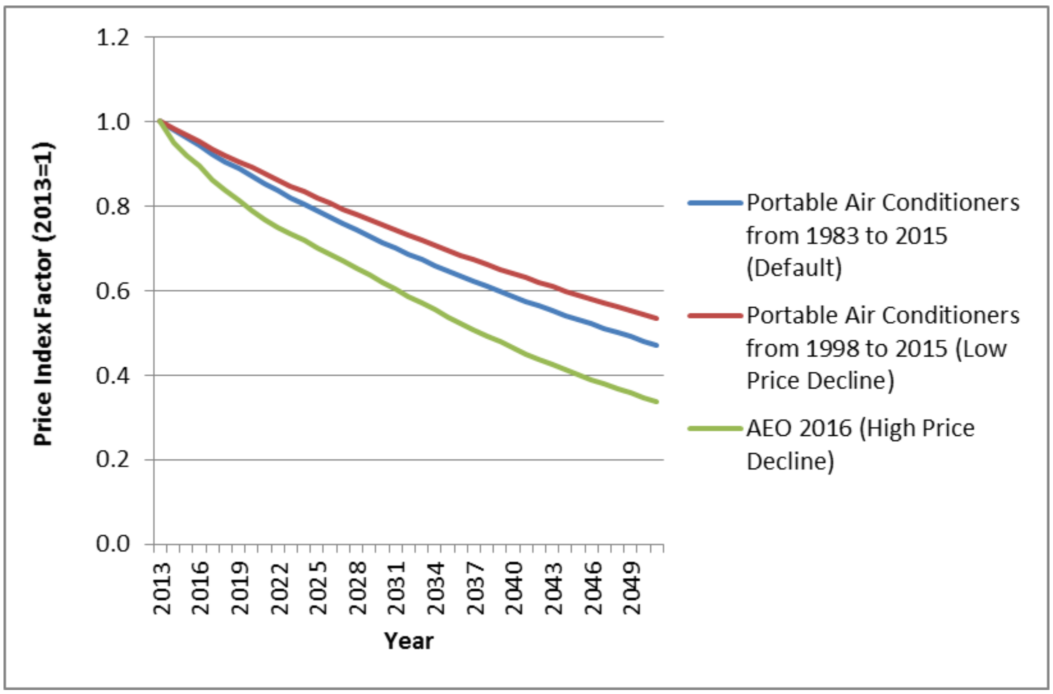

Figure 10C.3.1 Price Factor Indexes for the Default and Sensitivity Cases for Portable ACs

10C.4 NET PRESENT VALUE USING ALTERNATIVE PRICE TRENDS

Table 10C.4.1 presents the NPV of financial impacts under the three alternative product price trends for all four TSLs for purchases in both the residential and commercial sectors at a 3-percent discount rate. Table 10C.4.2 presents similar results for a 7-percent discount rate.

Table 10C.4.1 NPV of Impacts for Residential and Commercial Purchases Under Alternative Product Price Forecasts (3-Percent Discount Rate)

Price Trend	TSL	Residential *Billion 2015$*	Commercial *Billion 2015$*	Total *Billion 2015$*
Default	1	0.62	0.20	0.81
	2	2.30	0.76	3.06
	3	4.15	1.41	5.56
	4	5.98	1.99	7.96
Increasing Price	1	0.60	0.19	0.80
	2	2.24	0.75	2.99
	3	4.02	1.39	5.41
	4	5.82	1.96	7.79
Decreasing Price	1	0.64	0.20	0.85
	2	2.44	0.78	3.22
	3	4.45	1.45	5.91
	4	6.34	2.04	8.39

Table 10C.4.2 NPV of Impacts for Residential and Commercial Purchases Under Alternative Product Price Forecasts (7-Percent Discount Rate)

Price Trend	TSL	Residential *Billion 2015$*	Commercial *Billion 2015$*	Total *Billion 2015$*
Default	1	0.26	0.09	0.35
	2	0.93	0.32	1.25
	3	1.59	0.58	2.17
	4	2.37	0.84	3.21
Increasing Price	1	0.25	0.09	0.34
	2	0.90	0.32	1.22
	3	1.53	0.57	2.11
	4	2.30	0.83	3.13
Decreasing Price	1	0.27	0.09	0.36
	2	1.00	0.33	1.33
	3	1.74	0.60	2.34
	4	2.56	0.87	3.42

REFERENCES

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APPENDIX 10D. NATIONAL ENERGY SAVINGS AND NET PRESENT VALUE USING ALTERNATIVE GROWTH SCENARIOS

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APPENDIX 10D. NATIONAL ENERGY SAVINGS AND NET PRESENT VALUE USING ALTERNATIVE GROWTH SCENARIOS

10D.1 INTRODUCTION

This appendix presents national energy savings (NES) and net present value (NPV) results from operating the national impact analysis model using inputs from alternative economic growth scenarios. The results indicate the range in NES and NPV for the four trial standard levels (TSLs) for portable air conditioners (ACs). The alternative scenarios use the energy prices and housing starts projected for the high and low economic growth cases in the Energy Information Administration's (EIA's) *Annual Energy Outlook 2016* (AEO 2016).[1] Figure 10D.1.1 shows the projections for total housing stock under the three economic growth scenarios considered in the AEO 2016.

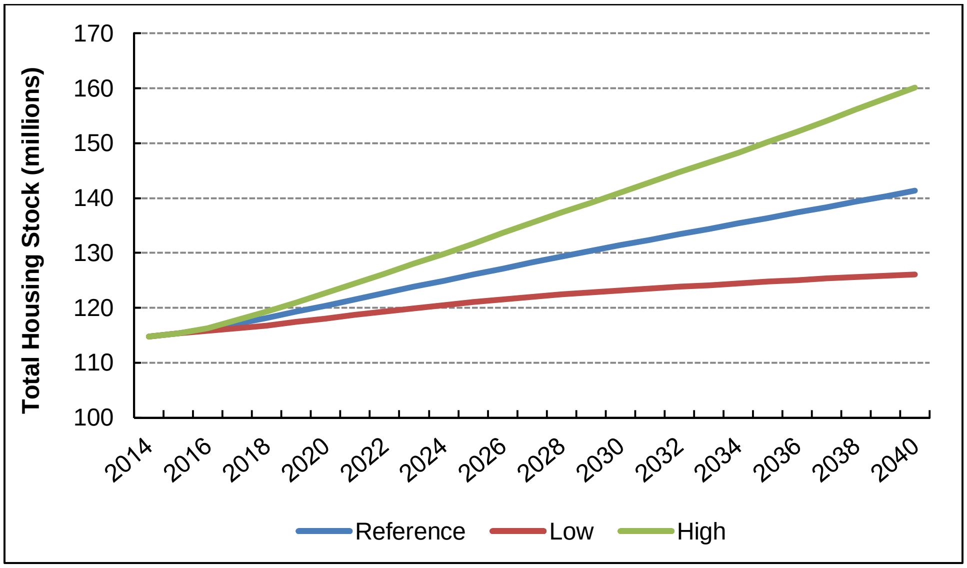

Figure 10D.1.1 Projections for Total Housing Stock under Three AEO 2016 Economic Growth Scenarios

Figure 10D.1.2 shows the projections for electricity prices for residential applications under the three economic growth scenarios. Figure 10D.1.3 shows the projections for electricity prices for commercial applications. AEO 2016 provides economic projections to 2040. To estimate the trend after 2040, DOE followed guidelines that the EIA provided to the Federal Energy Management Program, which called for extending the average rate of change for electricity prices during 2030–2040.

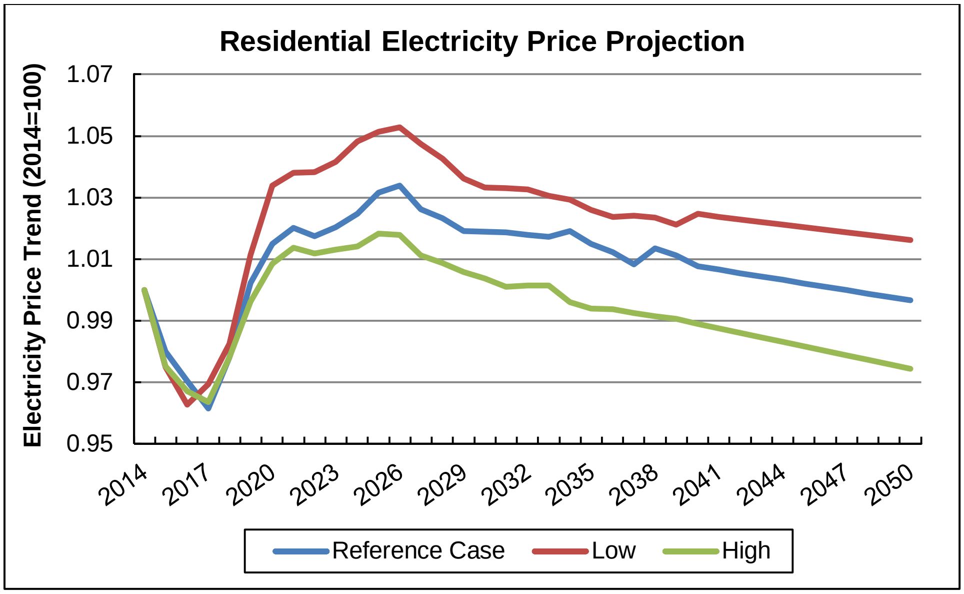

Figure 10D.1.2 Projections for Average Residential Electricity Prices under Three AEO 2016 Economic Growth Scenarios

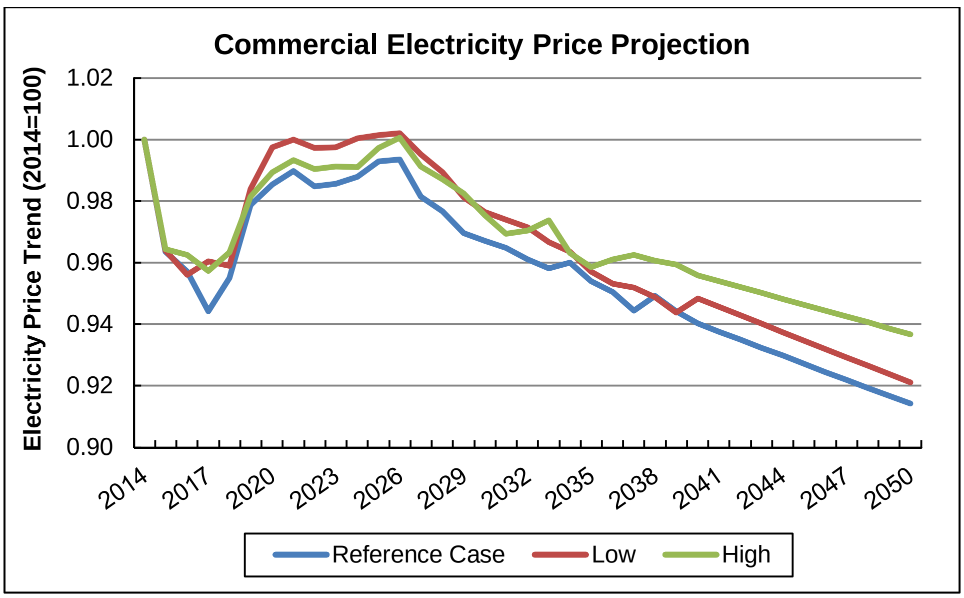

Figure 10D.1.3 Projections for Average Commercial Electricity Prices under Three AEO 2016 Economic Growth Scenarios

10D.2 ANALYTICAL RESULTS FOR HIGH ECONOMIC GROWTH SCENARIO

The results of running the NIA model for the AEO 2016 reference economic growth case are presented in chapter 10. The following three tables present results of the NIA calculation using inputs from the AEO 2016 high economic growth scenario in the analysis. Table 10D.2.1 presents cumulative national primary energy savings under the high growth scenario for the four TSLs considered for residential portable ACs.

Table 10D.2.1 Cumulative National Primary Energy Savings in Quads, High Economic Growth Scenario

TSL	Residential Portable ACs in Residential Sites, Primary *Quads*	Residential Portable ACs in Commercial Sites, Primary *Quads*	Portable ACs in both sectors, Primary *Quads*	Portable ACs in both sectors, Primary (15% Rebound) *Quads*
1	0.11	0.04	0.15	0.13
2	0.43	0.16	0.60	0.51
3	0.84	0.32	1.16	0.99
4	1.14	0.43	1.57	1.34

Table 10D.2.2 presents cumulative energy savings in terms of the full-fuel-cycle (FFC) for the AEO 2016 high economic growth scenario.

Table 10D.2.2 Cumulative Full-Fuel-Cycle Energy Savings in Quads, High Economic Growth Scenario

TSL	Residential Portable ACs in Residential Sites, FFC *Quads*	Residential Portable ACs in Commercial Sites, FFC *Quads*	Portable ACs in both sectors, FFC *Quads*	Portable ACs in both sectors, FFC (15% Rebound) *Quads*
1	0.11	0.04	0.15	0.13
2	0.45	0.17	0.62	0.53
3	0.88	0.33	1.21	1.03
4	1.19	0.45	1.64	1.40

Table 10D.2.3 presents the cumulative NPV of monetary benefits to buyers of portable ACs under the AEO 2016 high economic growth scenario. Benefits are shown for discount rates of both 3 percent and 7 percent.

Table 10D.2.3 Cumulative NPV of Benefits to Buyers of Portable ACs, High Economic Growth Scenario

TSL	NPV @ 3% *Billion 2015$*			NPV @ 7% *Billion 2015$*		
	Residential	**Commercial**	**Total**	**Residential**	**Commercial**	**Total**
1	0.65	0.21	0.86	0.27	0.09	0.36
2	2.42	0.83	3.26	0.97	0.35	1.32
3	4.37	1.55	5.93	1.66	0.63	2.29
4	6.30	2.19	8.48	2.48	0.91	3.39

10D.3 ANALYTICAL RESULTS FOR LOW ECONOMIC GROWTH SCENARIO

The following three tables present results of the NIA calculation using inputs from the AEO 2016 low economic growth scenario in the analysis. Table 10D.3.1 presents cumulative national primary energy savings under the low growth scenario for the four TSLs considered for residential portable ACs.

Table 10D.3.1 Cumulative National Primary Energy Savings in Quads, Low Economic Growth Scenario

TSL	Residential Portable ACs in Residential Sites, Primary *Quads*	Residential Portable ACs in Commercial Sites, Primary *Quads*	Portable ACs in both sectors, Primary *Quads*	Portable ACs in both sectors, Primary (15% Rebound) *Quads*
1	0.09	0.03	0.13	0.11
2	0.37	0.14	0.51	0.43
3	0.71	0.27	0.98	0.84
4	0.97	0.37	1.34	1.14

Table 10D.3.2 presents cumulative energy savings in terms of the full-fuel-cycle (FFC) for the AEO 2016 low economic growth scenario.

Table 10D.3.2 Cumulative Full-Fuel-Cycle Energy Savings in Quads, Low Economic Growth Scenario

TSL	Residential Portable ACs in Residential Sites, FFC *Quads*	Residential Portable ACs in Commercial Sites, FFC *Quads*	Portable ACs in both sectors, FFC *Quads*	Portable ACs in both sectors, FFC (15% Rebound) *Quads*
1	0.10	0.04	0.13	0.11
2	0.38	0.15	0.53	0.45
3	0.75	0.28	1.03	0.87
4	1.01	0.39	1.40	1.19

Table 10D.3.3 presents the cumulative NPV of monetary benefits to buyers of portable ACs under the AEO 2016 low economic growth scenario. Benefits are shown for discount rates of both 3 percent and 7 percent.

Table 10D.3.3 Cumulative Net Present Value of Consumer Benefits, Low Economic Growth Scenario

TSL	NPV @ 3% *Billion 2015$*			NPV @ 7% *Billion 2015$*		
	Residential	**Commercial**	**Total**	**Residential**	**Commercial**	**Total**
1	0.59	0.19	0.77	0.25	0.08	0.33
2	2.19	0.71	2.91	0.90	0.31	1.20
3	3.95	1.32	5.27	1.53	0.55	2.08
4	5.69	1.87	7.56	2.29	0.80	3.08

REFERENCES

1 U.S. Department of Energy–Energy Information Administration. *Annual Energy Outlook 2016 with Projections to 2040.* 2016. Report Number: DOE/EIA-0383(2016). Washington, D.C. (Last accessed August 22, 2016.) <http://www.eia.gov/forecasts/aeo/>

APPENDIX 10E. NIA SENSITIVITY ANALYSIS FOR REDUCED COOLING HOURS

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APPENDIX 10E. NIA SENSITIVITY ANALYSIS FOR REDUCED COOLING HOURS

10E.1 INTRODUCTION

In addition to its reference scenario presented in chapter 10 of this NOPR TSD, DOE performed a sensitivity scenario based on reduced cooling hours. For this sensitivity analysis, DOE assumed that portable ACs are in cooling mode for 50% of the time that room ACs are in cooling mode. The LCC results of the sensitivity analysis can be seen in appendix 8F. This appendix shows the NIA results.

Table 10E.1.1 shows the annual energy use of portable ACs for both the residential and commercial venues.

Table 10E.1.1 Annual Energy Consumption in Residential and Commercial Sectors, Reduced Cooling Hours

Efficiency Level	Annual Energy Use *kWh/yr*	
	Residential	**Commercial**
Baseline	407	1,026
1	364	918
2	312	789
3	263	668
4	213	539

10E.2 ANALYTICAL RESULTS FOR REDUCED COOLING HOURS

Table 10E.2.1 shows primary energy savings and Table 10E.2.2 shows full-fuel cycle energy savings for the portable AC TSLs analyzed for the reduced cooling hours scenario. Table 10E.2.3 shows the NPV results for the TSLs analyzed for portable ACs. The table presents the NPV at both a 3-percent and a 7-percent discount rate.

Table 10E.2.1 National Primary Energy Savings in Quads, Reduced Cooling Hours

TSL	Portable ACs in Residential Sites, Primary *Quads*	Portable ACs in Commercial Sites, Primary *Quads*	Portable ACs in both Sectors, Primary *Quads*	Portable ACs in both Sectors, (15% Rebound) Primary *Quads*
1	0.05	0.02	0.07	0.06
2	0.20	0.08	0.28	0.24
3	0.39	0.15	0.54	0.46
4	0.53	0.20	0.74	0.62

Table 10E.2.2 National Energy Savings for Full-Fuel-Cycle, Reduced Cooling Hours

TSL	Portable ACs in Residential Sites, FFC *Quads*	Portable ACs in Commercial Sites, FFC *Quads*	Portable ACs in both Sectors, FFC *Quads*	Portable ACs in both Sectors, (15% Rebound) FFC *Quads*
1	0.05	0.02	0.07	0.06
2	0.21	0.08	0.29	0.25
3	0.41	0.16	0.57	0.48
4	0.56	0.21	0.77	0.65

Table 10E.2.3 Cumulative Consumer Net Present Value for Each TSL, Reduced Cooling Hours

TSL	NPV at 3% Discount Rate *Billion, 2015$*			NPV at 7% Discount Rate *Billion, 2015$*		
	Residential	Commercial	Total	Residential	Commercial	Total
1	0.22	0.09	0.31	0.08	0.04	0.12
2	0.76	0.32	1.08	0.25	0.13	0.38
3	1.19	0.57	1.77	0.31	0.22	0.53
4	1.89	0.84	2.73	0.59	0.33	0.92

APPENDIX 12A MANUFACTURER IMPACT ANALYSIS INTERVIEW GUIDE

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APPENDIX 12A MANUFACTURER IMPACT ANALYSIS INTERVIEW GUIDE

12A.1 MANUFACTURER IMPACT ANALYSIS INTERVIEW GUIDE FOR PORTABLE AIR CONDITIONERS

1 KEY ISSUES

1.1 What are the key issues for your company regarding this portable air conditioner rulemaking?

2 BUSINESS OVERVIEW

2.1 Do you have a parent company and/or subsidiary? If so, please provide their name(s).

2.2 What are your product line niches and relative strengths in the portable AC market?

2.3 Do you manufacture any products other than portable ACs? If so, what other products do you manufacture?

2.4 What percentage of your overall revenue corresponds to portable AC sales? What percentage of your overall shipments corresponds to portable AC shipments?

2.5 What percentage of your portable AC manufacturing corresponds to each product type, in terms of both revenue and shipments? Please also indicate whether you purchase your portable AC products from other manufacturers, and whether the factory that supplies the products is located in the United States. Finally, please indicate your company's approximate market share in the U.S. in each of the product types that you offer.

Table 2-1 2014 U.S. Portable Air Conditioner Business

Product Type	2014 U.S. Revenue	2014 U.S. Shipments	% Made	% Bought	% Made in U.S.	2014 U.S. Market Share
Single-Duct						
Dual-Duct						

2.6 What percentage of your company's portable AC <u>sales</u> is domestic?

3 SHIPMENT AND MARKET SHARE TRENDS AND PROJECTIONS

3.1 Please provide comment on your company's historical and projected shipments (assuming no standards) for each product class in the table below.

Table 3-2 Portable Air Conditioner Shipments Trends

Product	Shipments 10 years ago	Shipments 5 years ago	Shipments today (2014)	Projected shipments 5 years from now [Assuming no standards]
Single-Duct				
Dual-Duct				

3.2 How would you expect shipments to change for the industry as a whole as a function of standards and why?

3.3 Looking at price/cost effects only, how would you expect shipments to change for a 5%, 10%, or 25% manufacturer price/cost increase? Would you expect energy conservation standards to have a significant influence on the end-users decisions about the type of equipment to purchase?

3.4 How would new standards affect your ability to compete? Would you expect your market share to change once standards become effective? Does your outlook change with higher efficiency levels?

3.5 Can you provide an estimate of your primary competitors' market shares?

3.6 Could new standards disproportionately advance or harm the competitive positions of some firms?

3.7 Could new standards result in disproportionate economic or performance penalties for particular consumer/user subgroups?

3.8 Beyond price and energy efficiency, could new standards result in products that will be more or less desirable to consumers due to changes in product functionality, utility, or other features?

4 MARKUPS AND PROFITABILITY

One of the primary objectives of the Manufacturer Impact Analysis (MIA) is to assess the impact of energy conservation standards on industry profitability. In this section, DOE would like to understand the markup structure of the industry and how setting an energy conservation standard would impact your company's markup structure and profitability.

The manufacturer markup is a multiplier applied to manufacturer production cost to cover per unit research and development, selling, general, and administrative expenses, and profit. It is NOT a profit margin. The manufacturer production cost multiplied by the manufacturer markup plus the shipping costs covers all costs involved in manufacturing and profit for the product.

4.1 As presented in the recently published preliminary analysis, DOE assumed a markup of 1.42 for portable ACs. Is this markup a representative average for the industry?

4.2 Does the per-unit markup vary by product efficiency? Is the markup (or margin) on incremental costs for more efficient designs different than the markup for baseline models?

4.3 What factors besides efficiency affect markups for products that are in the same product class?

4.4 What distribution channels are used from the manufacturer to the retail outlet? What is the share of product going through each distribution channel?

4.5 How would your company's product mix and marketing strategy change with a new efficiency standard?

5 FINANCIAL PARAMETERS

DOE's contractor has developed a "straw man" model of financial performance called the Government Regulatory Impact Model (GRIM) using publicly available data. This section attempts to understand how your company's financial situation could differ from the industry aggregate picture.

Please compare your company's financial parameters relating to Portable Air Conditioners to the GRIM parameters tabulated below.

Table 7-3 Financial Parameters for Portable Air Conditioners

GRIM Input	Definition	Industry Estimated Value	Your Actual
Income Tax Rate	Corporate effective income tax paid (percentage of earnings before taxes, EBT)	27.4%	
Discount Rate	Weighted average cost of capital (inflation-adjusted weighted average of corporate cost of debt and return on equity)	6.6%	
Working Capital	Current assets less current liabilities (percentage of revenues)	19.4%	
SG&A	Selling, general, and administrative expenses (percentage of revenues)	19.0%	
R&D	Research and development expenses (percentage of revenues)	1.4%	
Depreciation	Amortization of fixed assets (percentage of revenues)	2.7%	
Capital Expenditures	Outlay of cash to acquire or improve capital assets (percentage of revenues, not including acquisition or sale of business units)	2.8%	
Cost of Goods Sold	Includes material, labor, overhead, and depreciation (percentage of revenues)	72.1%	

6 CONVERSION COSTS

An increase in energy conservation standards may cause the industry to incur capital and product conversion costs to meet the amended energy conservation standard. The MIA considers three types of conversion expenditures:

- Capital conversion costs -- One-time investments in plant, property, and equipment (PPE) necessitated by an energy conservation standard. These may be incremental changes to existing PPE or the replacement of existing PPE. Included are expenditures on buildings, equipment, and tooling.
- Product conversion costs – Cost related to research, product development, testing, marketing and other costs for redesigning products necessitated by an energy conservation standard.
- Stranded assets -- Assets replaced before the end of their useful lives as a direct result of the change in energy conservation standard.

With a detailed understanding of the conversion costs necessitated by different standard levels, DOE can better model the impact on the portable ACs manufacturing industry resulting from a new energy conservation standard.

6.1 What level of conversion costs do you anticipate incurring with each design option?

Please provide dollar amounts as well as descriptions of the kind of changes that would need to be implemented (e.g., retooling, changes to production lines and production facilities).

Table 6-4 Portable Air Conditioner Expected Conversion Costs

Design Option	***Capital Conversion Costs***	***R&D & Other Product Conversion Costs***	***Testing Costs***
Dual-duct with 50% infiltration air (improved from single-duct)			
Dual-duct with 25% infiltration air (improved from 50%)			
Dual-duct with 0% infiltration air (improved from 25%)			
Increased heat exchanger area (10% increase in cross-sectional area)			
Improved Compressor Efficiency (maximum efficiency compressor)			
Improved Blower Motor Efficiency (permanent-magnet motor)			
Low-Standby-Power Electronic Controls			
Additional Design Options			
Improved Duct Connections			
Improved Case Insulation			
Increased Heat-Transfer Coefficients			

6.2 How would the imposition of new energy conservation standards affect capacity utilization and manufacturing assets at your domestic production facilities? Would a new standard result in stranded capital assets? Would any facilities be closed or downsized? Added or upgraded?

7 CUMULATIVE REGULATORY BURDEN

Cumulative regulatory burden refers to the burden that industry faces from overlapping effects of new or revised DOE standards, and/or other regulatory actions affecting the same product or industry.

7.1 Are there other recent or impending standards that portable air conditioner manufacturers face from DOE, other US federal agencies, State regulators, foreign government agencies, or other standard setting bodies? If so, please identify the regulation and the corresponding possible effective dates for those regulations. Below is a preliminary list of regulations that could possibly affect manufacturers of portable ACs. Please provide comments on the listed regulations.

Table 9-5: Other Regulations Identified by DOE

Regulation	Expected Effective Date(s)	Expected Expenses / Comments
Microwave Ovens	2016	$43.1 M (2011$)
Residential Clothes Washers	2018	$418.5 M (2010$)
Packaged Terminal Air Conditioners and Heat Pumps	2019	$7.6 M (2013$)
Conventional Ovens	2019	$109.9 M (2014$)
Residential Dehumidifiers	2019	$50.7 M (2013$)
Dishwashers	2019	TBD
Miscellaneous Residential Refrigeration Products	2021s	TBD
Residential Refrigerators and Freezers	2020	TBD
Room Air Conditioners	2020	TBD
Residential Clothes Dryers	2021	TBD

7.2 Are there any additional regulatory burdens that DOE should take into consideration? If so, please identify the regulation, the corresponding effective dates, and your expected compliance cost.

8 DIRECT EMPLOYMENT IMPACT ASSESSMENT

The impact of energy conservation standards on employment is an important consideration in the rulemaking process. This section of the interview guide seeks to explore current trends in portable air conditioner production employment and solicit manufacturer views on how domestic employment patterns might be affected by energy conservation standards.

8.1 Where are your portable air conditioner manufacturing facilities that produce products for the United States located? What type of product is manufactured at each location? Please provide production figures for your company's manufacturing at each location by product class.

Table 9.1 Manufacturing Locations and Employee Counts

Location	Product Types Manufactured	Employees (Production)	Employees (Non-production)	Units/Yr Produced

8.2 Are higher efficiency products built at different plants than lower efficiency products of the same product class?

8.3 Would your domestic employment levels be expected to change significantly under amended energy conservation standards? If so, please identify particular standard levels which may trigger changes in employment.

9 OUTSOURCING/ FOREIGN COMPETITION

Disparity between domestic and foreign energy conservation standards could impact exports or imports. Labor content and material changes, resulting from energy conservation standards, may impact sourcing decisions.

9.1 Absent amended energy conservation standards, are production facilities being relocated to foreign countries?

9.2 Would amended energy conservation standards impact your domestic vs. foreign manufacturing decision?

9.3 What percentage of the U.S. market for portable air conditioners is imported? Would amended energy conservation standards have an impact on foreign competition?

10 CONSOLIDATION

Energy conservation standards can alter the competitive dynamics of the market. This can include prompting companies to enter or exit the market, or to merge. DOE and the Department of Justice are both interested in any potential reduction in competition that would result from an energy conservation standard.

10.1 Please comment on industry consolidation over the last 10 years.

10.2 In the absence of amended energy conservation standards, do you expect any industry consolidation in the future? Please describe your expectations.

10.3 How would industry competition change as a result of amended energy conservation standards?

10.4 To your knowledge, are there any niche manufacturers for which the adoption of amended energy conservation standards would have a particularly severe impact?

10.5 To your knowledge, are there any component manufacturers for which the adoption of amended energy conservation standards would have a particularly severe impact?

11 IMPACTS ON SMALL BUSINESS

11.1 The Small Business Association (SBA) denotes a small business in the Air-Conditioning and Warm Air Heating Equipment and Commercial and Industrial Refrigeration Equipment Manufacturing industry as having less than 750 employees.[1] By this definition, is your company considered a small business?

11.2 Are there any U.S.-based small manufacturers producing portable ACs?

11.3 Are there any reasons that a small business might be at a disadvantage relative to a larger business under amended energy conservation standards? Please consider such factors as technical expertise, access to capital, bulk purchasing power for materials/components, engineering resources, and any other relevant issues.

[1] DOE uses the SBA small business size standards effective November 5, 2010 to determine whether a company is a small business. The manufacturers of the products covered in this rulemaking have a primary NAICS code of 333415: Air-Conditioning and Warm Air Heating Equipment and Commercial and Industrial Refrigeration Equipment Manufacturing. The Small Business Association defines a small business as a company that has fewer than 750 employees for NAICS code 333415. The employee threshold includes all employees in a business's parent company and any other subsidiaries.

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APPENDIX 12B. GOVERNMENT REGULATORY IMPACT MODEL OVERVIEW

12B.1 INTRODUCTION AND PURPOSE

The purpose of the Government Regulatory Impact Model (GRIM) is to help quantify the impacts of energy conservation standards and other regulations on manufacturers. The basic mode of analysis is to estimate the change in the value of the industry or manufacturers(s) following a regulation or a series of regulations. The model structure also allows an analysis of multiple equipment types with regulations taking effect over a period of time, and of multiple regulations on the same equipment.

Industry net present value is defined, for the purpose of this analysis, as the discounted sum of industry free cash flows plus a discounted terminal value. The model calculates the actual cash flows by year and then determines the present value of those cash flows both without an energy conservation standard (*i.e.*, the base case) and under different trial standard levels (*i.e.*, the standards case).

Outputs from the model consist of summary financial metrics, graphs of major variables, and, when appropriate, access to the complete cash flow calculation.

12B.2 MODEL DESCRIPTION

The basic structure of the GRIM is a standard annual cash flow analysis that uses manufacturer selling prices, manufacturing costs, a shipments forecast, and financial parameters as inputs and accepts a set of regulatory conditions as changes in costs and investments. The cash flow analysis is separated into two major blocks: income and cash flow. The income calculation determines net operating profit after taxes. The cash flow calculation converts net operating profit after taxes into an annual cash flow by including investment and non-cash items. Below are definitions of listed items on the printout of the output sheet of the GRIM.

(1) ***Revenues:*** Annual revenues – computed by multiplying equipment unit prices at each efficiency level by the appropriate manufacturer markup.

(2) ***Total Shipments:*** Total annual shipments for the industry were obtained from the National Impact Analysis Spreadsheet.

(3) ***Material:*** The portion of COGS that includes materials.

(4) ***Labor:*** The portion of cost of goods sold (COGS) that includes direct labor, commissions, dismissal pay, bonuses, vacation, sick leave, social security contributions, fringe, and assembly labor up-time.

(5) ***Depreciation:*** The portion of overhead that includes an allowance for the total amount of fixed assets used to produce that one unit. Annual depreciation is computed as a percentage of ***COGS.*** While included in overhead, the depreciation is shown as a separate line item.

(6) ***Overhead:*** The portion of COGS that includes indirect labor, indirect material, energy use, maintenance, depreciation, property taxes, and insurance related to assets. While included in overhead, the depreciation is shown as a separate line item.

(7) ***Standard SG&A:*** Selling, general, and administrative costs are computed as a percentage of ***Revenues (1)***.

(8) ***R&D:*** GRIM separately accounts for ordinary research and development (R&D) as a percentage of ***Revenues (1)***.

(9) ***Product Conversion Costs:*** Product conversion costs are one-time investments in research, development, testing, marketing, and other costs focused on making equipment designs comply with the new energy conservation standard. The GRIM allocates these costs over the period between the standard's announcement and compliance dates.

(10) ***Stranded Assets:*** In the year the standard becomes effective, a one-time write-off of stranded assets is accounted for.

(11) ***Earnings Before Interest and Taxes (EBIT):*** Includes profits before deductions for interest paid and taxes.

(12) ***EBIT as a Percentage of Sales (EBIT/Revenues):*** GRIM calculates EBIT as a percentage of sales to compare with the industry's average reported in financial statements.

(13) ***Taxes:*** Taxes on ***EBIT (11)*** are calculated by multiplying the tax rate contained in Major Assumptions by ***EBIT (11)***.

(14) ***Net Operating Profits After Taxes (NOPAT):*** Computed by subtracting ***Cost of Goods Sold ((3) to (6))***, ***SG&A (7)***, ***R&D (8)***, ***Product Conversion Costs (9)***, and ***Taxes (13)*** from ***Revenues (1)***.

(15) ***NOPAT repeated***: NOPAT is repeated in the Statement of Cash Flows.

(16) ***Depreciation repeated***: Depreciation and Stranded Assets are added back in the Statement of Cash Flows because they are non-cash expenses.

(17) ***Change in Working Capital***: Change in cash tied up in accounts receivable, inventory, and other cash investments necessary to support operations is calculated by multiplying working capital (as a percentage of revenues) by the change in annual revenues.

(18) ***Cash Flow from Operations***: Calculated by taking ***NOPAT (15)***, adding back non-cash items such as a ***Depreciation (16)***, and subtracting the ***Change in Working Capital (17)***.

(19) ***Ordinary Capital Expenditures:*** Ordinary investments in property, plant, and equipment to maintain and replace existing production assets, computed as a percentage of ***Revenues (1)***.

(20) ***Capital Conversion Costs:*** Capital conversion costs are one-time investments in property, plant, and equipment to adapt or change existing production facilities so that new

equipment designs can be fabricated and assembled under the new regulation. The GRIM allocates these costs over the period between the standard's announcement and compliance dates.

(21) ***Capital Investment:*** Total investments in property, plant, and equipment are computed by adding ***Ordinary Capital Expenditures (19)*** and ***Capital Conversion Costs (20)***.

(22) ***Free Cash Flow:*** Annual cash flow from operations and investments; computed by subtracting ***Capital Investment (21)*** from ***Cash Flow from Operations (18)***.

(23) ***Terminal Value:*** Estimate of the continuing value of the industry after the analysis period. Computed by growing the Free Cash Flow at a constant rate in perpetuity.

(24) ***Present Value Factor:*** Factor used to calculate an estimate of the present value of an amount to be received in the future.

(25) ***Discounted Cash Flow: Free Cash Flows (22)*** multiplied by the ***Present Value Factor (24)***. For the end of 2051, the discounted cash flow includes the discounted ***Terminal Value (23)***.

(26) ***Industry Value thru the end of 2051:*** The sum of ***Discounted Cash Flows (25)***.

Table 12B.1 Detailed Cash Flow Example

		Ancmt Yr					Std Yr			
Industry Income Statement (in 2015$ millions)	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**
Revenues	$ 713.1	$ 703.5	$ 694.1	$ 684.7	$ 675.5	$ 666.4	$ 657.5	$ 649.3	$ 641.2	$ 633.2
Total Shipments *(million units)*	1.337	1.345	1.353	1.362	1.370	1.379	1.387	1.396	1.405	1.414
- Materials	$ 428.3	$ 422.5	$ 416.8	$ 411.2	$ 405.7	$ 400.2	$ 394.9	$ 390.0	$ 385.2	$ 380.4
- Labor	$ 8.6	$ 8.5	$ 8.4	$ 8.3	$ 8.2	$ 8.1	$ 7.9	$ 7.8	$ 7.7	$ 7.6
- Depreciation	$ 29.8	$ 29.4	$ 29.0	$ 28.7	$ 28.3	$ 27.9	$ 27.5	$ 27.1	$ 26.8	$ 26.4
- Overhead	$ 35.5	$ 35.0	$ 34.5	$ 34.1	$ 33.6	$ 33.2	$ 32.7	$ 32.3	$ 31.9	$ 31.5
- Standard SG&A	$ 128.4	$ 126.6	$ 124.9	$ 123.3	$ 121.6	$ 120.0	$ 118.3	$ 116.9	$ 115.4	$ 114.0
- R&D	$ 12.1	$ 12.0	$ 11.8	$ 11.6	$ 11.5	$ 11.3	$ 11.2	$ 11.0	$ 10.9	$ 10.8
- Product Conversion Costs	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
- Stranded Assets	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Earnings Before Interest and Taxes (EBIT)	$ 70.4	$ 69.5	$ 68.6	$ 67.6	$ 66.7	$ 65.8	$ 64.9	$ 64.1	$ 63.3	$ 62.5
Per Unit EBIT *($/unit)*	$ 52.70	$ 51.67	$ 50.66	$ 49.67	$ 48.69	$ 47.74	$ 46.81	$ 45.94	$ 45.08	$ 44.24
EBIT/Revenues (%)	*9.9%*	*9.9%*	*9.9%*	*9.9%*	*9.9%*	*9.9%*	*9.9%*	*9.9%*	*9.9%*	*9.9%*
- Taxes	$ 19.3	$ 19.0	$ 18.8	$ 18.5	$ 18.3	$ 18.0	$ 17.8	$ 17.6	$ 17.4	$ 17.1
Net Operating Profit after Taxes (NOPAT)	**$ 51.1**	**$ 50.4**	**$ 49.8**	**$ 49.1**	**$ 48.4**	**$ 47.8**	**$ 47.1**	**$ 46.6**	**$ 46.0**	**$ 45.4**

Cash Flow Statement										
NOPAT	$ 51.1	$ 50.4	$ 49.8	$ 49.1	$ 48.4	$ 47.8	$ 47.1	$ 46.6	$ 46.0	$ 45.4
+ Depreciation	$ 29.8	$ 29.4	$ 29.0	$ 28.7	$ 28.3	$ 27.9	$ 27.5	$ 27.1	$ 26.8	$ 26.4
+ Loss on Disposal of Stranded Assets	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
- Change in Working Capital	$ -	$ (1.6)	$ (1.6)	$ (1.5)	$ (1.5)	$ (1.5)	$ (1.5)	$ (1.4)	$ (1.3)	$ (1.3)
Cash Flows from Operations	$ 81.0	$ 81.5	$ 80.4	$ 79.3	$ 78.2	$ 77.2	$ 76.1	$ 75.1	$ 74.1	$ 73.1
- Ordinary Capital Expenditures	$ 28.5	$ 28.1	$ 27.8	$ 27.4	$ 27.0	$ 26.7	$ 26.3	$ 26.0	$ 25.6	$ 25.3
- Capital Conversion Costs	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Free Cash Flow	**$ 52.5**	**$ 53.3**	**$ 52.6**	**$ 51.9**	**$ 51.2**	**$ 50.5**	**$ 49.8**	**$ 49.1**	**$ 48.4**	**$ 47.8**

Discounted Cash Flow										
Free Cash Flow	$ 52.5	$ 53.3	$ 52.6	$ 51.9	$ 51.2	$ 50.5	$ 49.8	$ 49.1	$ 48.4	$ 47.8
Terminal Value	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Present Value Factor	*0.000*	*1.000*	*0.938*	*0.880*	*0.826*	*0.774*	*0.726*	*0.681*	*0.639*	*0.600*
Discounted Cash Flow	**$ -**	**$ 53.3**	**$ 49.4**	**$ 45.7**	**$ 42.3**	**$ 39.1**	**$ 36.2**	**$ 33.5**	**$ 31.0**	**$ 28.7**

INPV at Baseline	**$ 738.5**

APPENDIX 13A. EMISSIONS ANALYSIS METHODOLOGY

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APPENDIX 13A. EMISSIONS ANALYSIS METHODOLOGY

13A.1 INTRODUCTION

The emissions analysis consists of two components. The first component estimates the effect of potential energy conservation standards on power sector and site combustion emissions of carbon dioxide (CO_2), nitrogen oxides (NO_X), sulfur dioxide (SO_2) and mercury (Hg). The second component estimates the impacts of a potential standard on emissions of two additional greenhouse gases, methane (CH_4) and nitrous oxide (N_2O), as well as the reductions to emissions of all species due to "upstream" activities in the fuel production chain. These upstream activities comprise extraction, processing, and transporting fuels to the site of combustion. The associated emissions are referred to as upstream emissions. Together, these emissions account for the full-fuel-cycle (FFC), in accordance with DOE's FFC Statement of Policy. 76 FR 51282 (Aug. 18, 2011).

The analysis of power sector emissions uses marginal emissions intensity factors calculated by DOE. DOE's methodology is based on results published with the most recent edition of the *Annual Energy Outlook (AEO)* which is published by the Energy Information Agency (EIA). For this analysis DOE used *AEO2016*.[1] DOE developed end-use specific emissions intensity coefficients, in units of mass of pollutant per kWh of site electricity, for each pollutant. The methodology is based on the more general approach used for all the utility sector impacts calculations, which is described in appendix 15A of this TSD and in the report "Utility Sector Impacts of Reduced Electricity Demand" (Coughlin, 2014).[2] This appendix describes the methodology used to estimate the upstream emissions factors, and presents the values used for all emissions factors.

13A.2 POWER SECTOR AND SITE EMISSIONS FACTORS

Power sector marginal emissions factors are calculated by looking at the difference, over the full analysis period, in fuel consumption and emissions across a variety of cases published with the AEO. The analysis produces a set of emissions intensity factors that quantify the reduction in emissions of a given pollutant per unit reduction of fuel used in electricity generation for each of the primary fossil fuel types (coal, natural gas and oil). These factors are combined with estimates of the fraction of generation allocated to each fuel type, also calculated from *AEO2016* data, for each sector and end-use. The result is a set of end-use specific marginal emissions intensity factors, summarized in the tables below. Total emissions reductions are estimated by multiplying the intensity factors times the energy savings calculated in the national impact analysis (chapter 10). Power sector emissions factors are presented in Table 13A.4.2 through Table 13A.4.7.

Site combustion of fossil fuels in buildings (for example in water-heating, space-heating or cooking applications) also produces emissions of CO_2 and other pollutants. To quantify the reduction in these emissions from a considered standard level, DOE used emissions intensity factors from Environmental Protection Agency (EPA) publications.[3] These factors, presented in Table 13A.4.1, are constant in time. The EPA defines SO_2 emissions in terms of a formula that depends on the sulfur content of the fuel. The typical use of petroleum-based fuels in buildings if for heating, and a typical sulfur content for heating oils is a few hundred parts-per-million (ppm). The value provided in Table 13A.4.1 corresponds to a sulfur content of approximately 100 ppm.

13A.3 UPSTREAM FACTORS

The FFC upstream emissions are estimated based on the methodology developed by Coughlin (2013).[4] The upstream emissions include both emissions from fuel combustion during extraction, processing and transportation of fuel, and "fugitive" emissions (direct leakage to the atmosphere) of CH_4 and CO_2.

The FFC accounting approach is described briefly in appendix 10B and in Coughlin (2013).[4] When demand for a particular fuel is reduced, there is a corresponding reduction in the upstream activities associated with production of that fuel (mining, refining etc.) These upstream activities also consume energy and therefore produce combustion emissions. The FFC accounting estimates the total consumption of electricity, natural gas and petroleum-based fuels in these upstream activities. The relevant combustion emissions factors are then applied to this fuel use to determine the total upstream emissions intensities from combustion, per unit of fuel delivered to the consumer.

In addition to combustion emissions, extraction and processing of fossil fuels also produces fugitive emissions of CO_2 and CH_4. Fugitive emissions of CO_2 are small relative to combustion emissions, comprising about 2-3 percent of total CO_2 emissions for natural gas and 1-2 percent for petroleum fuels. In contrast, the fugitive emissions of methane from fossil fuel production are relatively large compared to combustion emissions of CH_4. Hence, fugitive emissions make up over 99 percent of total methane emissions for natural gas, about 95 percent for coal, and 93 percent for petroleum fuels.

Fugitive emissions factors for CO_2 and methane from coal mining and natural gas production were estimated based on a review of recent studies compiled by Burnham (2011).[5] This review includes estimates of the difference between fugitive emissions factors for conventional production of natural vs. unconventional (shale or tight gas). These estimates rely in turn on data gathered by EPA under new GHG reporting requirements for the petroleum and natural gas industries.[6,7] The value for methane, if it were translated to a leakage rate, would be equivalent to 1.3%. Actual leakage rates of methane at various stages of the production process are highly variable and the subject of ongoing research. In a comprehensive review of the literature, Brandt et al. (2014)[8] find that, while regional studies with very high emissions rates may not be representative of typical natural gas systems, it is also true that official inventories have most likely underestimated methane emissions. As more data are made available, DOE will continue to update these estimated emissions factors.

Upstream emissions factors account for both fugitive emissions and combustion emissions in extraction, processing, and transport of primary fuels. For ease of application in its analysis, DOE developed all of the emissions factors using site (point of use) energy savings in the denominator. Table 13A.4.1 presents the electricity upstream emissions factors for selected years. The caps that apply to power sector NO_X emissions do not apply to upstream combustion sources, so some components of the upstream fuel cycle (particularly off-road mobile engines) can contribute significantly to the upstream NO_x emissions factors.

13A.4 DATA TABLES

Summary tables of all the emissions factor data used by DOE for rules using *AEO 2016* are presented in the tables below. Table 13A.4.1 provides combustion emissions factors for fuels commonly used in buildings. Table 13A.4.2 to Table 13A.4.7 present the marginal power sector emissions factors as a function of sector and end use for a selected set of years. Table 13A.4.8 to Table 13A.4.10 provide the upstream emissions factors for all pollutants, for site electricity, natural gas and petroleum fuels. In all cases, the emissions factors are defined relative to site use of the fuel.

Table 13A.4.1 Site Combustion Emissions Factors

Species	Natural Gas lb/mmcf	Distillate Oil lb/1000 gal
CO_2	1.2E+05	2.3E+04
SO_2	6.0E-01	1.2E+01
NOx	9.6E+01	1.9E+01
N_2O	2.3E-01	4.5E-01
CH_4	2.3E+00	7.0E-01

Table 13A.4.2 Power Sector Emissions Factors for CO_2 (Tons of CO_2 per MWh of Site Electricity Use)

	2020	2025	2030	2035	2040
Commercial Sector					
cooking	7.048E-01	6.382E-01	6.106E-01	5.773E-01	5.429E-01
lighting	6.907E-01	6.090E-01	5.808E-01	5.508E-01	5.189E-01
office equipment (non-pc)	6.534E-01	5.653E-01	5.387E-01	5.121E-01	4.828E-01
office equipment (pc)	6.917E-01	6.045E-01	5.771E-01	5.481E-01	5.165E-01
other uses	6.885E-01	6.075E-01	5.801E-01	5.510E-01	5.199E-01
refrigeration	7.103E-01	6.329E-01	6.057E-01	5.752E-01	5.428E-01
space cooling	6.737E-01	6.232E-01	5.953E-01	5.607E-01	5.264E-01
space heating	7.127E-01	6.199E-01	5.947E-01	5.696E-01	5.418E-01
ventilation	7.064E-01	6.220E-01	5.942E-01	5.647E-01	5.328E-01
water heating	6.857E-01	6.216E-01	5.945E-01	5.621E-01	5.289E-01
Industrial Sector					
all uses	6.792E-01	6.120E-01	5.865E-01	5.556E-01	5.244E-01
Residential Sector					
ceiling fans	7.440E-01	6.485E-01	6.180E-01	5.872E-01	5.536E-01
clothes dryers	6.728E-01	6.138E-01	5.869E-01	5.536E-01	5.198E-01
cooking	6.683E-01	6.050E-01	5.786E-01	5.467E-01	5.137E-01
electronics	6.656E-01	5.856E-01	5.605E-01	5.333E-01	5.034E-01
freezers	6.858E-01	6.139E-01	5.874E-01	5.570E-01	5.253E-01
furnace fans	7.656E-01	6.313E-01	5.998E-01	5.758E-01	5.480E-01
lighting	6.574E-01	5.817E-01	5.553E-01	5.261E-01	4.953E-01
other uses	6.701E-01	6.230E-01	5.995E-01	5.677E-01	5.343E-01
refrigeration	6.611E-01	5.818E-01	5.562E-01	5.287E-01	4.989E-01
space cooling	6.771E-01	6.332E-01	6.029E-01	5.634E-01	5.250E-01
space heating	6.708E-01	6.239E-01	6.011E-01	5.703E-01	5.395E-01
water heating	6.862E-01	6.344E-01	6.072E-01	5.715E-01	5.360E-01

Table 13A.4.3 Power Sector Emissions Factors for Hg (tons/TWh of Site Electricity Use)

	2020	2025	2030	2035	2040
Commercial Sector					
cooking	2.043E-03	1.573E-03	1.496E-03	1.366E-03	1.259E-03
lighting	1.985E-03	1.558E-03	1.477E-03	1.356E-03	1.254E-03
office equipment (non-pc)	1.827E-03	1.486E-03	1.410E-03	1.301E-03	1.210E-03
office equipment (pc)	1.903E-03	1.562E-03	1.484E-03	1.366E-03	1.275E-03
other uses	2.003E-03	1.564E-03	1.487E-03	1.371E-03	1.267E-03
refrigeration	2.043E-03	1.610E-03	1.537E-03	1.415E-03	1.310E-03
space cooling	2.220E-03	1.514E-03	1.430E-03	1.298E-03	1.151E-03
space heating	1.983E-03	1.637E-03	1.572E-03	1.467E-03	1.379E-03
ventilation	2.039E-03	1.600E-03	1.519E-03	1.399E-03	1.293E-03
water heating	2.031E-03	1.537E-03	1.462E-03	1.336E-03	1.224E-03
Industrial Sector					
all uses	2.030E-03	1.569E-03	1.506E-03	1.386E-03	1.274E-03
Residential Sector					
ceiling fans	2.097E-03	1.692E-03	1.610E-03	1.489E-03	1.380E-03
clothes dryers	1.944E-03	1.497E-03	1.425E-03	1.297E-03	1.189E-03
cooking	1.902E-03	1.494E-03	1.425E-03	1.301E-03	1.197E-03
electronics	1.861E-03	1.502E-03	1.430E-03	1.318E-03	1.223E-03
freezers	1.960E-03	1.556E-03	1.488E-03	1.369E-03	1.266E-03
furnace fans	1.997E-03	1.771E-03	1.681E-03	1.578E-03	1.506E-03
lighting	1.871E-03	1.480E-03	1.404E-03	1.285E-03	1.182E-03
other uses	2.013E-03	1.502E-03	1.442E-03	1.320E-03	1.203E-03
refrigeration	1.857E-03	1.500E-03	1.429E-03	1.318E-03	1.223E-03
space cooling	2.142E-03	1.497E-03	1.414E-03	1.271E-03	1.123E-03
space heating	1.947E-03	1.495E-03	1.440E-03	1.319E-03	1.213E-03
water heating	1.941E-03	1.513E-03	1.445E-03	1.311E-03	1.203E-03

Table 13A.4.4 Power Sector Emissions Factors for NO_x (tons/MWh of Site Electricity Use)

	2020	2025	2030	2035	2040
Commercial Sector					
cooking	4.193E-04	3.306E-04	2.646E-04	2.546E-04	2.557E-04
lighting	3.937E-04	3.203E-04	2.612E-04	2.517E-04	2.522E-04
office equipment (non-pc)	3.547E-04	2.983E-04	2.458E-04	2.371E-04	2.372E-04
office equipment (pc)	3.785E-04	3.156E-04	2.582E-04	2.494E-04	2.496E-04
other uses	3.963E-04	3.220E-04	2.643E-04	2.545E-04	2.553E-04
refrigeration	4.171E-04	3.359E-04	2.770E-04	2.676E-04	2.684E-04
space cooling	4.303E-04	3.246E-04	2.538E-04	2.410E-04	2.434E-04
space heating	4.110E-04	3.408E-04	2.946E-04	2.879E-04	2.896E-04
ventilation	4.000E-04	3.272E-04	2.670E-04	2.574E-04	2.583E-04
water heating	4.133E-04	3.244E-04	2.611E-04	2.515E-04	2.533E-04
Industrial Sector					
all uses	4.350E-04	3.407E-04	2.910E-04	2.796E-04	2.780E-04
Residential Sector					
ceiling fans	4.198E-04	3.458E-04	2.866E-04	2.760E-04	2.756E-04
clothes dryers	4.172E-04	3.228E-04	2.615E-04	2.513E-04	2.515E-04
cooking	4.052E-04	3.184E-04	2.593E-04	2.495E-04	2.497E-04
electronics	3.749E-04	3.079E-04	2.529E-04	2.445E-04	2.453E-04
freezers	4.191E-04	3.322E-04	2.787E-04	2.689E-04	2.688E-04
furnace fans	3.792E-04	3.429E-04	2.965E-04	2.893E-04	2.894E-04
lighting	3.806E-04	3.075E-04	2.522E-04	2.428E-04	2.430E-04
other uses	4.358E-04	3.310E-04	2.709E-04	2.617E-04	2.626E-04
refrigeration	3.757E-04	3.086E-04	2.553E-04	2.466E-04	2.472E-04
space cooling	4.452E-04	3.298E-04	2.582E-04	2.447E-04	2.453E-04
space heating	4.300E-04	3.286E-04	2.689E-04	2.611E-04	2.643E-04
water heating	4.273E-04	3.280E-04	2.623E-04	2.524E-04	2.530E-04

Table 13A.4.5 Power Sector Emissions Factors for SO_2 (tons/MWh of Site Electricity Use)

	2020	2025	2030	2035	2040
Commercial Sector					
cooking	6.250E-04	4.593E-04	4.376E-04	3.810E-04	3.808E-04
lighting	5.429E-04	4.367E-04	4.482E-04	3.956E-04	3.878E-04
office equipment (non-pc)	4.420E-04	3.974E-04	4.390E-04	3.944E-04	3.839E-04
office equipment (pc)	4.736E-04	4.205E-04	4.536E-04	4.088E-04	4.076E-04
other uses	5.504E-04	4.408E-04	4.556E-04	4.023E-04	3.891E-04
refrigeration	5.753E-04	4.604E-04	4.656E-04	4.116E-04	4.044E-04
space cooling	7.916E-04	4.793E-04	4.170E-04	3.360E-04	3.004E-04
space heating	4.781E-04	4.549E-04	4.935E-04	4.493E-04	4.449E-04
ventilation	5.528E-04	4.461E-04	4.640E-04	4.097E-04	3.971E-04
water heating	6.331E-04	4.549E-04	4.306E-04	3.711E-04	3.620E-04
Industrial Sector					
all uses	5.998E-04	4.742E-04	4.634E-04	4.044E-04	3.903E-04
Residential Sector					
ceiling fans	5.329E-04	4.652E-04	5.001E-04	4.480E-04	4.322E-04
clothes dryers	6.128E-04	4.517E-04	4.128E-04	3.558E-04	3.552E-04
cooking	5.723E-04	4.409E-04	4.183E-04	3.648E-04	3.625E-04
electronics	4.869E-04	4.153E-04	4.348E-04	3.876E-04	3.816E-04
freezers	5.589E-04	4.565E-04	4.499E-04	3.971E-04	3.911E-04
furnace fans	3.203E-04	4.306E-04	5.526E-04	5.197E-04	5.145E-04
lighting	5.144E-04	4.200E-04	4.238E-04	3.708E-04	3.606E-04
other uses	6.820E-04	4.729E-04	4.153E-04	3.549E-04	3.492E-04
refrigeration	4.845E-04	4.169E-04	4.376E-04	3.901E-04	3.816E-04
space cooling	7.839E-04	4.852E-04	3.995E-04	3.202E-04	2.954E-04
space heating	6.499E-04	4.648E-04	4.113E-04	3.542E-04	3.544E-04
water heating	6.347E-04	4.591E-04	4.084E-04	3.528E-04	3.595E-04

Table 13A.4.6 Power Sector Emissions Factors for CH_4 (tons/MWh of Site Electricity Use)

	2020	2025	2030	2035	2040
Commercial Sector					
Cooking	6.421E-05	6.242E-05	5.866E-05	5.520E-05	5.095E-05
Lighting	6.338E-05	6.141E-05	5.776E-05	5.451E-05	5.042E-05
office equipment (non-pc)	6.170E-05	5.960E-05	5.615E-05	5.310E-05	4.917E-05
office equipment (pc)	6.337E-05	6.143E-05	5.785E-05	5.466E-05	5.056E-05
other uses	6.329E-05	6.136E-05	5.779E-05	5.460E-05	5.055E-05
Refrigeration	6.439E-05	6.261E-05	5.900E-05	5.573E-05	5.159E-05
space cooling	6.272E-05	6.080E-05	5.700E-05	5.344E-05	4.923E-05
space heating	6.456E-05	6.277E-05	5.942E-05	5.649E-05	5.264E-05
Ventilation	6.393E-05	6.202E-05	5.839E-05	5.516E-05	5.103E-05
water heating	6.342E-05	6.157E-05	5.787E-05	5.447E-05	5.033E-05
Industrial Sector					
all uses	6.361E-05	6.195E-05	5.850E-05	5.523E-05	5.121E-05
Residential Sector					
ceiling fans	6.555E-05	6.367E-05	5.994E-05	5.668E-05	5.242E-05
clothes dryers	6.327E-05	6.137E-05	5.762E-05	5.413E-05	4.995E-05
cooking	6.299E-05	6.109E-05	5.741E-05	5.401E-05	4.987E-05
electronics	6.244E-05	6.044E-05	5.694E-05	5.380E-05	4.980E-05
freezers	6.375E-05	6.192E-05	5.835E-05	5.507E-05	5.101E-05
furnace fans	6.591E-05	6.394E-05	6.045E-05	5.767E-05	5.374E-05
lighting	6.221E-05	6.015E-05	5.657E-05	5.330E-05	4.927E-05
other uses	6.331E-05	6.162E-05	5.804E-05	5.465E-05	5.049E-05
refrigeration	6.230E-05	6.032E-05	5.684E-05	5.371E-05	4.975E-05
space cooling	6.336E-05	6.141E-05	5.737E-05	5.353E-05	4.915E-05
space heating	6.342E-05	6.174E-05	5.814E-05	5.476E-05	5.071E-05
water heating	6.397E-05	6.220E-05	5.834E-05	5.471E-05	5.041E-05

Table 13A.4.7 Power Sector Emissions Factors for N_2O (tons/MWh of Site Electricity Use)

	2020	2025	2030	2035	2040
Commercial Sector					
cooking	9.200E-06	8.932E-06	8.379E-06	7.874E-06	7.250E-06
lighting	9.083E-06	8.789E-06	8.254E-06	7.780E-06	7.178E-06
office equipment (non-pc)	8.845E-06	8.530E-06	8.023E-06	7.579E-06	7.002E-06
office equipment (pc)	9.083E-06	8.793E-06	8.267E-06	7.802E-06	7.199E-06
other uses	9.071E-06	8.783E-06	8.258E-06	7.793E-06	7.198E-06
refrigeration	9.229E-06	8.964E-06	8.433E-06	7.957E-06	7.348E-06
space cooling	8.980E-06	8.694E-06	8.136E-06	7.618E-06	7.000E-06
space heating	9.260E-06	8.994E-06	8.500E-06	8.074E-06	7.507E-06
ventilation	9.162E-06	8.877E-06	8.344E-06	7.873E-06	7.265E-06
water heating	9.085E-06	8.809E-06	8.267E-06	7.770E-06	7.162E-06
Industrial Sector					
all uses	9.123E-06	8.874E-06	8.366E-06	7.890E-06	7.299E-06
Residential Sector					
ceiling fans	9.400E-06	9.118E-06	8.570E-06	8.094E-06	7.468E-06
clothes dryers	9.065E-06	8.782E-06	8.231E-06	7.722E-06	7.109E-06
cooking	9.027E-06	8.742E-06	8.203E-06	7.706E-06	7.099E-06
electronics	8.949E-06	8.650E-06	8.136E-06	7.679E-06	7.090E-06
freezers	9.140E-06	8.866E-06	8.341E-06	7.864E-06	7.267E-06
furnace fans	9.459E-06	9.165E-06	8.651E-06	8.246E-06	7.668E-06
lighting	8.916E-06	8.609E-06	8.082E-06	7.607E-06	7.014E-06
other uses	9.071E-06	8.818E-06	8.293E-06	7.798E-06	7.186E-06
refrigeration	8.930E-06	8.634E-06	8.122E-06	7.667E-06	7.085E-06
space cooling	9.072E-06	8.782E-06	8.191E-06	7.631E-06	6.988E-06
space heating	9.087E-06	8.835E-06	8.306E-06	7.812E-06	7.218E-06
water heating	9.163E-06	8.899E-06	8.334E-06	7.803E-06	7.171E-06

Table 13A.4.8 Electricity Upstream Emissions Factors

Species	Unit	2021	2025	2030	2035	2040
CH_4	g/MWh	2.13E+03	2.22E+03	2.29E+03	2.29E+03	2.32E+03
CO_2	kg/MWh	2.83E+01	2.89E+01	2.92E+01	2.89E+01	2.89E+01
Hg	g/MWh	1.15E-05	1.10E-05	1.02E-05	9.44E-06	8.50E-06
N_2O	g/MWh	2.40E-01	2.36E-01	2.29E-01	2.17E-01	2.03E-01
NO_x	g/MWh	3.59E+02	3.67E+02	3.72E+02	3.72E+02	3.75E+02
SO_2	g/MWh	4.92E+00	4.90E+00	4.65E+00	4.37E+00	4.06E+00

Table 13A.4.9 Natural Gas Upstream Emissions Factors

Species	Unit	2021	2025	2030	2035	2040
CH_4	g/ mcf	6.76E+02	6.76E+02	6.74E+02	6.77E+02	6.78E+02
CO_2	kg/ mcf	7.13E+00	7.02E+00	6.91E+00	6.99E+00	7.02E+00
N_2O	g/ mcf	1.11E-02	1.09E-02	1.07E-02	1.09E-02	1.09E-02
NO_x	g/ mcf	1.01E+02	9.91E+01	9.73E+01	9.87E+01	9.93E+01
SO_2	g/ mcf	3.03E-02	2.97E-02	2.92E-02	2.96E-02	2.98E-02

Table 13A.4.10 Fuel Oil Upstream Emissions Factors

	Unit	2021	2025	2030	2035	2040
CH_4	g/bbl	9.14E+02	9.22E+02	9.37E+02	9.47E+02	9.54E+02
CO_2	kg/bbl	7.01E+01	6.99E+01	7.01E+01	7.04E+01	7.07E+01
Hg	g/bbl	7.23E-06	6.81E-06	6.31E-06	6.12E-06	5.88E-06
N_2O	g/bbl	6.09E-01	6.01E-01	5.92E-01	5.85E-01	5.82E-01
NO_x	g/bbl	7.78E+02	7.69E+02	7.59E+02	7.53E+02	7.51E+02
SO_2	g/bbl	1.49E+01	1.48E+01	1.44E+01	1.42E+01	1.42E+01

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APPENDIX 14A. SOCIAL COST OF CARBON FOR REGULATORY IMPACT ANALYSIS UNDER EXECUTIVE ORDER 12866

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APPENDIX 14A. SOCIAL COST OF CARBON FOR REGULATORY IMPACT ANALYSIS UNDER EXECUTIVE ORDER 12866[a]

14A.1 EXECUTIVE SUMMARY

Under Executive Order 12866, agencies are required, to the extent permitted by law, "to assess both the costs and the benefits of the intended regulation and, recognizing that some costs and benefits are difficult to quantify, propose or adopt a regulation only upon a reasoned determination that the benefits of the intended regulation justify its costs." The purpose of the "social cost of carbon" (SCC) estimates presented here is to allow agencies to incorporate the social benefits of reducing carbon dioxide (CO_2) emissions into cost-benefit analyses of regulatory actions that have small, or "marginal," impacts on cumulative global emissions. The estimates are presented with an acknowledgement of the many uncertainties involved and with a clear understanding that they should be updated over time to reflect increasing knowledge of the science and economics of climate impacts.

The SCC is an estimate of the monetized damages associated with an incremental increase in carbon emissions in a given year. It is intended to include (but is not limited to) changes in net agricultural productivity, human health, property damages from increased flood risk, and the value of ecosystem services due to climate change.

This document presents a summary of the interagency process that developed these SCC estimates. Technical experts from numerous agencies met on a regular basis to consider public comments, explore the technical literature in relevant fields, and discuss key model inputs and assumptions. The main objective of this process was to develop a range of SCC values using a defensible set of input assumptions grounded in the existing scientific and economic literatures. In this way, key uncertainties and model differences transparently and consistently inform the range of SCC estimates used in the rulemaking process.

The interagency group selected four SCC values for use in regulatory analyses. Three values are based on the average SCC from three integrated assessment models, at discount rates of 2.5, 3, and 5 percent. The fourth value, which represents the 95^{th} percentile SCC estimate across all three models at a 3 percent discount rate, is included to represent higher-than-expected impacts from temperature change further out in the tails of the SCC distribution.

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[a] Prepared by Interagency Working Group on Social Cost of Carbon, United States Government.
With participation by: Council of Economic Advisers; Council on Environmental Quality; Department of Agriculture; Department of Commerce; Department of Energy; Department of Transportation; Environmental Protection Agency; National Economic Council; Office of Energy and Climate Change; Office of Management and Budget; Office of Science and Technology Policy; Department of the Treasury

Table 14A.1.1 Social Cost of CO_2, 2010 – 2050 (in 2007 dollars)

	Discount Rate			
	5%	3%	2.5%	3%
Year	Avg	Avg	Avg	95th
2010	4.7	21.4	35.1	64.9
2015	5.7	23.8	38.4	72.8
2020	6.8	26.3	41.7	80.7
2025	8.2	29.6	45.9	90.4
2030	9.7	32.8	50.0	100.0
2035	11.2	36.0	54.2	109.7
2040	12.7	39.2	58.4	119.3
2045	14.2	42.1	61.7	127.8
2050	15.7	44.9	65.0	136.2

14A.2 MONETIZING CARBON DIOXIDE EMISSIONS

The SCC is an estimate of the monetized damages associated with an incremental increase in carbon emissions in a given year. We report estimates of the SCC in dollars per metric ton of carbon dioxide throughout this document.[b]

When attempting to assess the incremental economic impacts of carbon dioxide emissions, the analyst faces a number of serious challenges. A recent report from the National Academies of Science (NRC 2009) points out that any assessment will suffer from uncertainty, speculation, and lack of information about (1) future emissions of greenhouse gases, (2) the effects of past and future emissions on the climate system, (3) the impact of changes in climate on the physical and biological environment, and (4) the translation of these environmental impacts into economic damages. As a result, any effort to quantify and monetize the harms associated with climate change will raise serious questions of science, economics, and ethics and should be viewed as provisional.

Despite the serious limits of both quantification and monetization, SCC estimates can be useful in estimating the social benefits of reducing carbon dioxide emissions. Under Executive Order 12866, agencies are required, to the extent permitted by law, "to assess both the costs and the benefits of the intended regulation and, recognizing that some costs and benefits are difficult to quantify, propose or adopt a regulation only upon a reasoned determination that the benefits of the intended regulation justify its costs." The purpose of the SCC estimates presented here is to make it possible for agencies to incorporate the social benefits from reducing carbon dioxide emissions into cost-benefit analyses of regulatory actions that have small, or "marginal," impacts

[b] In this document, we present all values of the SCC as the cost per metric ton of CO_2 emissions. Alternatively, one could report the SCC as the cost per metric ton of carbon emissions. The multiplier for translating between mass of CO_2 and the mass of carbon is 3.67 (the molecular weight of CO_2 divided by the molecular weight of carbon = 44/12 = 3.67).

on cumulative global emissions. Most federal regulatory actions can be expected to have marginal impacts on global emissions.

For such policies, the benefits from reduced (or costs from increased) emissions in any future year can be estimated by multiplying the change in emissions in that year by the SCC value appropriate for that year. The net present value of the benefits can then be calculated by multiplying each of these future benefits by an appropriate discount factor and summing across all affected years. This approach assumes that the marginal damages from increased emissions are constant for small departures from the baseline emissions path, an approximation that is reasonable for policies that have effects on emissions that are small relative to cumulative global carbon dioxide emissions. For policies that have a large (non-marginal) impact on global cumulative emissions, there is a separate question of whether the SCC is an appropriate tool for calculating the benefits of reduced emissions; we do not attempt to answer that question here.

An interagency group convened on a regular basis to consider public comments, explore the technical literature in relevant fields, and discuss key inputs and assumptions in order to generate SCC estimates. Agencies that actively participated in the interagency process include the Environmental Protection Agency, and the Departments of Agriculture, Commerce, Energy, Transportation, and Treasury. This process was convened by the Council of Economic Advisers and the Office of Management and Budget, with active participation and regular input from the Council on Environmental Quality, National Economic Council, Office of Energy and Climate Change, and Office of Science and Technology Policy. The main objective of this process was to develop a range of SCC values using a defensible set of input assumptions that are grounded in the existing literature. In this way, key uncertainties and model differences can more transparently and consistently inform the range of SCC estimates used in the rulemaking process.

The interagency group selected four SCC estimates for use in regulatory analyses. For 2010, these estimates are \$5, \$21, \$35, and \$65 (in 2007 dollars). The first three estimates are based on the average SCC across models and socioeconomic and emissions scenarios at the 5, 3, and 2.5 percent discount rates, respectively. The fourth value is included to represent the higher-than-expected impacts from temperature change further out in the tails of the SCC distribution. For this purpose, we use the SCC value for the 95^{th} percentile at a 3 percent discount rate. The central value is the average SCC across models at the 3 percent discount rate. For purposes of capturing the uncertainties involved in regulatory impact analysis, we emphasize the importance and value of considering the full range. These SCC estimates also grow over time. For instance, the central value increases to \$24 per ton of CO_2 in 2015 and \$26 per ton of CO_2 in 2020. See section 14-A.9 for the full range of annual SCC estimates from 2010 to 2050.

It is important to emphasize that the interagency process is committed to updating these estimates as the science and economic understanding of climate change and its impacts on society improves over time. Specifically, we have set a preliminary goal of revisiting the SCC values within two years or at such time as substantially updated models become available, and to continue to support research in this area. In the meantime, we will continue to explore the issues raised in this document and consider public comments as part of the ongoing interagency process.

14A.3 SOCIAL COST OF CARBON VALUES USED IN PAST REGULATORY ANALYSES

To date, economic analyses for Federal regulations have used a wide range of values to estimate the benefits associated with reducing carbon dioxide emissions. In the final model year 2011 CAFE rule, the Department of Transportation (DOT) used both a “domestic” SCC value of \$2 per ton of CO_2 and a “global” SCC value of \$33 per ton of CO_2 for 2007 emission reductions (in 2007 dollars), increasing both values at 2.4 percent per year. It also included a sensitivity analysis at \$80 per ton of CO_2. A domestic SCC value is meant to reflect the value of damages in the United States resulting from a unit change in carbon dioxide emissions, while a global SCC value is meant to reflect the value of damages worldwide.

A 2008 regulation proposed by DOT assumed a domestic SCC value of \$7 per ton CO_2 (in 2006 dollars) for 2011 emission reductions (with a range of \$0-\$14 for sensitivity analysis), also increasing at 2.4 percent per year. A regulation finalized by DOE in October of 2008 used a domestic SCC range of \$0 to \$20 per ton CO_2 for 2007 emission reductions (in 2007 dollars). In addition, EPA’s 2008 Advance Notice of Proposed Rulemaking for Greenhouse Gases identified what it described as “very preliminary” SCC estimates subject to revision. EPA’s global mean values were \$68 and \$40 per ton CO_2 for discount rates of approximately 2 percent and 3 percent, respectively (in 2006 dollars for 2007 emissions).

In 2009, an interagency process was initiated to offer a preliminary assessment of how best to quantify the benefits from reducing carbon dioxide emissions. To ensure consistency in how benefits are evaluated across agencies, the Administration sought to develop a transparent and defensible method, specifically designed for the rulemaking process, to quantify avoided climate change damages from reduced CO_2 emissions. The interagency group did not undertake any original analysis. Instead, it combined SCC estimates from the existing literature to use as interim values until a more comprehensive analysis could be conducted.

The outcome of the preliminary assessment by the interagency group was a set of five interim values: global SCC estimates for 2007 (in 2006 dollars) of \$55, \$33, \$19, \$10, and \$5 per ton of CO_2. The \$33 and \$5 values represented model-weighted means of the published estimates produced from the most recently available versions of three integrated assessment models—DICE, PAGE, and FUND—at approximately 3 and 5 percent discount rates. The \$55 and \$10 values were derived by adjusting the published estimates for uncertainty in the discount rate (using factors developed by Newell and Pizer (2003)) at 3 and 5 percent discount rates, respectively. The \$19 value was chosen as a central value between the \$5 and \$33 per ton estimates. All of these values were assumed to increase at 3 percent annually to represent growth in incremental damages over time as the magnitude of climate change increases.

These interim values represent the first sustained interagency effort within the U.S. government to develop an SCC for use in regulatory analysis. The results of this preliminary effort were presented in several proposed and final rules and were offered for public comment in connection with proposed rules, including the joint EPA-DOT fuel economy and CO_2 tailpipe emission proposed rules.

14A.4 APPROACH AND KEY ASSUMPTIONS

Since the release of the interim values, the interagency group has reconvened on a regular basis to generate improved SCC estimates. Specifically, the group has considered public comments and further explored the technical literature in relevant fields. This section details the several choices and assumptions that underlie the resulting estimates of the SCC.

It is important to recognize that a number of key uncertainties remain, and that current SCC estimates should be treated as provisional and revisable, since they will evolve with improved scientific and economic understanding. The interagency group also recognizes that the existing models are imperfect and incomplete. The National Academy of Science (2009) points out that there is tension between the goal of producing quantified estimates of the economic damages from an incremental ton of carbon and the limits of existing efforts to model these effects. Throughout this document, we highlight a number of concerns and problems that should be addressed by the research community, including research programs housed in many of the agencies participating in the interagency process to estimate the SCC.

The U.S. Government will periodically review and reconsider estimates of the SCC used for cost-benefit analyses to reflect increasing knowledge of the science and economics of climate impacts, as well as improvements in modeling. In this context, statements recognizing the limitations of the analysis and calling for further research take on exceptional significance. The interagency group offers the new SCC values with all due humility about the uncertainties embedded in them and with a sincere promise to continue work to improve them.

14A.4.1 Integrated Assessment Models

We rely on three integrated assessment models (IAMs) commonly used to estimate the SCC: the FUND, DICE, and PAGE models.[c] These models are frequently cited in the peer-reviewed literature and used in the IPCC assessment. Each model is given equal weight in the SCC values developed through this process, bearing in mind their different limitations (discussed below).

These models are useful because they combine climate processes, economic growth, and feedbacks between the climate and the global economy into a single modeling framework. At the same time, they gain this advantage at the expense of a more detailed representation of the underlying climatic and economic systems. DICE, PAGE, and FUND all take stylized, reduced-form approaches (see NRC 2009 for a more detailed discussion; see Nordhaus 2008 on the possible advantages of this approach). Other IAMs may better reflect the complexity of the

[c] The DICE (Dynamic Integrated Climate and Economy) model by William Nordhaus evolved from a series of energy models and was first presented in 1990 (Nordhaus and Boyer 2000, Nordhaus 2008). The PAGE (Policy Analysis of the Greenhouse Effect) model was developed by Chris Hope in 1991 for use by European decision-makers in assessing the marginal impact of carbon emissions (Hope 2006, Hope 2008). The FUND (Climate Framework for Uncertainty, Negotiation, and Distribution) model, developed by Richard Tol in the early 1990s, originally to study international capital transfers in climate policy is now widely used to study climate impacts (*e.g.*, Tol 2002a, Tol 2002b, Anthoff et al. 2009, Tol 2009).

science in their modeling frameworks but do not link physical impacts to economic damages. There is currently a limited amount of research linking climate impacts to economic damages, which makes this exercise even more difficult. Underlying the three IAMs selected for this exercise are a number of simplifying assumptions and judgments reflecting the various modelers' best attempts to synthesize the available scientific and economic research characterizing these relationships.

The three IAMs translate emissions into changes in atmospheric greenhouse concentrations, atmospheric concentrations into changes in temperature, and changes in temperature into economic damages. The emissions projections used in the models are based on specified socioeconomic (GDP and population) pathways. These emissions are translated into concentrations using the carbon cycle built into each model, and concentrations are translated into warming based on each model's simplified representation of the climate and a key parameter, climate sensitivity. Each model uses a different approach to translate warming into damages. Finally, transforming the stream of economic damages over time into a single value requires judgments about how to discount them.

Each model takes a slightly different approach to model how changes in emissions result in changes in economic damages. In PAGE, for example, the consumption-equivalent damages in each period are calculated as a fraction of GDP, depending on the temperature in that period relative to the pre-industrial average temperature in each region. In FUND, damages in each period also depend on the rate of temperature change from the prior period. In DICE, temperature affects both consumption and investment. We describe each model in greater detail here. In a later section, we discuss key gaps in how the models account for various scientific and economic processes (*e.g.* the probability of catastrophe, and the ability to adapt to climate change and the physical changes it causes).

The parameters and assumptions embedded in the three models vary widely. A key objective of the interagency process was to enable a consistent exploration of the three models while respecting the different approaches to quantifying damages taken by the key modelers in the field. An extensive review of the literature was conducted to select three sets of input parameters for these models: climate sensitivity, socioeconomic and emissions trajectories, and discount rates. A probability distribution for climate sensitivity was specified as an input into all three models. In addition, the interagency group used a range of scenarios for the socioeconomic parameters and a range of values for the discount rate. All other model features were left unchanged, relying on the model developers' best estimates and judgments. In DICE, these parameters are handled deterministically and represented by fixed constants; in PAGE, most parameters are represented by probability distributions. FUND was also run in a mode in which parameters were treated probabilistically.

The sensitivity of the results to other aspects of the models (*e.g.* the carbon cycle or damage function) is also important to explore in the context of future revisions to the SCC but has not been incorporated into these estimates. Areas for future research are highlighted at the end of this document.

The DICE Model

The DICE model is an optimal growth model based on a global production function with an extra stock variable (atmospheric carbon dioxide concentrations). Emission reductions are treated as analogous to investment in “natural capital.” By investing in natural capital today through reductions in emissions—implying reduced consumption—harmful effects of climate change can be avoided and future consumption thereby increased.

For purposes of estimating the SCC, carbon dioxide emissions are a function of global GDP and the carbon intensity of economic output, with the latter declining over time due to technological progress. The DICE damage function links global average temperature to the overall impact on the world economy. It varies quadratically with temperature change to capture the more rapid increase in damages expected to occur under more extreme climate change, and is calibrated to include the effects of warming on the production of market and nonmarket goods and services. It incorporates impacts on agriculture, coastal areas (due to sea level rise), “other vulnerable market sectors” (based primarily on changes in energy use), human health (based on climate-related diseases, such as malaria and dengue fever, and pollution), non-market amenities (based on outdoor recreation), and human settlements and ecosystems. The DICE damage function also includes the expected value of damages associated with low probability, high impact “catastrophic” climate change. This last component is calibrated based on a survey of experts (Nordhaus 1994). The expected value of these impacts is then added to the other market and non-market impacts mentioned above.

No structural components of the DICE model represent adaptation explicitly, though it is included implicitly through the choice of studies used to calibrate the aggregate damage function. For example, its agricultural impact estimates assume that farmers can adjust land use decisions in response to changing climate conditions, and its health impact estimates assume improvements in healthcare over time. In addition, the small impacts on forestry, water systems, construction, fisheries, and outdoor recreation imply optimistic and costless adaptation in these sectors (Nordhaus and Boyer, 2000; Warren et al., 2006). Costs of resettlement due to sea level rise are incorporated into damage estimates, but their magnitude is not clearly reported. Mastrandrea’s (2009) review concludes that “in general, DICE assumes very effective adaptation, and largely ignores adaptation costs."

Note that the damage function in DICE has a somewhat different meaning from the damage functions in FUND and PAGE. Because GDP is endogenous in DICE and because damages in a given year reduce investment in that year, damages propagate forward in time and reduce GDP in future years. In contrast, GDP is exogenous in FUND and PAGE, so damages in any given year do not propagate forward.[d]

[d] Using the default assumptions in DICE 2007, this effect generates an approximately 25 percent increase in the SCC relative to damages calculated by fixing GDP. In DICE2007, the time path of GDP is endogenous. Specifically, the path of GDP depends on the rate of saving and level of abatement in each period chosen by the optimizing representative agent in the model. We made two modifications to DICE to make it consistent with EMF GDP trajectories (see next section): we assumed a fixed rate of savings of 20 percent, and we re-calibrated the exogenous path of total factor productivity so that DICE would produce GDP projections in the absence of warming that exactly matched the EMF scenarios.

The PAGE Model

PAGE2002 (version 1.4epm) treats GDP growth as exogenous. It divides impacts into economic, non-economic, and catastrophic categories and calculates these impacts separately for eight geographic regions. Damages in each region are expressed as a fraction of output, where the fraction lost depends on the temperature change in each region. Damages are expressed as power functions of temperature change. The exponents of the damage function are the same in all regions but are treated as uncertain, with values ranging from 1 to 3 (instead of being fixed at 2 as in DICE).

PAGE2002 includes the consequences of catastrophic events in a separate damage sub-function. Unlike DICE, PAGE2002 models these events probabilistically. The probability of a "discontinuity" (*i.e.*, a catastrophic event) is assumed to increase with temperature above a specified threshold. The threshold temperature, the rate at which the probability of experiencing a discontinuity increases above the threshold, and the magnitude of the resulting catastrophe are all modeled probabilistically.

Adaptation is explicitly included in PAGE. Impacts are assumed to occur for temperature increases above some tolerable level (2°C for developed countries and 0°C for developing countries for economic impacts, and 0°C for all regions for non-economic impacts), but adaptation is assumed to reduce these impacts. Default values in PAGE2002 assume that the developed countries can ultimately eliminate up to 90 percent of all economic impacts beyond the tolerable 2°C increase and that developing countries can eventually eliminate 50 percent of their economic impacts. All regions are assumed to be able to mitigate 25 percent of the non-economic impacts through adaptation (Hope 2006).

The FUND Model

Like PAGE, the FUND model treats GDP growth as exogenous. It includes separately calibrated damage functions for eight market and nonmarket sectors: agriculture, forestry, water, energy (based on heating and cooling demand), sea level rise (based on the value of land lost and the cost of protection), ecosystems, human health (diarrhea, vector-borne diseases, and cardiovascular and respiratory mortality), and extreme weather. Each impact sector has a different functional form, and is calculated separately for sixteen geographic regions. In some impact sectors, the fraction of output lost or gained due to climate change depends not only on the absolute temperature change but also on the rate of temperature change and level of regional income.[e] In the forestry and agricultural sectors, economic damages also depend on CO_2 concentrations.

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[e] In the deterministic version of FUND, the majority of damages are attributable to increased air conditioning demand, while reduced cold stress in Europe, North America, and Central and East Asia results in health benefits in those regions at low to moderate levels of warming (Warren et al., 2006).

Tol (2009) discusses impacts not included in FUND, noting that many are likely to have a relatively small effect on damage estimates (both positive and negative). However, he characterizes several omitted impacts as “big unknowns”: for instance, extreme climate scenarios, biodiversity loss, and effects on economic development and political violence. With regard to potentially catastrophic events, he notes, “Exactly what would cause these sorts of changes or what effects they would have are not well-understood, although the chance of any one of them happening seems low. But they do have the potential to happen relatively quickly, and if they did, the costs could be substantial. Only a few studies of climate change have examined these issues.”

Adaptation is included both implicitly and explicitly in FUND. Explicit adaptation is seen in the agriculture and sea level rise sectors. Implicit adaptation is included in sectors such as energy and human health, where wealthier populations are assumed to be less vulnerable to climate impacts. For example, the damages to agriculture are the sum of three effects: (1) those due to the rate of temperature change (damages are always positive); (2) those due to the level of temperature change (damages can be positive or negative depending on region and temperature); and (3) those from CO_2 fertilization (damages are generally negative but diminishing to zero).

Adaptation is incorporated into FUND by allowing damages to be smaller if climate change happens more slowly. The combined effect of CO_2 fertilization in the agricultural sector, positive impacts to some regions from higher temperatures, and sufficiently slow increases in temperature across these sectors can result in negative economic damages from climate change.

Damage Functions

To generate revised SCC values, we rely on the IAM modelers’ current best judgments of how to represent the effects of climate change (represented by the increase in global-average surface temperature) on the consumption-equivalent value of both market and non-market goods (represented as a fraction of global GDP). We recognize that these representations are incomplete and highly uncertain. But given the paucity of data linking the physical impacts to economic damages, we were not able to identify a better way to translate changes in climate into net economic damages, short of launching our own research program.

The damage functions for the three IAMs are presented in Figure 14A.4.1 and Figure 14A.4.2, using the modeler’s default scenarios and mean input assumptions. There are significant differences between the three models both at lower (Figure 14A.4.2) and higher (Figure 14A.4.1) increases in global-average temperature.

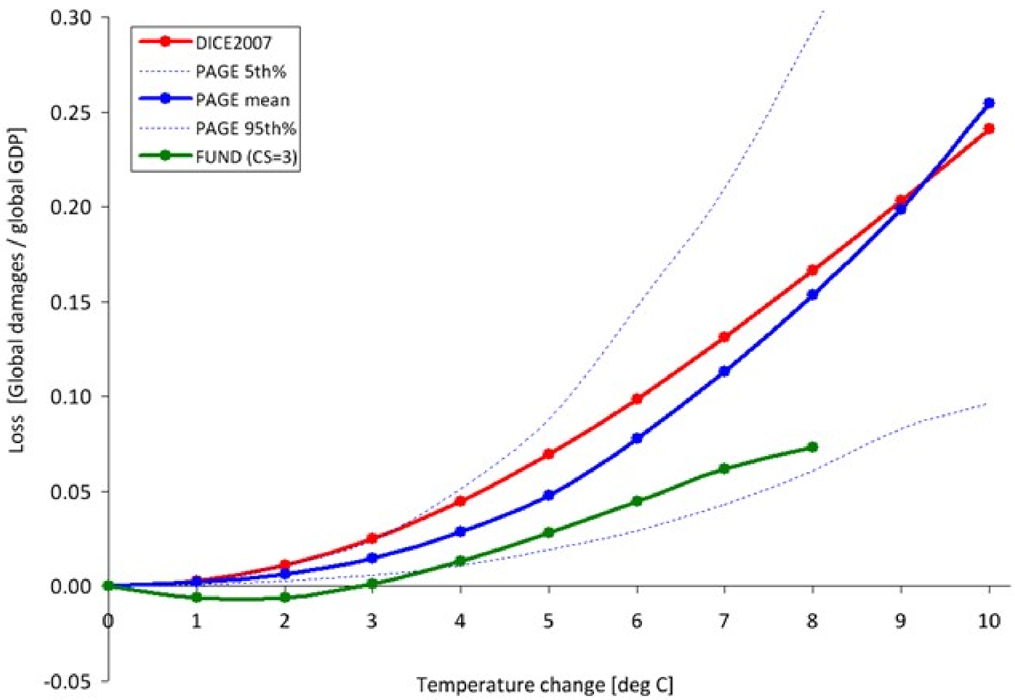

Figure 14A.4.1 Annual Consumption Loss as a Fraction of Global GDP in 2100 Due to an Increase in Annual Global Temperature in the DICE, FUND, and PAGE models[f]

The lack of agreement among the models at lower temperature increases is underscored by the fact that the damages from FUND are well below the 5th percentile estimated by PAGE, while the damages estimated by DICE are roughly equal to the 95th percentile estimated by PAGE. This is significant because at higher discount rates we expect that a greater proportion of the SCC value is due to damages in years with lower temperature increases. For example, when the discount rate is 2.5 percent, about 45 percent of the 2010 SCC value in DICE is due to damages that occur in years when the temperature is less than or equal to 3 °C. This increases to approximately 55 percent and 80 percent at discount rates of 3 and 5 percent, respectively.

These differences underscore the need for a thorough review of damage functions—in particular, how the models incorporate adaptation, technological change, and catastrophic damages. Gaps in the literature make modifying these aspects of the models challenging, which highlights the need for additional research. As knowledge improves, the Federal government is committed to exploring how these (and other) models can be modified to incorporate more accurate estimates of damages.

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[f] The x-axis represents increases in annual, rather than equilibrium, temperature, while the y-axis represents the annual stream of benefits as a share of global GDP. Each specific combination of climate sensitivity, socioeconomic, and emissions parameters will produce a different realization of damages for each IAM. The damage functions represented in Figures 1A and 1B are the outcome of default assumptions. For instance, under alternate assumptions, the damages from FUND may cross from negative to positive at less than or greater than 3 °C.

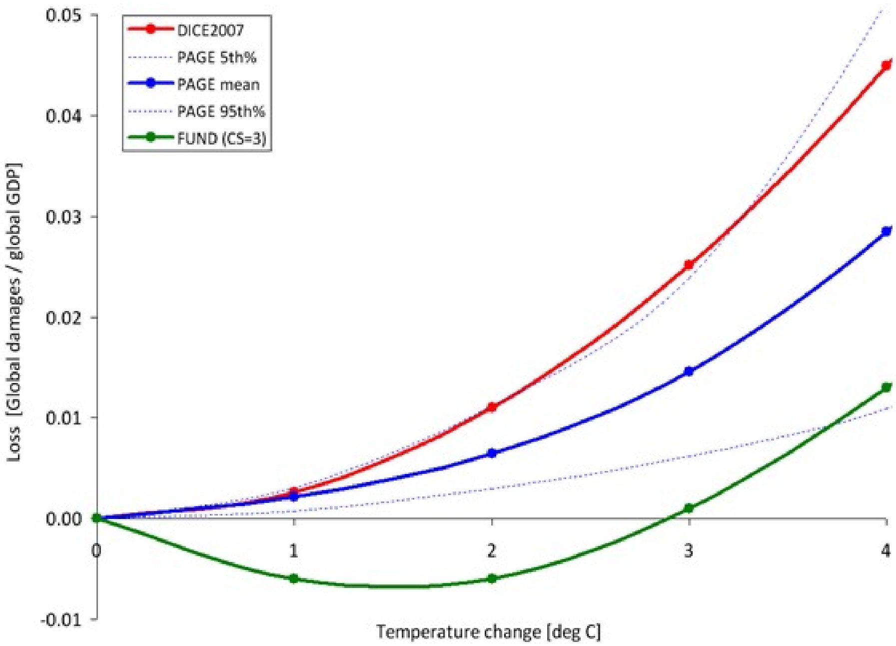

Figure 14A.4.2 Annual Consumption Loss for Lower Temperature Changes in DICE, FUND, and PAGE

14A.4.2 Global versus Domestic Measures of SCC

Because of the distinctive nature of the climate change problem, we center our current attention on a global measure of SCC. This approach is the same as that taken for the interim values, but it otherwise represents a departure from past practices, which tended to put greater emphasis on a domestic measure of SCC (limited to impacts of climate change experienced within U.S. borders). As a matter of law, consideration of both global and domestic values is generally permissible; the relevant statutory provisions are usually ambiguous and allow selection of either measure.[g]

Global SCC

Under current OMB guidance contained in Circular A-4, analysis of economically significant proposed and final regulations from the domestic perspective is required, while analysis from the international perspective is optional. However, the climate change problem is highly unusual in at least two respects. First, it involves a global externality: emissions of most greenhouse gases contribute to damages around the world even when they are emitted in the United States. Consequently, to address the global nature of the problem, the SCC must incorporate the full (global) damages caused by GHG emissions. Second, climate change presents a problem that the United States alone cannot solve. Even if the United States were to

[g] It is true that federal statutes are presumed not to have extraterritorial effect, in part to ensure that the laws of the United States respect the interests of foreign sovereigns. But use of a global measure for the SCC does not give extraterritorial effect to federal law and hence does not intrude on such interests.

reduce its greenhouse gas emissions to zero, that step would be far from enough to avoid substantial climate change. Other countries would also need to take action to reduce emissions if significant changes in the global climate are to be avoided. Emphasizing the need for a global solution to a global problem, the United States has been actively involved in seeking international agreements to reduce emissions and in encouraging other nations, including emerging major economies, to take significant steps to reduce emissions. When these considerations are taken as a whole, the interagency group concluded that a global measure of the benefits from reducing U.S. emissions is preferable.

When quantifying the damages associated with a change in emissions, a number of analysts (*e.g.*, Anthoff, et al. 2009a) employ "equity weighting" to aggregate changes in consumption across regions. This weighting takes into account the relative reductions in wealth in different regions of the world. A per-capita loss of $500 in GDP, for instance, is weighted more heavily in a country with a per-capita GDP of $2,000 than in one with a per-capita GDP of $40,000. The main argument for this approach is that a loss of $500 in a poor country causes a greater reduction in utility or welfare than does the same loss in a wealthy nation. Notwithstanding the theoretical claims on behalf of equity weighting, the interagency group concluded that this approach would not be appropriate for estimating a SCC value used in domestic regulatory analysis.[h] For this reason, the group concluded that using the global (rather than domestic) value, without equity weighting, is the appropriate approach.

Domestic SCC

As an empirical matter, the development of a domestic SCC is greatly complicated by the relatively few region- or country-specific estimates of the SCC in the literature. One potential source of estimates comes from the FUND model. The resulting estimates suggest that the ratio of domestic to global benefits of emission reductions varies with key parameter assumptions. For example, with a 2.5 or 3 percent discount rate, the U.S. benefit is about 7-10 percent of the global benefit, on average, across the scenarios analyzed. Alternatively, if the fraction of GDP lost due to climate change is assumed to be similar across countries, the domestic benefit would be proportional to the U.S. share of global GDP, which is currently about 23 percent.[i]

On the basis of this evidence, the interagency workgroup determined that a range of values from 7 to 23 percent should be used to adjust the global SCC to calculate domestic effects. Reported domestic values should use this range. It is recognized that these values are approximate, provisional, and highly speculative. There is no a priori reason why domestic benefits should be a constant fraction of net global damages over time. Further, FUND does not account for how damages in other regions could affect the United States (*e.g.*, global migration,

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[h] It is plausible that a loss of $X inflicts more serious harm on a poor nation than on a wealthy one, but development of the appropriate "equity weight" is challenging. Emissions reductions also impose costs, and hence a full account would have to consider that a given cost of emissions reductions imposes a greater utility or welfare loss on a poor nation than on a wealthy one. Even if equity weighting—for both the costs and benefits of emissions reductions—is appropriate when considering the utility or welfare effects of international action, the interagency group concluded that it should not be used in developing an SCC for use in regulatory policy at this time.

[i] Based on 2008 GDP (in current US dollars) from the *World Bank Development Indicators Report*.

economic and political destabilization). If more accurate methods for calculating the domestic SCC become available, the Federal government will examine these to determine whether to update its approach.

14A.4.3 Valuing Non-CO_2 Emissions

While CO_2 is the most prevalent greenhouse gas emitted into the atmosphere, the U.S. included five other greenhouse gases in its recent endangerment finding: methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride. The climate impact of these gases is commonly discussed in terms of their 100-year global warming potential (GWP). GWP measures the ability of different gases to trap heat in the atmosphere (*i.e.*, radiative forcing per unit of mass) over a particular timeframe relative to CO_2. However, because these gases differ in both radiative forcing and atmospheric lifetimes, their relative damages are not constant over time. For example, because methane has a short lifetime, its impacts occur primarily in the near term and thus are not discounted as heavily as those caused by longer-lived gases. Impacts other than temperature change also vary across gases in ways that are not captured by GWP. For instance, CO_2 emissions, unlike methane and other greenhouse gases, contribute to ocean acidification. Likewise, damages from methane emissions are not offset by the positive effect of CO_2 fertilization. Thus, transforming gases into CO_2-equivalents using GWP, and then multiplying the carbon-equivalents by the SCC, would not result in accurate estimates of the social costs of non-CO_2 gases.

In light of these limitations, and the significant contributions of non-CO_2 emissions to climate change, further research is required to link non-CO_2 emissions to economic impacts. Such work would feed into efforts to develop a monetized value of reductions in non-CO_2 greenhouse gas emissions. As part of ongoing work to further improve the SCC estimates, the interagency group hopes to develop methods to value these other greenhouse gases. The goal is to develop these estimates by the time we issue revised SCC estimates for carbon dioxide emissions.

14A.4.4 Equilibrium Climate Sensitivity

Equilibrium climate sensitivity (ECS) is a key input parameter for the DICE, PAGE, and FUND models.[j] It is defined as the long-term increase in the annual global-average surface temperature from a doubling of atmospheric CO_2 concentration relative to pre-industrial levels (or stabilization at a concentration of approximately 550 parts per million (ppm)). Uncertainties in this important parameter have received substantial attention in the peer-reviewed literature.

The most authoritative statement about equilibrium climate sensitivity appears in the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC):

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[j] The equilibrium climate sensitivity includes the response of the climate system to increased greenhouse gas concentrations over the short to medium term (up to 100-200 years), but it does not include long-term feedback effects due to possible large-scale changes in ice sheets or the biosphere, which occur on a time scale of many hundreds to thousands of years (*e.g.* Hansen et al. 2007).

Basing our assessment on a combination of several independent lines of evidence…including observed climate change and the strength of known feedbacks simulated in [global climate models], we conclude that the global mean equilibrium warming for doubling CO_2, or 'equilibrium climate sensitivity', is likely to lie in the range 2 °C to 4.5 °C, with a most likely value of about 3 °C. Equilibrium climate sensitivity is very likely larger than 1.5 °C. [k]

For fundamental physical reasons as well as data limitations, values substantially higher than 4.5 °C still cannot be excluded, but agreement with observations and proxy data is generally worse for those high values than for values in the 2 °C to 4.5 °C range. (Meehl et al., 2007, p 799)

After consulting with several lead authors of this chapter of the IPCC report, the interagency workgroup selected four candidate probability distributions and calibrated them to be consistent with the above statement: Roe and Baker (2007), log-normal, gamma, and Weibull. Table 14A.4.1 included below gives summary statistics for the four calibrated distributions.

Table 14A.4.1 Summary Statistics for Four Calibrated Climate Sensitivity Distributions

	Roe & Baker	Log-normal	Gamma	Weibull
Pr(ECS < 1.5°C)	0.013	0.050	0.070	0.102
Pr(2°C < ECS < 4.5°C)	0.667	0.667	0.667	0.667
5th percentile	1.72	1.49	1.37	1.13
10th percentile	1.91	1.74	1.65	1.48
Mode	2.34	2.52	2.65	2.90
Median (50th percentile)	3.00	3.00	3.00	3.00
Mean	3.50	3.28	3.19	3.07
90th percentile	5.86	5.14	4.93	4.69
95th percentile	7.14	5.97	5.59	5.17

Each distribution was calibrated by applying three constraints from the IPCC:

(1) a median equal to 3°C, to reflect the judgment of "a most likely value of about 3 °C";[l]

[k] This is in accord with the judgment that it "is likely to lie in the range 2 °C to 4.5 °C" and the IPCC definition of "likely" as greater than 66 percent probability (Le Treut et al.2007). "Very likely" indicates a greater than 90 percent probability.

[l] Strictly speaking, "most likely" refers to the mode of a distribution rather than the median, but common usage would allow the mode, median, or mean to serve as candidates for the central or "most likely" value and the IPCC report is not specific on this point. For the distributions we considered, the median was between the mode and the mean. For the Roe and Baker distribution, setting the median equal to 3°C, rather than the mode or mean, gave a 95th percentile that is more consistent with IPCC judgments and the literature. For example, setting the mean and mode equal to 3°C produced 95th percentiles of 5.6 and 8.6 °C, respectively, which are in the lower and upper end of the range in the literature. Finally, the median is closer to 3°C than is the mode for the truncated distributions selected by the IPCC (Hegerl, et al., 2006); the average median is 3.1 °C and the average mode is 2.3 °C, which is most consistent with a Roe and Baker distribution with the median set equal to 3 °C.

(2) two-thirds probability that the equilibrium climate sensitivity lies between 2 and 4.5 °C; and
(3) zero probability that it is less than 0°C or greater than 10°C (see Hegerl et al. 2006, p. 721).

We selected the calibrated Roe and Baker distribution from the four candidates for two reasons. First, the Roe and Baker distribution is the only one of the four that is based on a theoretical understanding of the response of the climate system to increased greenhouse gas concentrations (Roe and Baker 2007, Roe 2008). In contrast, the other three distributions are mathematical functions that are arbitrarily chosen based on simplicity, convenience, and general shape. The Roe and Baker distribution results from three assumptions about climate response: (1) absent feedback effects, the equilibrium climate sensitivity is equal to 1.2 °C; (2) feedback factors are proportional to the change in surface temperature; and (3) uncertainties in feedback factors are normally distributed. There is widespread agreement on the first point and the second and third points are common assumptions.

Second, the calibrated Roe and Baker distribution better reflects the IPCC judgment that "values substantially higher than 4.5°C still cannot be excluded." Although the IPCC made no quantitative judgment, the 95th percentile of the calibrated Roe & Baker distribution (7.1 °C) is much closer to the mean and the median (7.2 °C) of the 95th percentiles of 21 previous studies summarized by Newbold and Daigneault (2009). It is also closer to the mean (7.5 °C) and median (7.9 °C) of the nine truncated distributions examined by the IPCC (Hegerl, et al., 2006) than are the 95th percentiles of the three other calibrated distributions (5.2-6.0 °C).

Finally, we note the IPCC judgment that the equilibrium climate sensitivity "is very likely larger than 1.5°C." Although the calibrated Roe & Baker distribution, for which the probability of equilibrium climate sensitivity being greater than 1.5 °C is almost 99 percent, is not inconsistent with the IPCC definition of "very likely" as "greater than 90 percent probability," it reflects a greater degree of certainty about very low values of ECS than was expressed by the IPCC.

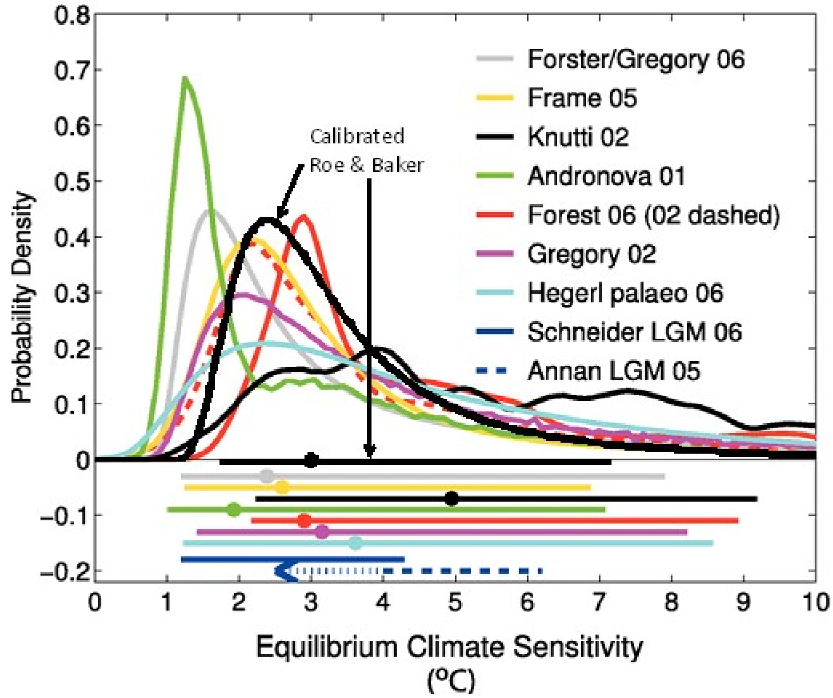

Figure 14A.4.3 Estimates of the Probability Density Function for Equilibrium Climate Sensitivity (°C)

To show how the calibrated Roe and Baker distribution compares to different estimates of the probability distribution function of equilibrium climate sensitivity in the empirical literature, Figure 14A.4.3 (above) overlays it on Figure 9.20 from the IPCC Fourth Assessment Report. These functions are scaled to integrate to unity between 0 °C and 10 °C. The horizontal bars show the respective 5 percent to 95 percent ranges; dots indicate the median estimate.[m]

14A.4.5 Socioeconomic and Emissions Trajectories

Another key issue considered by the interagency group is how to select the set of socioeconomic and emissions parameters for use in PAGE, DICE, and FUND. Socioeconomic pathways are closely tied to climate damages because, all else equal, more and wealthier people tend to emit more greenhouse gases and also have a higher (absolute) willingness to pay to avoid climate disruptions. For this reason, we consider how to model several input parameters in tandem: GDP, population, CO_2 emissions, and non-CO_2 radiative forcing. A wide variety of scenarios have been developed and used for climate change policy simulations (*e.g.*, SRES 2000, CCSP 2007, EMF 2009). In determining which scenarios are appropriate for inclusion, we aimed to select scenarios that span most of the plausible ranges of outcomes for these variables.

[m] The estimates based on instrumental data are from Andronova and Schlesinger (2001), Forest et al. (2002; dashed line, anthropogenic forcings only), Forest et al. (2006; solid line, anthropogenic and natural forcings), Gregory et al. (2002a), Knutti et al. (2002), Frame et al. (2005), and Forster and Gregory (2006). Hegerl et al. (2006) are based on multiple palaeoclimatic reconstructions of north hemisphere mean temperatures over the last 700 years. Also shown are the 5-95 percent approximate ranges for two estimates from the last glacial maximum (dashed, Annan et al. 2005; solid, Schneider von Deimling et al. 2006), which are based on models with different structural properties.

To accomplish this task in a transparent way, we decided to rely on the recent Stanford Energy Modeling Forum exercise, EMF-22. EMF-22 uses ten well-recognized models to evaluate substantial, coordinated global action to meet specific stabilization targets. A key advantage of relying on these data is that GDP, population, and emission trajectories are internally consistent for each model and scenario evaluated. The EMF-22 modeling effort also is preferable to the IPCC SRES due to their age (SRES were developed in 1997) and the fact that 3 of 4 of the SRES scenarios are now extreme outliers in one or more variables. Although the EMF-22 scenarios have not undergone the same level of scrutiny as the SRES scenarios, they are recent, peer-reviewed, published, and publicly available.

To estimate the SCC for use in evaluating domestic policies that will have a small effect on global cumulative emissions, we use socioeconomic and emission trajectories that span a range of plausible scenarios. Five trajectories were selected from EMF-22 (see Table 14A.4.2 below). Four of these represent potential business-as-usual (BAU) growth in population, wealth, and emissions and are associated with CO_2 (only) concentrations ranging from 612 to 889 ppm in 2100. One represents an emissions pathway that achieves stabilization at 550 ppm CO_2e (i.*e.*, CO_2-only concentrations of 425 – 484 ppm or a radiative forcing of 3.7 W/m^2) in 2100, a lower-than-BAU trajectory.[n] Out of the 10 models included in the EMF-22 exercise, we selected the trajectories used by MiniCAM, MESSAGE, IMAGE, and the optimistic scenario from MERGE. For the BAU pathways, we used the GDP, population, and emission trajectories from each of these four models. For the 550 ppm CO_2e scenario, we averaged the GDP, population, and emission trajectories implied by these same four models.

[n] Such an emissions path would be consistent with widespread action by countries to mitigate GHG emissions, though it could also result from technological advances. It was chosen because it represents the most stringent case analyzed by the EMF-22 where all the models converge: a 550 ppm, not to exceed, full participation scenario.

Table 14A.4.2 Socioeconomic and Emissions Projections from Select EMF-22 Reference Scenarios

Reference Fossil and Industrial CO_2 Emissions ($GtCO_2$/yr)

EMF – 22 Based Scenarios	2000	2010	2020	2030	2050	2100
IMAGE	26.6	31.9	36.9	40.0	45.3	60.1
MERGE Optimistic	24.6	31.5	37.6	45.1	66.5	117.9
MESSAGE	26.8	29.2	37.6	42.1	43.5	42.7
MiniCAM	26.5	31.8	38.0	45.1	57.8	80.5
550 ppm average	26.2	31.1	33.2	32.4	20.0	12.8

Reference GDP (using market exchange rates in trillion 2005$)[o]

EMF – 22 Based Scenarios	2000	2010	2020	2030	2050	2100
IMAGE	38.6	53.0	73.5	97.2	156.3	396.6
MERGE Optimistic	36.3	45.9	59.7	76.8	122.7	268.0
MESSAGE	38.1	52.3	69.4	91.4	153.7	334.9
MiniCAM	36.1	47.4	60.8	78.9	125.7	369.5
550 ppm average	37.1	49.6	65.6	85.5	137.4	337.9

Global Population (billions)

EMF – 22 Based Scenarios	2000	2010	2020	2030	2050	2100
IMAGE	6.1	6.9	7.6	8.2	9.0	9.1
MERGE Optimistic	6.0	6.8	7.5	8.2	9.0	9.7
MESSAGE	6.1	6.9	7.7	8.4	9.4	10.4
MiniCAM	6.0	6.8	7.5	8.1	8.8	8.7
550 ppm average	6.1	6.8	7.6	8.2	8.7	9.1

We explore how sensitive the SCC is to various assumptions about how the future will evolve without prejudging what is likely to occur. The interagency group considered formally assigning probability weights to different states of the world, but this proved challenging to do in an analytically rigorous way given the dearth of information on the likelihood of a full range of future socioeconomic pathways.

[o] While the EMF-22 models used market exchange rates (MER) to calculate global GDP, it is also possible to use purchasing power parity (PPP). PPP takes into account the different price levels across countries, so it more accurately describes relative standards of living across countries. MERs tend to make low-income countries appear poorer than they actually are. Because many models assume convergence in per capita income over time, use of MER-adjusted GDP gives rise to projections of higher economic growth in low income countries. There is an ongoing debate about how much this will affect estimated climate impacts. Critics of the use of MER argue that it leads to overstated economic growth and hence a significant upward bias in projections of greenhouse gas emissions, and unrealistically high future temperatures (*e.g.*, Castles and Henderson 2003). Others argue that convergence of the emissions-intensity gap across countries at least partially offset the overstated income gap so that differences in exchange rates have less of an effect on emissions (Holtsmark and Alfsen, 2005; Tol, 2006). Nordhaus (2007b) argues that the ideal approach is to use superlative PPP accounts (i.e., using cross-sectional PPP measures for relative incomes and outputs and national accounts price and quantity indexes for time-series extrapolations). However, he notes that it important to keep this debate in perspective; it is by no means clear that exchange-rate-conversion issues are as important as uncertainties about population, technological change, or the many geophysical uncertainties.

There are a number of caveats. First, EMF BAU scenarios represent the modelers' judgment of the most likely pathway absent mitigation policies to reduce greenhouse gas emissions, rather than the wider range of possible outcomes. Nevertheless, these views of the most likely outcome span a wide range, from the more optimistic (*e.g.*, abundant low-cost, low-carbon energy) to more pessimistic (*e.g.*, constraints on the availability of nuclear and renewables).[p] Second, the socioeconomic trajectories associated with a 550 ppm CO_2e concentration scenario are not derived from an assessment of what policy is optimal from a benefit-cost standpoint. Rather, it is indicative of one possible future outcome. The emission trajectories underlying some BAU scenarios (*e.g.*, MESSAGE's 612 ppm) also are consistent with some modest policy action to address climate change.[q] We chose not to include socioeconomic trajectories that achieve even lower GHG concentrations at this time, given the difficulty many models had in converging to meet these targets.

For comparison purposes, the Energy Information Agency in its 2009 Annual Energy Outlook projected that global carbon dioxide emissions will grow to 30.8, 35.6, and 40.4 gigatons in 2010, 2020, and 2030, respectively, while world GDP is projected to be $51.8, $71.0 and $93.9 trillion (in 2005 dollars using market exchange rates) in 2010, 2020, and 2030, respectively. These projections are consistent with one or more EMF-22 scenarios. Likewise, the United Nations' 2008 Population Prospect projects population will grow from 6.1 billion people in 2000 to 9.1 billion people in 2050, which is close to the population trajectories for the IMAGE, MiniCAM, and MERGE models.

In addition to fossil and industrial CO_2 emissions, each EMF scenario provides projections of methane, nitrous oxide, fluorinated greenhouse gases, and net land use CO_2 emissions out to 2100. These assumptions also are used in the three models while retaining the default radiative forcings due to other factors (*e.g.*, aerosols and other gases). See the Annex for greater detail.

14A.4.6 Discount Rate

The choice of a discount rate, especially over long periods of time, raises highly contested and exceedingly difficult questions of science, economics, philosophy, and law. Although it is well understood that the discount rate has a large influence on the current value of future damages, there is no consensus about what rates to use in this context. Because carbon dioxide emissions are long-lived, subsequent damages occur over many years. In calculating the SCC, we first estimate the future damages to agriculture, human health, and other market and non-market sectors from an additional unit of carbon dioxide emitted in a particular year in terms of reduced consumption (or consumption equivalents) due to the impacts of elevated temperatures, as represented in each of the three IAMs. Then we discount the stream of future damages to its present value in the year when the additional unit of emissions was released using

[p] For instance, in the MESSAGE model's reference case total primary energy production from nuclear, biomass, and non-biomass renewables is projected to increase from about 15 percent of total primary energy in 2000 to 54 percent in 2100. In comparison, the MiniCAM reference case shows 10 percent in 2000 and 21 percent in 2100.
[q] For example, MiniCAM projects if all non-US OECD countries reduce CO_2 emissions to 83 percent below 2005 levels by 2050 (per the G-8 agreement) but all other countries continue along a BAU path CO_2 concentrations in 2100 would drop from 794 ppmv in its reference case to 762 ppmv.

the selected discount rate, which is intended to reflect society's marginal rate of substitution between consumption in different time periods.

For rules with both intra- and intergenerational effects, agencies traditionally employ constant discount rates of both 3 percent and 7 percent in accordance with OMB Circular A-4. As Circular A-4 acknowledges, however, the choice of discount rate for intergenerational problems raises distinctive problems and presents considerable challenges. After reviewing those challenges, Circular A-4 states, “If your rule will have important intergenerational benefits or costs you might consider a further sensitivity analysis using a lower but positive discount rate in addition to calculating net benefits using discount rates of 3 and 7 percent.” For the specific purpose of developing the SCC, we adapt and revise that approach here.

Arrow et al. (1996) outlined two main approaches to determine the discount rate for climate change analysis, which they labeled “descriptive” and “prescriptive.” The descriptive approach reflects a positive (non-normative) perspective based on observations of people’s actual choices—*e.g.,* savings versus consumption decisions over time, and allocations of savings among more and less risky investments. Advocates of this approach generally call for inferring the discount rate from market rates of return “because of a lack of justification for choosing a social welfare function that is any different than what decision makers [individuals] actually use” (Arrow et al. 1996).

One theoretical foundation for the cost-benefit analyses in which the social cost of carbon will be used—the Kaldor-Hicks potential-compensation test—also suggests that market rates should be used to discount future benefits and costs, because it is the market interest rate that would govern the returns potentially set aside today to compensate future individuals for climate damages that they bear (*e.g.*, Just et al. 2004). As some have noted, the word “potentially” is an important qualification; there is no assurance that such returns will actually be set aside to provide compensation, and the very idea of compensation is difficult to define in the intergenerational context. On the other hand, societies provide compensation to future generations through investments in human capital and the resulting increase in knowledge, as well as infrastructure and other physical capital.

The prescriptive approach specifies a social welfare function that formalizes the normative judgments that the decision-maker wants explicitly to incorporate into the policy evaluation—*e.g.*, how inter-personal comparisons of utility should be made, and how the welfare of future generations should be weighed against that of the present generation. Ramsey (1928), for example, has argued that it is “ethically indefensible” to apply a positive pure rate of time preference to discount values across generations, and many agree with this view.

Other concerns also motivate making adjustments to descriptive discount rates. In particular, it has been noted that the preferences of future generations with regard to consumption versus environmental amenities may not be the same as those today, making the current market rate on consumption an inappropriate metric by which to discount future climate-related damages. Others argue that the discount rate should be below market rates to correct for market distortions and uncertainties or inefficiencies in intergenerational transfers of wealth, which in the Kaldor-Hicks logic are presumed to compensate future generations for damage (a potentially controversial assumption, as noted above) (Arrow et al. 1996, Weitzman 1999).

Further, a legitimate concern about both descriptive and prescriptive approaches is that they tend to obscure important heterogeneity in the population. The utility function that underlies the prescriptive approach assumes a representative agent with perfect foresight and no credit constraints. This is an artificial rendering of the real world that misses many of the frictions that characterize individuals' lives and indeed the available descriptive evidence supports this. For instance, many individuals smooth consumption by borrowing with credit cards that have relatively high rates. Some are unable to access traditional credit markets and rely on payday lending operations or other high-cost forms of smoothing consumption. Whether one puts greater weight on the prescriptive or descriptive approach, the high interest rates that credit-constrained individuals accept suggest that some account should be given to the discount rates revealed by their behavior.

We draw on both approaches but rely primarily on the descriptive approach to inform the choice of discount rate. With recognition of its limitations, we find this approach to be the most defensible and transparent given its consistency with the standard contemporary theoretical foundations of benefit-cost analysis and with the approach required by OMB's existing guidance. The logic of this framework also suggests that market rates should be used for discounting future consumption-equivalent damages. Regardless of the theoretical approach used to derive the appropriate discount rate(s), we note the inherent conceptual and practical difficulties of adequately capturing consumption trade-offs over many decades or even centuries. While relying primarily on the descriptive approach in selecting specific discount rates, the interagency group has been keenly aware of the deeply normative dimensions of both the debate over discounting in the intergenerational context and the consequences of selecting one discount rate over another.

Historically Observed Interest Rates

In a market with no distortions, the return to savings would equal the private return on investment, and the market rate of interest would be the appropriate choice for the social discount rate. In the real world risk, taxes, and other market imperfections drive a wedge between the risk-free rate of return on capital and the consumption rate of interest. Thus, the literature recognizes two conceptual discount concepts—the consumption rate of interest and the opportunity cost of capital.

According to OMB's Circular A-4, it is appropriate to use the rate of return on capital when a regulation is expected to displace or alter the use of capital in the private sector. In this case, OMB recommends Agencies use a discount rate of 7 percent. When regulation is expected to primarily affect private consumption—for instance, via higher prices for goods and services—a lower discount rate of 3 percent is appropriate to reflect how private individuals trade-off current and future consumption.

The interagency group examined the economics literature and concluded that the consumption rate of interest is the correct concept to use in evaluating the benefits and costs of a marginal change in carbon emissions (see Lind 1990, Arrow et al 1996, and Arrow 2000). The consumption rate of interest also is appropriate when the impacts of a regulation are measured in consumption (-equivalent) units, as is done in the three integrated assessment models used for estimating the SCC.

Individuals use a variety of savings instruments that vary with risk level, time horizon, and tax characteristics. The standard analytic framework used to develop intuition about the discount rate typically assumes a representative agent with perfect foresight and no credit constraints. The risk-free rate is appropriate for discounting certain future benefits or costs, but the benefits calculated by IAMs are uncertain. To use the risk-free rate to discount uncertain benefits, these benefits first must be transformed into "certainty equivalents," that is the maximum certain amount that we would exchange for the uncertain amount. However, the calculation of the certainty-equivalent requires first estimating the correlation between the benefits of the policy and baseline consumption.

If the IAM projections of future impacts represent expected values (not certainty-equivalent values), then the appropriate discount rate generally does not equal the risk-free rate. If the benefits of the policy tend to be high in those states of the world in which consumption is low, then the certainty-equivalent benefits will be higher than the expected benefits (and vice versa). Since many (though not necessarily all) of the important impacts of climate change will flow through market sectors such as agriculture and energy, and since willingness to pay for environmental protections typically increases with income, we might expect a positive (though not necessarily perfect) correlation between the net benefits from climate policies and market returns. This line of reasoning suggests that the proper discount rate would exceed the riskless rate. Alternatively, a negative correlation between the returns to climate policies and market returns would imply that a discount rate below the riskless rate is appropriate.

This discussion suggests that both the post-tax riskless and risky rates can be used to capture individuals' consumption-equivalent interest rate. As a measure of the post-tax riskless rate, we calculate the average real return from Treasury notes over the longest time period available (those from Newell and Pizer 2003) and adjust for Federal taxes (the average marginal rate from tax years 2003 through 2006 is around 27 percent).[r] This calculation produces a real interest rate of about 2.7 percent, which is roughly consistent with Circular A-4's recommendation to use 3 percent to represent the consumption rate of interest.[s] A measure of the post-tax risky rate for investments whose returns are positively correlated with overall equity market returns can be obtained by adjusting pre-tax rates of household returns to risky investments (approximately 7 percent) for taxes, which yields a real rate of roughly 5 percent.[t]

[r] The literature argues for a risk-free rate on government bonds as an appropriate measure of the consumption rate of interest. Arrow (2000) suggests that it is roughly 3-4 percent. OMB cites evidence of a 3.1 percent pre-tax rate for 10-year Treasury notes in the A-4 guidance. Newell and Pizer (2003) find real interest rates between 3.5 and 4 percent for 30-year Treasury securities.

[s] The positive approach reflects how individuals make allocation choices across time, but it is important to keep in mind that we wish to reflect preferences for society as a whole, which generally has a longer planning horizon.

[t] Cambell et al (2001) estimates that the annual real return from stocks for 1900-1995 was about 7 percent. The annual real rate of return for the S&P 500 from 1950 – 2008 was about 6.8 percent. In the absence of a better way to population-weight the tax rates, we use the middle of the 20 – 40 percent range to derive a post-tax interest rate (Kotlikoff and Rapson 2006).

The Ramsey Equation

Ramsey discounting also provides a useful framework to inform the choice of a discount rate. Under this approach, the analyst applies either positive or normative judgments in selecting values for the key parameters of the Ramsey equation: η (coefficient of relative risk aversion or elasticity of the marginal utility of consumption) and ρ (pure rate of time preference).[u] These are then combined with g (growth rate of per-capita consumption) to equal the interest rate at which future monetized damages are discounted: $\rho + \eta \cdot g$.[v] In the simplest version of the Ramsey model, with an optimizing representative agent with perfect foresight, what we are calling the "Ramsey discount rate," $\rho + \eta \cdot g$, will be equal to the rate of return to capital, *i.e.*, the market interest rate.

A review of the literature provides some guidance on reasonable parameter values for the Ramsey discounting equation, based on both prescriptive and descriptive approaches.

- η. Most papers in the climate change literature adopt values for η in the range of 0.5 to 3 (Weitzman cites plausible values as those ranging from 1 to 4), although not all authors articulate whether their choice is based on prescriptive or descriptive reasoning.[w] Dasgupta (2008) argues that η should be greater than 1 and may be as high as 3, because η equal to 1 suggests savings rates that do not conform to observed behavior.

- ρ. With respect to the pure rate of time preference, most papers in the climate change literature adopt values for ρ in the range of 0 to 3 percent per year. The very low rates tend to follow from moral judgments involving intergenerational neutrality. Some have argued that to use any value other than $\rho = 0$ would unjustly discriminate against future generations (*e.g.*, Arrow et al. 1996, Stern et al. 2006). However, even in an inter-

[u] The parameter ρ measures the *pure rate of time preference*: people's behavior reveals a preference for an increase in utility today versus the future. Consequently, it is standard to place a lower weight on utility in the future. The parameter η captures *diminishing marginal utility*: consumption in the future is likely to be higher than consumption today, so diminishing marginal utility of consumption implies that the same monetary damage will cause a smaller reduction of utility for wealthier individuals, either in the future or in current generations. If $\eta = 0$, then a one dollar increase in income is equally valuable regardless of level of income; if $\eta = 1$, then a one percent increase in income is equally valuable no matter the level of income; and if $\eta > 1$, then a one percent increase in income is less valuable to wealthier individuals.
[v] In this case, g could be taken from the selected EMF socioeconomic scenarios or alternative assumptions about the rate of consumption growth.
[w] Empirical estimates of η span a wide range of values. A benchmark value of 2 is near the middle of the range of values estimated or used by Szpiro (1986), Hall and Jones (2007), Arrow (2007), Dasgupta (2006, 2008), Weitzman (2007, 2009), and Nordhaus (2008). However, Chetty (2006) developed a method of estimating η using data on labor supply behavior. He shows that existing evidence of the effects of wage changes on labor supply imposes a tight upper bound on the curvature of utility over wealth (CRRA < 2) with the mean implied value of 0.71 and concludes that the standard expected utility model cannot generate high levels of risk aversion without contradicting established facts about labor supply. Recent work has jointly estimated the components of the Ramsey equation. Evans and Sezer (2005) estimate $\eta = 1.49$ for 22 OECD countries. They also estimate $\rho = 1.08$ percent per year using data on mortality rates. Anthoff, et al. (2009b) estimate $\eta = 1.18$, and $\rho = 1.4$ percent. When they multiply the bivariate probability distributions from their work and Evans and Sezer (2005) together, they find $\eta = 1.47$, and $\rho = 1.07$.

generational setting, it may make sense to use a small positive pure rate of time preference because of the small probability of unforeseen cataclysmic events (Stern et al. 2006).

- g. A commonly accepted approximation is around 2 percent per year. For the socioeconomic scenarios used for this exercise, the EMF models assume that g is about 1.5-2 percent to 2100.

Some economists and non-economists have argued for constant discount rates below 2 percent based on the prescriptive approach. When grounded in the Ramsey framework, proponents of this approach have argued that a ρ of zero avoids giving preferential treatment to one generation over another. The choice of η has also been posed as an ethical choice linked to the value of an additional dollar in poorer countries compared to wealthier ones. Stern et al. (2006) applies this perspective through his choice of $\rho = 0.1$ percent per year, $\eta = 1$ and $g = 1.3$ percent per year, which yields an annual discount rate of 1.4 percent. In the context of permanent income savings behavior, however, Stern's assumptions suggest that individuals would save 93 percent of their income.[x]

Recently, Stern (2008) revisited the values used in Stern et al. (2006), stating that there is a case to be made for raising η due to the amount of weight lower values place on damages far in the future (over 90 percent of expected damages occur after 2200 with $\eta = 1$). Using Stern's assumption that $\rho = 0.1$ percent, combined with a η of 1.5 to 2 and his original growth rate, yields a discount rate of greater than 2 percent.

We conclude that arguments made under the prescriptive approach can be used to justify discount rates between roughly 1.4 and 3.1 percent. In light of concerns about the most appropriate value for η, we find it difficult to justify rates at the lower end of this range under the Ramsey framework.

Accounting for Uncertainty in the Discount Rate

While the consumption rate of interest is an important driver of the benefits estimate, it is uncertain over time. Ideally, we would formally model this uncertainty, just as we do for climate sensitivity. Weitzman (1998, 2001) showed theoretically and Newell and Pizer (2003) and Groom et al. (2006) confirm empirically that discount rate uncertainty can have a large effect on net present values. A main result from these studies is that if there is a persistent element to the uncertainty in the discount rate (*e.g.*, the rate follows a random walk), then it will result in an effective (or certainty-equivalent) discount rate that declines over time. Consequently, lower discount rates tend to dominate over the very long term (see Weitzman 1998, 1999, 2001; Newell and Pizer 2003; Groom et al. 2006; Gollier 2008; Summers and Zeckhauser 2008; and Gollier and Weitzman 2009).

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[x] Stern (2008) argues that building in a positive rate of exogenous technical change over time reduces the implied savings rate and that η at or above 2 are inconsistent with observed behavior with regard to equity. (At the same time, adding exogenous technical change—all else equal—would increase g as well.)

The proper way to model discount rate uncertainty remains an active area of research. Newell and Pizer (2003) employ a model of how long-term interest rates change over time to forecast future discount rates. Their model incorporates some of the basic features of how interest rates move over time, and its parameters are estimated based on historical observations of long-term rates. Subsequent work on this topic, most notably Groom et al. (2006), uses more general models of interest rate dynamics to allow for better forecasts. Specifically, the volatility of interest rates depends on whether rates are currently low or high and the variation in the level of persistence over time.

While Newell and Pizer (2003) and Groom et al (2006) attempt formally to model uncertainty in the discount rate, others argue for a declining scale of discount rates applied over time (*e.g.*, Weitzman 2001, and the UK's "Green Book" for regulatory analysis). This approach uses a higher discount rate initially, but applies a graduated scale of lower discount rates further out in time.[y] A key question that has emerged with regard to both of these approaches is the trade-off between potential time inconsistency and giving greater weight to far future outcomes (see the EPA Science Advisory Board's recent comments on this topic as part of its review of their *Guidelines for Economic Analysis*).[z]

The Discount Rates Selected for Estimating SCC

In light of disagreement in the literature on the appropriate market interest rate to use in this context and uncertainty about how interest rates may change over time, we use three discount rates to span a plausible range of certainty-equivalent constant discount rates: 2.5, 3, and 5 percent per year. Based on the review in the previous sections, the interagency workgroup determined that these three rates reflect reasonable judgments under both descriptive and prescriptive approaches.

The central value, 3 percent, is consistent with estimates provided in the economics literature and OMB's Circular A-4 guidance for the consumption rate of interest. As previously mentioned, the consumption rate of interest is the correct discounting concept to use when future damages from elevated temperatures are estimated in consumption-equivalent units. Further, 3 percent roughly corresponds to the after-tax riskless interest rate. The upper value of 5 percent is included to represent the possibility that climate damages are positively correlated with market returns. Additionally, this discount rate may be justified by the high interest rates that many consumers use to smooth consumption across periods.

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[y] For instance, the UK applies a discount rate of 3.5 percent to the first 30 years; 3 percent for years 31 - 75; 2.5 percent for years 76 - 125; 2 percent for years 126 - 200; 1.5 percent for years 201 - 300; and 1 percent after 300 years. As a sensitivity, it recommends a discount rate of 3 percent for the first 30 years, also decreasing over time.

[z] Uncertainty in future damages is distinct from uncertainty in the discount rate. Weitzman (2008) argues that Stern's choice of a low discount rate was "right for the wrong reasons." He demonstrates how the damages from a low probability, catastrophic event far in the future dominate the effect of the discount rate in a present value calculation and result in an infinite willingness-to-pay for mitigation today. Newbold and Daigneault, (2009) and Nordhaus (2009) find that Weitzman's result is sensitive to the functional forms chosen for climate sensitivity, utility, and consumption. Summers and Zeckhauser (2008) argue that uncertainty in future damages can also work in the other direction by increasing the benefits of waiting to learn the appropriate level of mitigation required.

The low value, 2.5 percent, is included to incorporate the concern that interest rates are highly uncertain over time. It represents the average certainty-equivalent rate using the mean-reverting and random walk approaches from Newell and Pizer (2003) starting at a discount rate of 3 percent. Using this approach, the certainty equivalent is about 2.2 percent using the random walk model and 2.8 percent using the mean reverting approach.[aa] Without giving preference to a particular model, the average of the two rates is 2.5 percent. Further, a rate below the riskless rate would be justified if climate investments are negatively correlated with the overall market rate of return. Use of this lower value also responds to certain judgments using the prescriptive or normative approach and to ethical objections that have been raised about rates of 3 percent or higher.

14A.5 REVISED SCC ESTIMATES

Our general approach to estimating SCC values is to run the three integrated assessment models (FUND, DICE, and PAGE) using the following inputs agreed upon by the interagency group:

- A Roe and Baker distribution for the climate sensitivity parameter bounded between 0 and 10 with a median of 3 °C and a cumulative probability between 2 and 4.5 °C of two-thirds.
- Five sets of GDP, population, and carbon emissions trajectories based on EMF-22.
- Constant annual discount rates of 2.5, 3, and 5 percent.

Because the climate sensitivity parameter is modeled probabilistically, and because PAGE and FUND incorporate uncertainty in other model parameters, the final output from each model run is a distribution over the SCC in year *t*.

For each of the IAMs, the basic computational steps for calculating the SCC in a particular year *t* are:

1. Input the path of emissions, GDP, and population from the selected EMF-22 scenarios, and the extrapolations based on these scenarios for post-2100 years.

2. Calculate the temperature effects and (consumption-equivalent) damages in each year resulting from the baseline path of emissions.

    a. In PAGE, the consumption-equivalent damages in each period are calculated as a fraction of the EMF GDP forecast, depending on the temperature in that period relative to the pre-industrial average temperature in each region.
    b. In FUND, damages in each period depend on both the level and the rate of temperature change in that period.

[aa] Calculations done by Pizer et al. using the original simulation program from Newell and Pizer (2003).

c. In DICE, temperature affects both consumption and investment, so we first adjust the EMF GDP paths as follows: Using the Cobb-Douglas production function with the DICE2007 parameters, we extract the path of exogenous technical change implied by the EMF GDP and population paths, then we recalculate the baseline GDP path taking into account climate damages resulting from the baseline emissions path.

3. Add an additional unit of carbon emissions in year *t*. (The exact unit varies by model.)

4. Recalculate the temperature effects and damages expected in all years beyond *t* resulting from this adjusted path of emissions, as in step 2.

5. Subtract the damages computed in step 2 from those in step 4 in each year. (DICE is run in 10-year time steps, FUND in annual time steps, while the time steps in PAGE vary.)

6. Discount the resulting path of marginal damages back to the year of emissions using the agreed upon fixed discount rates.

7. Calculate the SCC as the net present value of the discounted path of damages computed in step 6, divided by the unit of carbon emissions used to shock the models in step 3.

8. Multiply by 12/44 to convert from dollars per ton of carbon to dollars per ton of CO_2 (2007 dollars) in DICE and FUND. (All calculations are done in tons of CO_2 in PAGE).

The steps above were repeated in each model for multiple future years to cover the time horizons anticipated for upcoming rulemaking analysis. To maintain consistency across the three IAMs, climate damages are calculated as lost consumption in each future year.

It is important to note that each of the three models has a different default end year. The default time horizon is 2200 for PAGE, 2595 for DICE, and 3000 for the latest version of FUND. This is an issue for the multi-model approach because differences in SCC estimates may arise simply due to the model time horizon. Many consider 2200 too short a time horizon because it could miss a significant fraction of damages under certain assumptions about the growth of marginal damages and discounting, so each model is run here through 2300. This step required a small adjustment in the PAGE model only. This step also required assumptions about GDP, population, and greenhouse gas emission trajectories after 2100, the last year for which these data are available from the EMF-22 models. (A more detailed discussion of these assumptions is included in the Annex.)

This exercise produces 45 separate distributions of the SCC for a given year, the product of 3 models, 3 discount rates, and 5 socioeconomic scenarios. This is clearly too many separate distributions for consideration in a regulatory impact analysis.

To produce a range of plausible estimates that still reflects the uncertainty in the estimation exercise, the distributions from each of the models and scenarios are equally weighed and combined to produce three separate probability distributions for SCC in a given year, one for each assumed discount rate. These distributions are then used to define a range of point estimates for the global SCC. In this way, no IAM or socioeconomic scenario is given greater weight than another. Because the literature shows that the SCC is quite sensitive to assumptions about the discount rate, and because no consensus exists on the appropriate rate to use in an intergenerational context, we present SCCs based on the average values across models and socioeconomic scenarios for each discount rate.

The interagency group selected four SCC values for use in regulatory analyses. Three values are based on the average SCC across models and socioeconomic and emissions scenarios at the 2.5, 3, and 5 percent discount rates. The fourth value is included to represent the higher-than-expected economic impacts from climate change further out in the tails of the SCC distribution. For this purpose, we use the SCC value for the 95th percentile at a 3 percent discount rate. (The full set of distributions by model and scenario combination is included in the Annex.) As noted above, the 3 percent discount rate is the central value, and so the central value that emerges is the average SCC across models at the 3 percent discount rate. For purposes of capturing the uncertainties involved in regulatory impact analysis, we emphasize the importance and value of considering the full range.

As previously discussed, low probability, high impact events are incorporated into the SCC values through explicit consideration of their effects in two of the three models as well as the use of a probability density function for equilibrium climate sensitivity. Treating climate sensitivity probabilistically results in more high-temperature outcomes, which in turn lead to higher projections of damages. Although FUND does not include catastrophic damages (in contrast to the other two models), its probabilistic treatment of the equilibrium climate sensitivity parameter will directly affect the non-catastrophic damages that are a function of the rate of temperature change.

In Table 14A.5.1, we begin by presenting SCC estimates for 2010 by model, scenario, and discount rate to illustrate the variability in the SCC across each of these input parameters. As expected, higher discount rates consistently result in lower SCC values, while lower discount rates result in higher SCC values for each socioeconomic trajectory. It is also evident that there are differences in the SCC estimated across the three main models. For these estimates, FUND produces the lowest estimates, while PAGE generally produces the highest estimates.

Table 14A.5.1 Disaggregated Social Cost of CO_2 Values by Model, Socioeconomic Trajectory, and Discount Rate for 2010 (in 2007 dollars)

	Discount rate:	**5%**	**3%**	**2.5%**	**3%**
Model	*Scenario*	Avg	Avg	Avg	95th
DICE	IMAGE	10.8	35.8	54.2	70.8
	MERGE	7.5	22.0	31.6	42.1
	Message	9.8	29.8	43.5	58.6
	MiniCAM	8.6	28.8	44.4	57.9
	550 Average	8.2	24.9	37.4	50.8
PAGE	IMAGE	8.3	39.5	65.5	142.4
	MERGE	5.2	22.3	34.6	82.4
	Message	7.2	30.3	49.2	115.6
	MiniCAM	6.4	31.8	54.7	115.4
	550 Average	5.5	25.4	42.9	104.7
FUND	IMAGE	-1.3	8.2	19.3	39.7
	MERGE	-0.3	8.0	14.8	41.3
	Message	-1.9	3.6	8.8	32.1
	MiniCAM	-0.6	10.2	22.2	42.6
	550 Average	-2.7	-0.2	3.0	19.4

These results are not surprising when compared to the estimates in the literature for the latest versions of each model. For example, adjusting the values from the literature that were used to develop interim SCC values to 2007 dollars for the year 2010 (assuming, as we did for the interim process, that SCC grows at 3 percent per year), FUND yields SCC estimates at or near zero for a 5 percent discount rate and around $9 per ton for a 3 percent discount rate. There are far fewer estimates using the latest versions of DICE and PAGE in the literature: Using similar adjustments to generate 2010 estimates, we calculate a SCC from DICE (based on Nordhaus 2008) of around $9 per ton for a 5 percent discount rate, and a SCC from PAGE (based on Hope 2006, 2008) close to $8 per ton for a 4 percent discount rate. Note that these comparisons are only approximate since the literature generally relies on Ramsey discounting, while we have assumed constant discount rates.[bb]

The SCC estimates from FUND are sensitive to differences in emissions paths but relatively insensitive to differences in GDP paths across scenarios, while the reverse is true for DICE and PAGE. This likely occurs because of several structural differences among the models. Specifically in DICE and PAGE, the fraction of economic output lost due to climate damages increases with the level of temperature alone, whereas in FUND the fractional loss also increases with the rate of temperature change. Furthermore, in FUND increases in income over time decrease vulnerability to climate change (a form of adaptation), whereas this does not occur in DICE and PAGE. These structural differences among the models make FUND more sensitive to the path of emissions and less sensitive to GDP compared to DICE and PAGE.

Figure 14A.5.1 shows that IMAGE has the highest GDP in 2100 while MERGE Optimistic has the lowest. The ordering of global GDP levels in 2100 directly corresponds to the rank ordering of SCC for PAGE and DICE. For FUND, the correspondence is less clear, a result that is to be expected given its less direct relationship between its damage function and GDP.

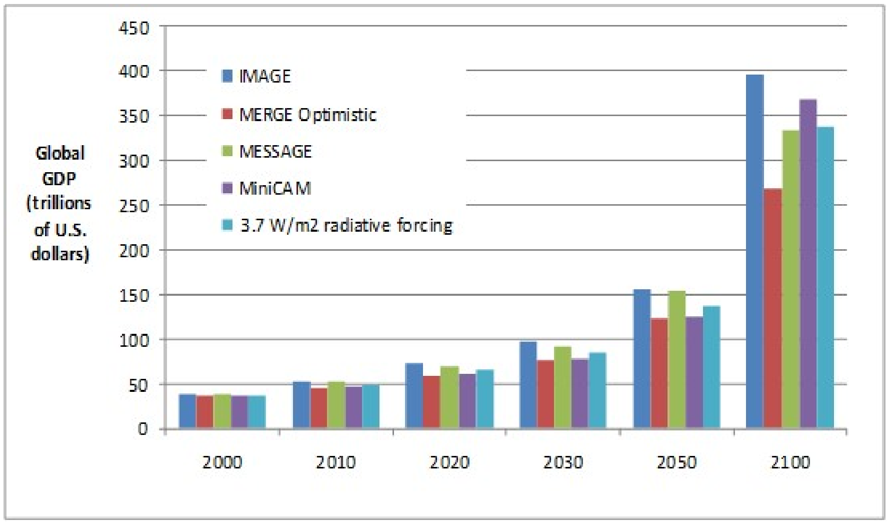

Figure 14A.5.1 Level of Global GDP across EMF Scenarios

Table 14A.5.2 shows the four selected SCC values in five-year increments from 2010 to 2050. Values for 2010, 2020, 2040, and 2050 are calculated by first combining all outputs

[bb] Nordhaus (2008) runs DICE2007 with ρ = 1.5 and η = 2. The default approach in PAGE2002 (version 1.4epm) treats ρ and η as random parameters, specified using a triangular distribution such that the min, mode, and max = 0.1, 1, and 2 for ρ, and 0.5, 1, and 2 for η, respectively. The FUND default value for η is 1, and Tol generates SCC estimates for values of ρ = 0, 1, and 3 in many recent papers (*e.g.* Anthoff et al. 2009). The path of per-capita consumption growth, g, varies over time but is treated deterministically in two of the three models. In DICE, g is endogenous. Under Ramsey discounting, as economic growth slows in the future, the large damages from climate change that occur far out in the future are discounted at a lower rate than impacts that occur in the nearer term.

(10,000 estimates per model run) from all scenarios and models for a given discount rate. Values for the years in between are calculated using a simple linear interpolation.

Table 14A.5.2 Social Cost of CO_2, 2010 – 2050 (in 2007 dollars)

Discount Year	5% Avg	3% Avg	2.5% Avg	3% 95th
2010	4.7	21.4	35.1	64.9
2015	5.7	23.8	38.4	72.8
2020	6.8	26.3	41.7	80.7
2025	8.2	29.6	45.9	90.4
2030	9.7	32.8	50.0	100.0
2035	11.2	36.0	54.2	109.7
2040	12.7	39.2	58.4	119.3
2045	14.2	42.1	61.7	127.8
2050	15.7	44.9	65.0	136.2

The SCC increases over time because future emissions are expected to produce larger incremental damages as physical and economic systems become more stressed in response to greater climatic change. Note that this approach allows us to estimate the growth rate of the SCC directly using DICE, PAGE, and FUND rather than assuming a constant annual growth rate as was done for the interim estimates (using 3 percent). This helps to ensure that the estimates are internally consistent with other modeling assumptions. Table 14A.5.3 illustrates how the growth rate for these four SCC estimates varies over time. The full set of annual SCC estimates between 2010 and 2050 is reported in the Annex.

Table 14A.5.3 Changes in the Average Annual Growth Rates of SCC Estimates between 2010 and 2050

Average Annual Growth Rate (%)	**5%** Avg	**3%** Avg	**2.5%** Avg	**3.0%** 95th
2010-2020	3.6%	2.1%	1.7%	2.2%
2020-2030	3.7%	2.2%	1.8%	2.2%
2030-2040	2.7%	1.8%	1.6%	1.8%
2040-2050	2.1%	1.4%	1.1%	1.3%

While the SCC estimate grows over time, the future monetized value of emissions reductions in each year (the SCC in year *t* multiplied by the change in emissions in year *t*) must be discounted to the present to determine its total net present value for use in regulatory analysis. Damages from future emissions should be discounted at the same rate as that used to calculate the SCC estimates themselves to ensure internal consistency—*i.e.*, future damages from climate change, whether they result from emissions today or emissions in a later year, should be discounted using the same rate. For example, climate damages in the year 2020 that are calculated using a SCC based on a 5 percent discount rate also should be discounted back to the analysis year using a 5 percent discount rate.[cc]

14A.6 LIMITATIONS OF THE ANALYSIS

As noted, any estimate of the SCC must be taken as provisional and subject to further refinement (and possibly significant change) in accordance with evolving scientific, economic, and ethical understandings. During the course of our modeling, it became apparent that there are several areas in particular need of additional exploration and research. These caveats, and additional observations in the following section, are necessary to consider when interpreting and applying the SCC estimates.

Incomplete treatment of non-catastrophic damages. The impacts of climate change are expected to be widespread, diverse, and heterogeneous. In addition, the exact magnitude of these impacts is uncertain because of the inherent complexity of climate processes, the economic behavior of current and future populations, and our inability to accurately forecast technological change and adaptation. Current IAMs do not assign value to all of the important physical, ecological, and economic impacts of climate change recognized in the climate change literature (some of which are discussed above) because of lack of precise information on the nature of damages and because the science incorporated into these models understandably lags behind the most recent research. Our ability to quantify and monetize impacts will undoubtedly improve with time. But it is also likely that even in future applications, a number of potentially significant damage categories will remain non-monetized. (Ocean acidification is one example of a potentially large damage from CO_2 emissions not quantified by any of the three models. Species and wildlife loss is another example that is exceedingly difficult to monetize.)

Incomplete treatment of potential catastrophic damages. There has been considerable recent discussion of the risk of catastrophic impacts and how best to account for extreme scenarios, such as the collapse of the Atlantic Meridional Overturning Circulation or the West Antarctic Ice Sheet, or large releases of methane from melting permafrost and warming oceans. Weitzman (2009) suggests that catastrophic damages are extremely large—so large, in fact, that the damages from a low probability, catastrophic event far in the future dominate the effect of the discount rate in a present value calculation and result in an infinite willingness-to-pay for mitigation today. However, Nordhaus (2009) concluded that the conditions under which Weitzman's results hold “are limited and do not apply to a wide range of potential uncertain scenarios."

Using a simplified IAM, Newbold and Daigneault (2009) confirmed the potential for large catastrophe risk premiums but also showed that the aggregate benefit estimates can be highly sensitive to the shapes of both the climate sensitivity distribution and the damage function at high temperature changes. Pindyck (2009) also used a simplified IAM to examine high-

[cc] However, it is possible that other benefits or costs of proposed regulations unrelated to CO_2 emissions will be discounted at rates that differ from those used to develop the SCC estimates.

impact, low-probability risks, using a right-skewed gamma distribution for climate sensitivity as well as an uncertain damage coefficient, but in most cases found only a modest risk premium. Given this difference in opinion, further research in this area is needed before its practical significance can be fully understood and a reasonable approach developed to account for such risks in regulatory analysis. (The next section discusses the scientific evidence on catastrophic impacts in greater detail.)

Uncertainty in extrapolation of damages to high temperatures: The damage functions in these IAMs are typically calibrated by estimating damages at moderate temperature increases (*e.g.*, DICE was calibrated at 2.5 °C) and extrapolated to far higher temperatures by assuming that damages increase as some power of the temperature change. Hence, estimated damages are far more uncertain under more extreme climate change scenarios.

Incomplete treatment of adaptation and technological change: Each of the three integrated assessment models used here assumes a certain degree of low- or no-cost adaptation. For instance, Tol assumes a great deal of adaptation in FUND, including widespread reliance on air conditioning; so much so, that the largest single benefit category in FUND is the reduced electricity costs from not having to run air conditioning as intensively (NRC 2009).

Climate change also will increase returns on investment to develop technologies that allow individuals to cope with adverse climate conditions, and IAMs to do not adequately account for this directed technological change.[dd] For example, scientists may develop crops that are better able to withstand higher and more variable temperatures. Although DICE and FUND have both calibrated their agricultural sectors under the assumption that farmers will change land use practices in response to climate change (Mastrandrea, 2009), they do not take into account technological changes that lower the cost of this adaptation over time. On the other hand, the calibrations do not account for increases in climate variability, pests, or diseases, which could make adaptation more difficult than assumed by the IAMs for a given temperature change. Hence, models do not adequately account for potential adaptation or technical change that might alter the emissions pathway and resulting damages. In this respect, it is difficult to determine whether the incomplete treatment of adaptation and technological change in these IAMs understate or overstate the likely damages.

Risk aversion: A key question unanswered during this interagency process is what to assume about relative risk aversion with regard to high-impact outcomes. These calculations do not take into account the possibility that individuals may have a higher willingness to pay to reduce the likelihood of low-probability, high-impact damages than they do to reduce the likelihood of higher-probability, but lower-impact, damages with the same expected cost. (The inclusion of the 95th percentile estimate in the final set of SCC values was largely motivated by this concern.) If individuals do show such a higher willingness to pay, a further question is whether that fact should be taken into account for regulatory policy. Even if individuals are not risk-averse for such scenarios, it is possible that regulatory policy should include a degree of risk-aversion.

[dd] However these research dollars will be diverted from whatever their next best use would have been in the absence of climate change (so productivity/GDP would have been still higher).

Assuming a risk-neutral representative agent is consistent with OMB's Circular A-4, which advises that the estimates of benefits and costs used in regulatory analysis are usually based on the average or the expected value and that "emphasis on these expected values is appropriate as long as society is 'risk neutral' with respect to the regulatory alternatives. While this may not always be the case, [analysts] should in general assume 'risk neutrality' in [their] analysis."

Nordhaus (2008) points to the need to explore the relationship between risk and income in the context of climate change across models and to explore the role of uncertainty regarding various parameters in the results. Using FUND, Anthoff et al (2009) explored the sensitivity of the SCC to Ramsey equation parameter assumptions based on observed behavior. They conclude that "the assumed rate of risk aversion is at least as important as the assumed rate of time preference in determining the social cost of carbon." Since Circular A-4 allows for a different assumption on risk preference in regulatory analysis if it is adequately justified, we plan to continue investigating this issue.

14A.7 A FURTHER DISCUSSION OF CATASTROPHIC IMPACTS AND DAMAGE FUNCTIONS

As noted above, the damage functions underlying the three IAMs used to estimate the SCC may not capture the economic effects of all possible adverse consequences of climate change and may therefore lead to underestimates of the SCC (Mastrandrea 2009). In particular, the models' functional forms may not adequately capture: (1) potentially discontinuous "tipping point" behavior in Earth systems, (2) inter-sectoral and inter-regional interactions, including global security impacts of high-end warming, and (3) limited near-term substitutability between damage to natural systems and increased consumption.

It is the hope of the interagency group that over time researchers and modelers will work to fill these gaps and that the SCC estimates used for regulatory analysis by the Federal government will continue to evolve with improvements in modeling. In the meantime, we discuss some of the available evidence.

Extrapolation of climate damages to high levels of warming

The damage functions in the models are calibrated at moderate levels of warming and should therefore be viewed cautiously when extrapolated to the high temperatures found in the upper end of the distribution. Recent science suggests that there are a number of potential climatic "tipping points" at which the Earth system may exhibit discontinuous behavior with potentially severe social and economic consequences (*e.g.*, Lenton et al, 2008, Kriegler et al., 2009). These tipping points include the disruption of the Indian Summer Monsoon, dieback of the Amazon Rainforest and boreal forests, collapse of the Greenland Ice Sheet and the West Antarctic Ice Sheet, reorganization of the Atlantic Meridional Overturning Circulation, strengthening of El Niño-Southern Oscillation, and the release of methane from melting permafrost. Many of these tipping points are estimated to have thresholds between about 3 °C and 5 °C (Lenton et al., 2008). Probabilities of several of these tipping points were assessed through expert elicitation in 2005–2006 by Kriegler et al. (2009); results from this study are highlighted in Table 14A.7.1. Ranges of probability are averaged across core experts on each topic.

As previously mentioned, FUND does not include potentially catastrophic effects. DICE assumes a small probability of catastrophic damages that increases with increased warming, but the damages from these risks are incorporated as expected values (*i.e.*, ignoring potential risk aversion). PAGE models catastrophic impacts in a probabilistic framework (see Figure 14A.4.1), so the high-end output from PAGE potentially offers the best insight into the SCC if the world were to experience catastrophic climate change. For instance, at the 95th percentile and a 3 percent discount rate, the SCC estimated by PAGE across the five socioeconomic and emission trajectories of $113 per ton of CO_2 is almost double the value estimated by DICE, $58 per ton in 2010. We cannot evaluate how well the three models account for catastrophic or non-catastrophic impacts, but this estimate highlights the sensitivity of SCC values in the tails of the distribution to the assumptions made about catastrophic impacts.

Table 14A.7.1 Probabilities of Various Tipping Points from Expert Elicitation

Possible Tipping Points	**Duration before effect is fully realized (in years)**	**Additional Warming by 2100**		
		0.5-1.5 C	**1.5-3.0 C**	**3-5 C**
Reorganization of Atlantic Meridional Overturning Circulation	about 100	0-18%	6-39%	18-67%
Greenland Ice Sheet collapse	at least 300	8-39%	33-73%	67-96%
West Antarctic Ice Sheet collapse	at least 300	5-41%	10-63%	33-88%
Dieback of Amazon rainforest	about 50	2-46%	14-84%	41-94%
Strengthening of El Niño-Southern Oscillation	about 100	1-13%	6-32%	19-49%
Dieback of boreal forests	about 50	13-43%	20-81%	34-91%
Shift in Indian Summer Monsoon	about 1	Not formally assessed		
Release of methane from melting permafrost	Less than 100	Not formally assessed.		

PAGE treats the possibility of a catastrophic event probabilistically, while DICE treats it deterministically (that is, by adding the expected value of the damage from a catastrophe to the aggregate damage function). In part, this results in different probabilities being assigned to a catastrophic event across the two models. For instance, PAGE places a probability near zero on a catastrophe at 2.5 °C warming, while DICE assumes a 4 percent probability of a catastrophe at 2.5 °C. By comparison, Kriegler et al. (2009) estimate a probability of at least 16-36 percent of crossing at least one of their primary climatic tipping points in a scenario with temperatures about 2-4 °C warmer than pre-Industrial levels in 2100.

It is important to note that crossing a climatic tipping point will not necessarily lead to an economic catastrophe in the sense used in the IAMs. A tipping point is a critical threshold across which some aspect of the Earth system starts to shifts into a qualitatively different state (for instance, one with dramatically reduced ice sheet volumes and higher sea levels). In the IAMs, a catastrophe is a low-probability environmental change with high economic impact.

Failure to incorporate inter-sectoral and inter-regional interactions

The damage functions do not fully incorporate either inter-sectoral or inter-regional interactions. For instance, while damages to the agricultural sector are incorporated, the effects of changes in food supply on human health are not fully captured and depend on the modeler's choice of studies used to calibrate the IAM. Likewise, the effects of climate damages in one region of the world on another region are not included in some of the models (FUND includes the effects of migration from sea level rise). These inter-regional interactions, though difficult to quantify, are the basis for climate-induced national and economic security concerns (*e.g.*, Campbell et al., 2007; U.S. Department of Defense 2010) and are particularly worrisome at higher levels of warming. High-end warming scenarios, for instance, project water scarcity affecting 4.3-6.9 billion people by 2050, food scarcity affecting about 120 million additional people by 2080, and the creation of millions of climate refugees (Easterling et al., 2007; Campbell et al., 2007).

Imperfect substitutability of environmental amenities

Data from the geological record of past climate changes suggests that 6 °C of warming may have severe consequences for natural systems. For instance, during the Paleocene-Eocene Thermal Maximum about 55.5 million years ago, when the Earth experienced a geologically rapid release of carbon associated with an approximately 5 °C increase in global mean temperatures, the effects included shifts of about 400-900 miles in the range of plants (Wing et al., 2005), and dwarfing of both land mammals (Gingerich, 2006) and soil fauna (Smith et al., 2009).

The three IAMs used here assume that it is possible to compensate for the economic consequences of damages to natural systems through increased consumption of non-climate goods, a common assumption in many economic models. In the context of climate change, however, it is possible that the damages to natural systems could become so great that no increase in consumption of non-climate goods would provide complete compensation (Levy et al., 2005). For instance, as water supplies become scarcer or ecosystems become more fragile and less bio-diverse, the services they provide may become increasingly more costly to replace. Uncalibrated attempts to incorporate the imperfect substitutability of such amenities into IAMs (Sterner and Persson, 2008) indicate that the optimal degree of emissions abatement can be considerably greater than is commonly recognized.

14A.8 CONCLUSION

The interagency group selected four SCC estimates for use in regulatory analyses. For 2010, these estimates are \$5, \$21, \$35, and \$65 (in 2007 dollars). The first three estimates are based on the average SCC across models and socioeconomic and emissions scenarios at the 5, 3, and 2.5 percent discount rates, respectively. The fourth value is included to represent the higher-than-expected impacts from temperature change further out in the tails of the SCC distribution. For this purpose, we use the SCC value for the 95th percentile at a 3 percent discount rate. The central value is the average SCC across models at the 3 percent discount rate. For purposes of capturing the uncertainties involved in regulatory impact analysis, we emphasize the importance and value of considering the full range. These SCC estimates also grow over time. For instance, the central value increases to \$24 per ton of CO_2 in 2015 and \$26 per ton of CO_2 in 2020.

We noted a number of limitations to this analysis, including the incomplete way in which the integrated assessment models capture catastrophic and non-catastrophic impacts, their incomplete treatment of adaptation and technological change, uncertainty in the extrapolation of damages to high temperatures, and assumptions regarding risk aversion. The limited amount of research linking climate impacts to economic damages makes this modeling exercise even more difficult. It is the hope of the interagency group that over time researchers and modelers will work to fill these gaps and that the SCC estimates used for regulatory analysis by the Federal government will continue to evolve with improvements in modeling.

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14A.9 ANNEX

Table 14A.9.1 Annual SCC Values: 2010–2050 (in 2007 dollars)

Discount Rate Year	5% Avg	3% Avg	2.5% Avg	3% 95th
2010	4.7	21.4	35.1	64.9
2011	4.9	21.9	35.7	66.5
2012	5.1	22.4	36.4	68.1
2013	5.3	22.8	37.0	69.6
2014	5.5	23.3	37.7	71.2
2015	5.7	23.8	38.4	72.8
2016	5.9	24.3	39.0	74.4
2017	6.1	24.8	39.7	76.0
2018	6.3	25.3	40.4	77.5
2019	6.5	25.8	41.0	79.1
2020	6.8	26.3	41.7	80.7
2021	7.1	27.0	42.5	82.6
2022	7.4	27.6	43.4	84.6
2023	7.7	28.3	44.2	86.5
2024	7.9	28.9	45.0	88.4
2025	8.2	29.6	45.9	90.4
2026	8.5	30.2	46.7	92.3
2027	8.8	30.9	47.5	94.2
2028	9.1	31.5	48.4	96.2
2029	9.4	32.1	49.2	98.1
2030	9.7	32.8	50.0	100.0
2031	10.0	33.4	50.9	102.0
2032	10.3	34.1	51.7	103.9
2033	10.6	34.7	52.5	105.8
2034	10.9	35.4	53.4	107.8
2035	11.2	36.0	54.2	109.7
2036	11.5	36.7	55.0	111.6
2037	11.8	37.3	55.9	113.6
2038	12.1	37.9	56.7	115.5
2039	12.4	38.6	57.5	117.4
2040	12.7	39.2	58.4	119.3
2041	13.0	39.8	59.0	121.0
2042	13.3	40.4	59.7	122.7
2043	13.6	40.9	60.4	124.4
2044	13.9	41.5	61.0	126.1
2045	14.2	42.1	61.7	127.8
2046	14.5	42.6	62.4	129.4
2047	14.8	43.2	63.0	131.1
2048	15.1	43.8	63.7	132.8
2049	15.4	44.4	64.4	134.5
2050	15.7	44.9	65.0	136.2

This Annex provides additional technical information about the non-CO_2 emission projections used in the modeling and the method for extrapolating emissions forecasts through 2300 and shows the full distribution of 2010 SCC estimates by model and scenario combination.

14A.9.1 Other (non-CO_2) gases

In addition to fossil and industrial CO_2 emissions, each EMF scenario provides projections of methane (CH_4), nitrous oxide (N_2O), fluorinated gases, and net land use CO_2 emissions to 2100. These assumptions are used in all three IAMs while retaining each model's default radiative forcings (RF) due to other factors (*e.g.*, aerosols and other gases). Specifically, to obtain the RF associated with the non-CO_2 EMF emissions only, we calculated the RF associated with the EMF atmospheric CO_2 concentrations and subtracted them from the EMF total RF.[ee] This approach respects the EMF scenarios as much as possible and at the same time takes account of those components not included in the EMF projections. Since each model treats non-CO_2 gases differently (*e.g.*, DICE lumps all other gases into one composite exogenous input), this approach was applied slightly differently in each of the models.

FUND: Rather than relying on RF for these gases, the actual emissions from each scenario were used in FUND. The model default trajectories for CH_4, N_20, SF_6, and the CO_2 emissions from land were replaced with the EMF values.

PAGE: PAGE models CO_2, CH_4, sulfur hexafluoride (SF_6), and aerosols and contains an "excess forcing" vector that includes the RF for everything else. To include the EMF values, we removed the default CH_4 and SF_6 factors[ff], decomposed the excess forcing vector, and constructed a new excess forcing vector that includes the EMF RF for CH_4, N_20, and fluorinated gases, as well as the model default values for aerosols and other factors. Net land use CO_2 emissions were added to the fossil and industrial CO_2 emissions pathway.

DICE: DICE presents the greatest challenge because all forcing due to factors other than industrial CO_2 emissions is embedded in an exogenous non-CO_2 RF vector. To decompose this exogenous forcing path into EMF non-CO_2 gases and other gases, we relied on the references in DICE2007 to the Intergovernmental Panel on Climate Change's (IPCC) Fourth Assessment Report (AR4) and the discussion of aerosol forecasts in the IPCC's Third Assessment Report (TAR) and in AR4, as explained below. In DICE2007, Nordhaus assumes that exogenous forcing from all non-CO_2 sources is -0.06 W/m^2 in 2005, as reported in AR4, and increases linearly to 0.3 W/m^2 in 2105, based on GISS projections, and then stays constant after that time.

According to AR4, the RF in 2005 from CH_4, N_20, and halocarbons (approximately similar to the F-gases in the EMF-22 scenarios) was 0.48 + 0.16 + 0.34 = 0.98 W/m^2 and RF from total aerosols was -1.2 W/m^2. Thus, the -.06 W/m^2 non-CO_2 forcing in DICE can be

[ee] Note EMF did not provide CO_2 concentrations for the IMAGE reference scenario. Thus, for this scenario, we fed the fossil, industrial, and land CO_2 emissions into MAGICC (considered a "neutral arbiter" model, which is tuned to emulate the major global climate models) and the resulting CO_2 concentrations were used. Note also that MERGE assumes a neutral biosphere so net land CO_2 emissions are set to zero for all years for the MERGE Optimistic reference scenario, and for the MERGE component of the average 550 scenario (i.e., we add up the land use emissions from the other three models and divide by 4).

[ff] Both the model default CH_4 emissions and the initial atmospheric CH_4 is set to zero to avoid double counting the effect of past CH_4 emissions.

decomposed into: 0.98 W/m^2 due to the EMF non-CO_2 gases, -1.2 W/m^2 due to aerosols, and the remainder, 0.16 W/m^2, due to other residual forcing.

For subsequent years, we calculated the DICE default RF from aerosols and other non-CO_2 gases based on the following two assumptions:

(1) RF from aerosols declines linearly from 2005 to 2100 at the rate projected by the TAR and then stays constant thereafter; and
(2) With respect to RF from non-CO_2 gases not included in the EMF-22 scenarios, the share of non-aerosol RF matches the share implicit in the AR4 summary statistics cited above and remains constant over time.

Assumption (1) means that the RF from aerosols in 2100 equals 66 percent of that in 2000, which is the fraction of the TAR projection of total RF from aerosols (including sulfates, black carbon, and organic carbon) in 2100 vs. 2000 under the A1B SRES emissions scenario. Since the SRES marker scenarios were not updated for the AR4, the TAR provides the most recent IPCC projection of aerosol forcing. We rely on the A1B projection from the TAR because it provides one of the lower aerosol forecasts among the SRES marker scenarios and is more consistent with the AR4 discussion of the post-SRES literature on aerosols:

> *Aerosols have a net cooling effect and the representation of aerosol and aerosol precursor emissions, including sulfur dioxide, black carbon and organic carbon, has improved in the post-SRES scenarios. Generally, these emissions are projected to be lower than reported in SRES. {WGIII 3.2, TS.3, SPM}.*[gg]

Assuming a simple linear decline in aerosols from 2000 to 2100 also is more consistent with the recent literature on these emissions. For example, the figure below shows that the sulfur dioxide emissions peak over the short term of some SRES scenarios above the upper bound estimates of the more recent scenarios.[hh] Recent scenarios project sulfur emissions to peak earlier and at lower levels compared to the SRES in part because of new information about present and planned sulfur legislation in some developing countries, such as India and China.[ii] The lower-bound projections of the recent literature have also shifted downward slightly compared to the SRES scenario (IPCC 2007).

[gg] AR4 Synthesis Report, p. 44, http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr.pdf

[hh] See Smith, S.J., R. Andres, E. Conception, and J. Lurz, 2004: Historical sulfur dioxide emissions, 1850-2000: methods and results. Joint Global Research Institute, College Park, 14 pp.

[ii] See Carmichael, G., D. Streets, G. Calori, M. Amann, M. Jacobson, J. Hansen, and H. Ueda, 2002: Changing trends in sulphur emissions in Asia: implications for acid deposition, air pollution, and climate. Environmental Science and Technology, 36(22):4707- 4713; Streets, D., K. Jiang, X. Hu, J. Sinton, X.-Q. Zhang, D. Xu, M. Jacobson, and J. Hansen, 2001: Recent reductions in China's greenhouse gas emissions. Science, 294(5548): 1835-1837.

With these assumptions, the DICE aerosol forcing changes from -1.2 in 2005 to -0.792 in 2105 W/m^2; forcing due to other non-CO_2 gases not included in the EMF scenarios declines from 0.160 to 0.153 W/m^2.

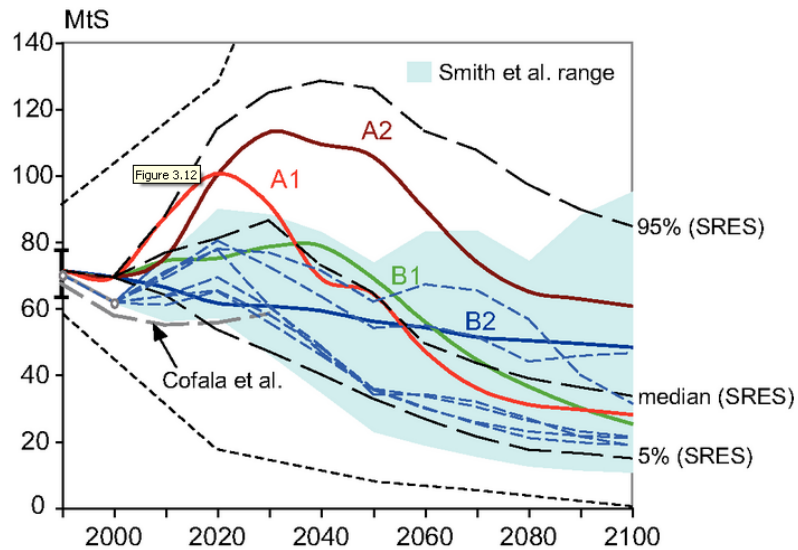

Figure 14A.9.2 Sulfur Dioxide Emission Scenarios

Notes: Thick colored lines depict the four SRES marker scenarios and black dashed lines show the median, 5th, and 95th percentile of the frequency distribution for the full ensemble of 40 SRES scenarios. The blue area (and the thin dashed lines in blue) illustrates individual scenarios and the range of Smith et al. (2004). Dotted lines indicate the minimum and maximum of SO_2 emissions scenarios developed pre-SRES. Source: IPCC (2007), AR4 WGIII 3.2, http://www.ipcc.ch/publications_and_data/ar4/wg3/en/ch3-ens3-2-2-4.html.

Although other approaches to decomposing the DICE exogenous forcing vector are possible, initial sensitivity analysis suggests that the differences among reasonable alternative approaches are likely to be minor. For example, adjusting the TAR aerosol projection above to assume that aerosols will be maintained at 2000 levels through 2100 reduces average SCC values (for 2010) by approximately 3 percent (or less than $2); assuming all aerosols are phased out by 2100 increases average 2010 SCC values by 6-7 percent (or $0.50-$3)–depending on the discount rate. These differences increase slightly for SCC values in later years but are still well within 10 percent of each other as far out as 2050.

Finally, as in PAGE, the EMF net land use CO_2 emissions are added to the fossil and industrial CO_2 emissions pathway.

14A.9.2 Extrapolating Emissions Projections to 2300

To run each model through 2300 requires assumptions about GDP, population, greenhouse gas emissions, and radiative forcing trajectories after 2100, the last year for which these projections are available from the EMF-22 models. These inputs were extrapolated from 2100 to 2300 as follows:

1. Population growth rate declines linearly, reaching zero in the year 2200.
2. GDP/per capita growth rate declines linearly, reaching zero in the year 2300.
3. The decline in the fossil and industrial carbon intensity (CO_2/GDP) growth rate over 2090-2100 is maintained from 2100 through 2300.
4. Net land use CO_2 emissions decline linearly, reaching zero in the year 2200.
5. Non-CO_2 radiative forcing remains constant after 2100.

Long run stabilization of GDP per capita was viewed as a more realistic simplifying assumption than a linear or exponential extrapolation of the pre-2100 economic growth rate of each EMF scenario. This is based on the idea that increasing scarcity of natural resources and the degradation of environmental sinks available for assimilating pollution from economic production activities may eventually overtake the rate of technological progress. Thus, the overall rate of economic growth may slow over the very long run. The interagency group also considered allowing an exponential decline in the growth rate of GDP per capita. However, since this would require an additional assumption about how close to zero the growth rate would get by 2300, the group opted for the simpler and more transparent linear extrapolation to zero by 2300.

The population growth rate is also assumed to decline linearly, reaching zero by 2200. This assumption is reasonably consistent with the United Nations long run population forecast, which estimates global population to be fairly stable after 2150 in the medium scenario (UN 2004).[jj] The resulting range of EMF population trajectories (figure below) also encompass the UN medium scenario forecasts through 2300—global population of 8.5 billion by 2200, and 9 billion by 2300.

Maintaining the decline in the 2090-2100 carbon intensity growth rate (*i.e.*, CO_2 per dollar of GDP) through 2300 assumes that technological improvements and innovations in the areas of energy efficiency and other carbon reducing technologies (possibly including currently unavailable methods) will continue to proceed at roughly the same pace that is projected to occur towards the end of the forecast period for each EMF scenario. This assumption implies that total cumulative emissions in 2300 will be between 5,000 and 12,000 GtC, which is within the range of the total potential global carbon stock estimated in the literature.

Net land use CO_2 emissions are expected to stabilize in the long run, so in the absence of any post 2100 projections, the group assumed a linear decline to zero by 2200. Given no a priori reasons for assuming a long run increase or decline in non-CO_2 radiative forcing, it is assumed to remain at the 2100 levels for each EMF scenario through 2300.

[jj] United Nations. 2004. *World Population to 2300*. http://www.un.org/esa/population/publications/longrange2/WorldPop2300final.pdf

Figures below show the paths of global population, GDP, fossil and industrial CO_2 emissions, net land CO_2 emissions, non-CO_2 radiative forcing, and CO_2 intensity (fossil and industrial CO_2 emissions/GDP) resulting from these assumptions.

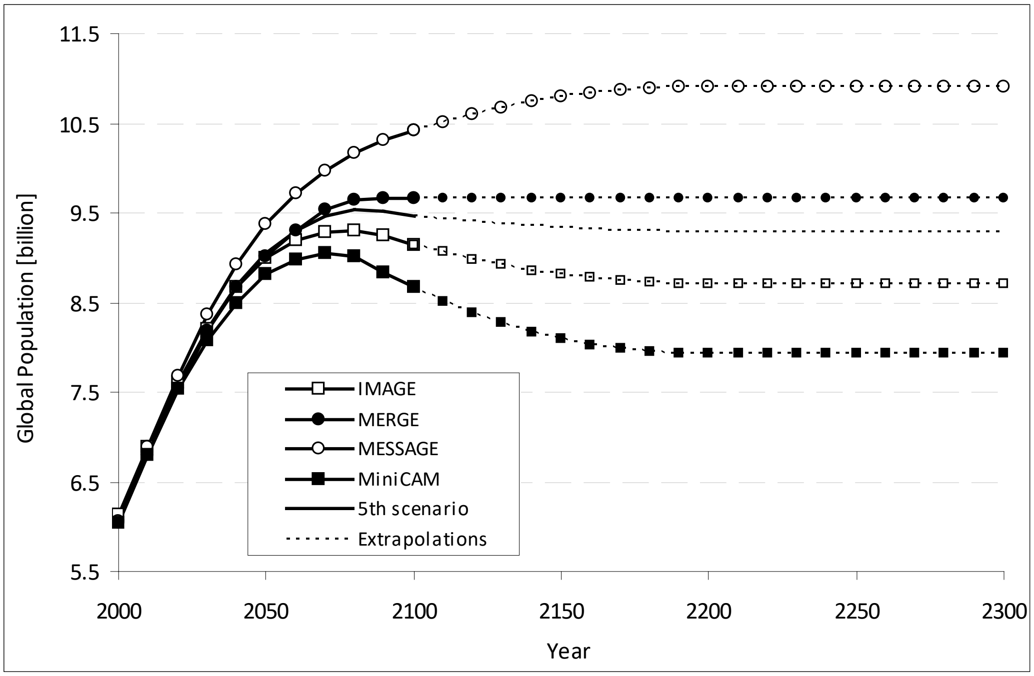

Figure 14A.9.3 Global Population, 2000-2300 (Post-2100 extrapolations assume the population growth rate changes linearly to reach a zero growth rate by 2200.)

Note: In the fifth scenario, 2000-2100 population is equal to the average of the population under the 550 ppm CO_2e, full-participation, not-to-exceed scenarios considered by each of the four models.

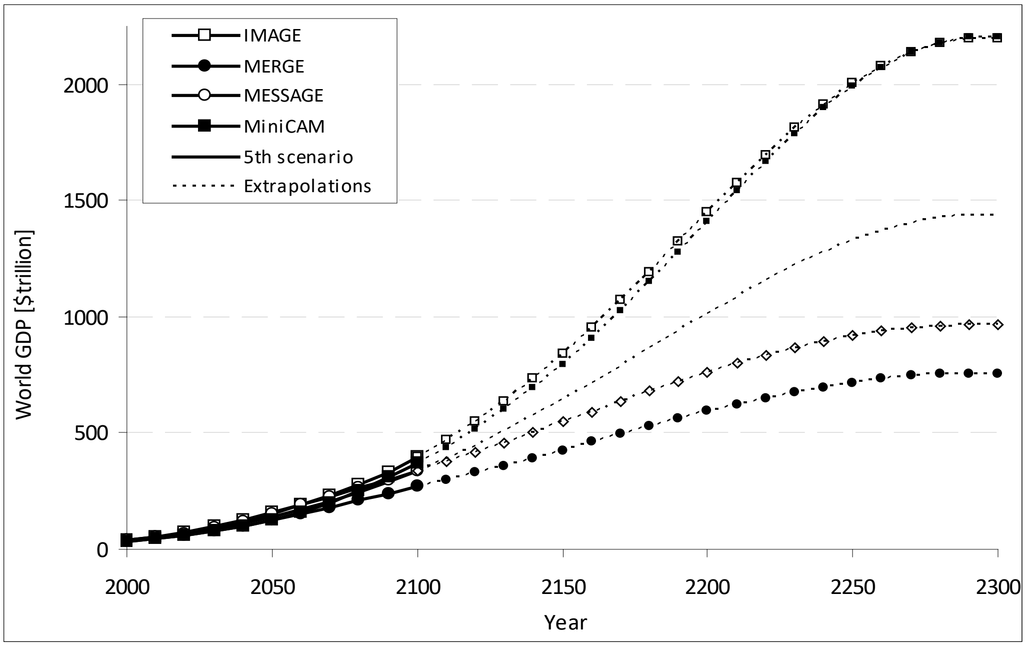

Figure 14A.9.4 World GDP, 2000-2300 (Post-2100 extrapolations assume GDP per capita growth declines linearly, reaching zero in the year 2300)

Note: In the fifth scenario, 2000-2100 GDP is equal to the average of the GDP under the 550 ppm CO_2e, full-participation, not-to-exceed scenarios considered by each of the four models.

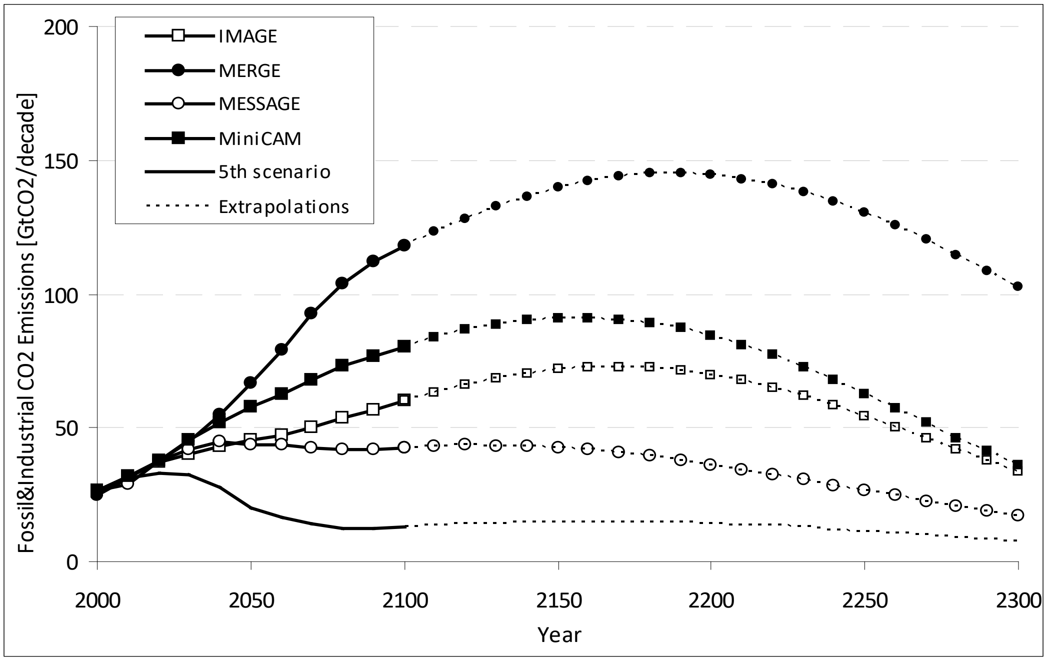

Figure 14A.9.5 Global Fossil and Industrial CO_2 Emissions, 2000-2300 (Post-2100 extrapolations assume growth rate of CO_2 intensity (CO_2/GDP) over 2090-2100 is maintained through 2300)

Note: In the fifth scenario, 2000-2100 emissions are equal to the average of the emissions under the 550 ppm CO_2e, full-participation, not-to-exceed scenarios considered by each of the four models.

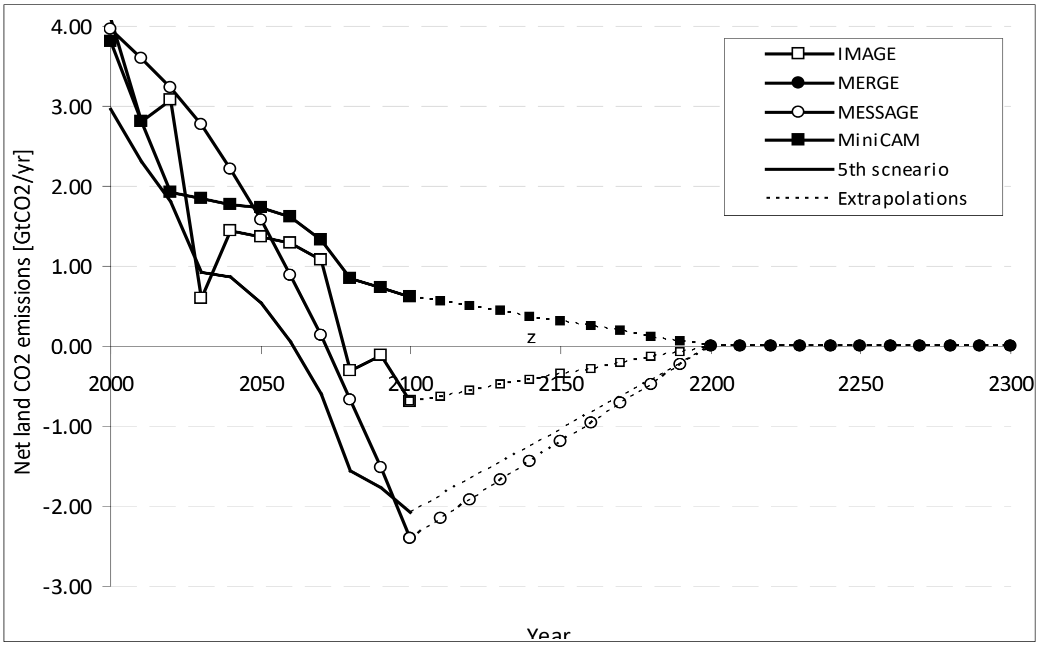

Figure 14A.9.6 Global Net Land Use CO_2 Emissions, 2000-2300 (Post-2100 extrapolations assume emissions decline linearly, reaching zero in the year 2200)[kk]

Note: In the fifth scenario, 2000-2100 emissions are equal to the average of the emissions under the 550 ppm CO_2e, full-participation, not-to-exceed scenarios considered by each of the four models.

[kk] MERGE assumes a neutral biosphere so net land CO_2 emissions are set to zero for all years for the MERGE Optimistic reference scenario, and for the MERGE component of the average 550 scenario (i.e., we add up the land use emissions from the other three models and divide by 4).

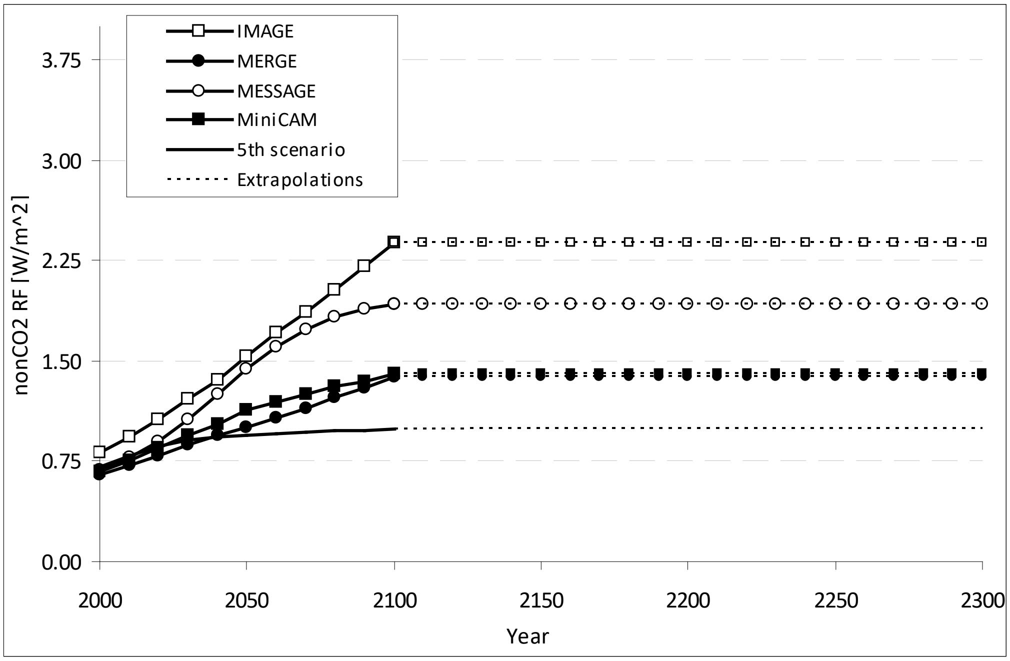

Figure 14A.9.7 Global Non-CO_2 Radiative Forcing, 2000-2300 (Post-2100 extrapolations assume constant non-CO_2 radiative forcing after 2100)

Note: In the fifth scenario, 2000-2100 emissions are equal to the average of the emissions under the 550 ppm CO_2e, full-participation, not-to-exceed scenarios considered by each of the four models.

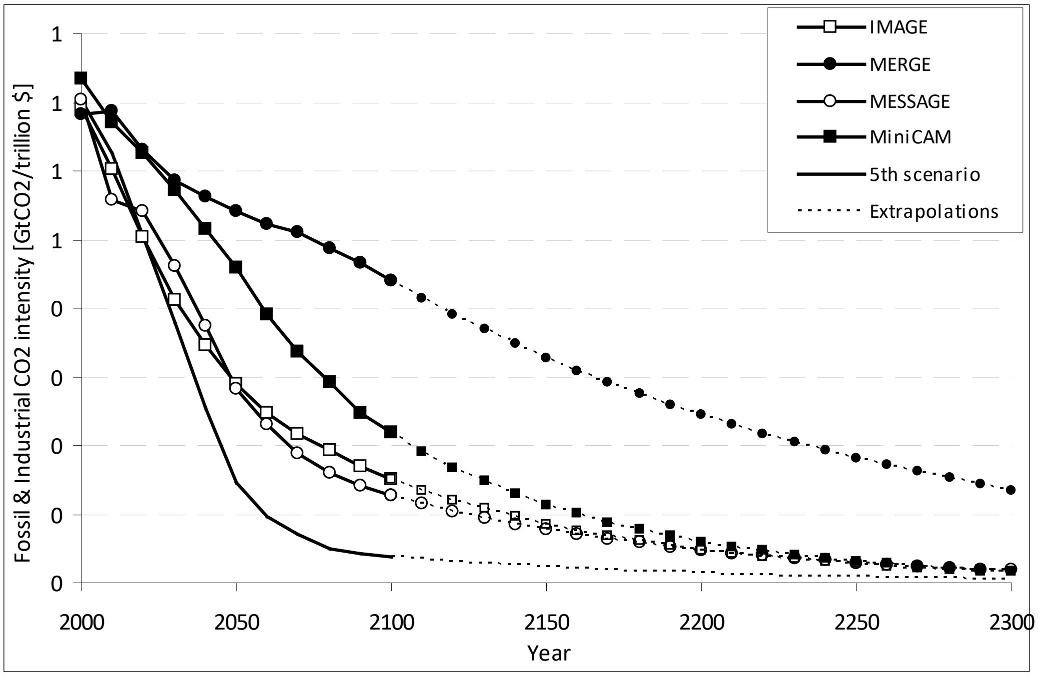

Figure 14A.9.8 Global CO_2 Intensity (fossil & industrial CO_2 emissions/GDP), 2000-2300 (Post-2100 extrapolations assume decline in CO_2/GDP growth rate over 2090-2100 is maintained through 2300)

Note: In the fifth scenario, 2000-2100 emissions are equal to the average of the emissions under the 550 ppm CO_2e, full-participation, not-to-exceed scenarios considered by each of the four models.

Table 14A.9.2 2010 Global SCC Estimates at 2.5 Percent Discount Rate (2007$/ton CO_2)

Percentile	1st	5th	10th	25th	50th	Avg	75th	90th	95th	99th
Scenario	**PAGE**									
IMAGE	3.3	5.9	8.1	13.9	28.8	65.5	68.2	147.9	239.6	563.8
MERGE optimistic	1.9	3.2	4.3	7.2	14.6	34.6	36.2	79.8	124.8	288.3
Message	2.4	4.3	5.8	9.8	20.3	49.2	50.7	114.9	181.7	428.4
MiniCAM base	2.7	4.6	6.4	11.2	22.8	54.7	55.7	120.5	195.3	482.3
5th scenario	2.0	3.5	4.7	8.1	16.3	42.9	41.5	103.9	176.3	371.9
Scenario	**DICE**									
IMAGE	16.4	21.4	25	33.3	46.8	54.2	69.7	96.3	111.1	130.0
MERGE optimistic	9.7	12.6	14.9	19.7	27.9	31.6	40.7	54.5	63.5	73.3
Message	13.5	17.2	20.1	27	38.5	43.5	55.1	75.8	87.9	103.0
MiniCAM base	13.1	16.7	19.8	26.7	38.6	44.4	56.8	79.5	92.8	109.3
5th scenario	10.8	14	16.7	22.2	32	37.4	47.7	67.8	80.2	96.8
Scenario	**FUND**									
IMAGE	-33.1	-18.9	-13.3	-5.5	4.1	19.3	18.7	43.5	67.1	150.7
MERGE optimistic	-33.1	-14.8	-10	-3	5.9	14.8	20.4	43.9	65.4	132.9
Message	-32.5	-19.8	-14.6	-7.2	1.5	8.8	13.8	33.7	52.3	119.2
MiniCAM base	-31.0	-15.9	-10.7	-3.4	6	22.2	21	46.4	70.4	152.9
5th scenario	-32.2	-21.6	-16.7	-9.7	-2.3	3	6.7	20.5	34.2	96.8

Table 14A.9.3 2010 Global SCC Estimates at 3 Percent Discount Rate (2007$/ton CO_2)

Percentile	1st	5th	10th	25th	50th	Avg	75th	90th	95th	99th
Scenario					**PAGE**					
IMAGE	2.0	3.5	4.8	8.1	16.5	39.5	41.6	90.3	142.4	327.4
MERGE optimistic	1.2	2.1	2.8	4.6	9.3	22.3	22.8	51.3	82.4	190.0
Message	1.6	2.7	3.6	6.2	12.5	30.3	31	71.4	115.6	263.0
MiniCAM base	1.7	2.8	3.8	6.5	13.2	31.8	32.4	72.6	115.4	287.0
5th scenario	1.3	2.3	3.1	5	9.6	25.4	23.6	62.1	104.7	222.5

Scenario					**DICE**					
IMAGE	11.0	14.5	17.2	22.8	31.6	35.8	45.4	61.9	70.8	82.1
MERGE optimistic	7.1	9.2	10.8	14.3	19.9	22	27.9	36.9	42.1	48.8
Message	9.7	12.5	14.7	19	26.6	29.8	37.8	51.1	58.6	67.4
MiniCAM base	8.8	11.5	13.6	18	25.2	28.8	36.9	50.4	57.9	67.8
5th scenario	7.9	10.1	11.8	15.6	21.6	24.9	31.8	43.7	50.8	60.6

Scenario					**FUND**					
IMAGE	-25.2	-15.3	-11.2	-5.6	0.9	8.2	10.4	25.4	39.7	90.3
MERGE optimistic	-24.0	-12.4	-8.7	-3.6	2.6	8	12.2	27	41.3	85.3
Message	-25.3	-16.2	-12.2	-6.8	-0.5	3.6	7.7	20.1	32.1	72.5
MiniCAM base	-23.1	-12.9	-9.3	-4	2.4	10.2	12.2	27.7	42.6	93.0
5th scenario	-24.1	-16.6	-13.2	-8.3	-3	-0.2	2.9	11.2	19.4	53.6

Table 14A.9.4 2010 Global SCC Estimates at 5 Percent Discount Rate (2007$/ton CO_2)

Percentile	1st	5th	10th	25th	50th	Avg	75th	90th	95th	99th
Scenario					PAGE					
IMAGE	0.5	0.8	1.1	1.8	3.5	8.3	8.5	19.5	31.4	67.2
MERGE optimistic	0.3	0.5	0.7	1.2	2.3	5.2	5.4	12.3	19.5	42.4
Message	0.4	0.7	0.9	1.6	3	7.2	7.2	17	28.2	60.8
MiniCAM base	0.3	0.6	0.8	1.4	2.7	6.4	6.6	15.9	24.9	52.6
5th scenario	0.3	0.6	0.8	1.3	2.3	5.5	5	12.9	22	48.7

Scenario					DICE					
IMAGE	4.2	5.4	6.2	7.6	10	10.8	13.4	16.8	18.7	21.1
MERGE optimistic	2.9	3.7	4.2	5.3	7	7.5	9.3	11.7	12.9	14.4
Message	3.9	4.9	5.5	7	9.2	9.8	12.2	15.4	17.1	18.8
MiniCAM base	3.4	4.2	4.7	6	7.9	8.6	10.7	13.5	15.1	16.9
5th scenario	3.2	4	4.6	5.7	7.6	8.2	10.2	12.8	14.3	16.0

Scenario					FUND					
IMAGE	-11.7	-8.4	-6.9	-4.6	-2.2	-1.3	0.7	4.1	7.4	17.4
MERGE optimistic	-10.6	-7.1	-5.6	-3.6	-1.3	-0.3	1.6	5.4	9.1	19.0
Message	-12.2	-8.9	-7.3	-4.9	-2.5	-1.9	0.3	3.5	6.5	15.6
MiniCAM base	-10.4	-7.2	-5.8	-3.8	-1.5	-0.6	1.3	4.8	8.2	18.0
5th scenario	-10.9	-8.3	-7	-5	-2.9	-2.7	-0.8	1.4	3.2	9.2

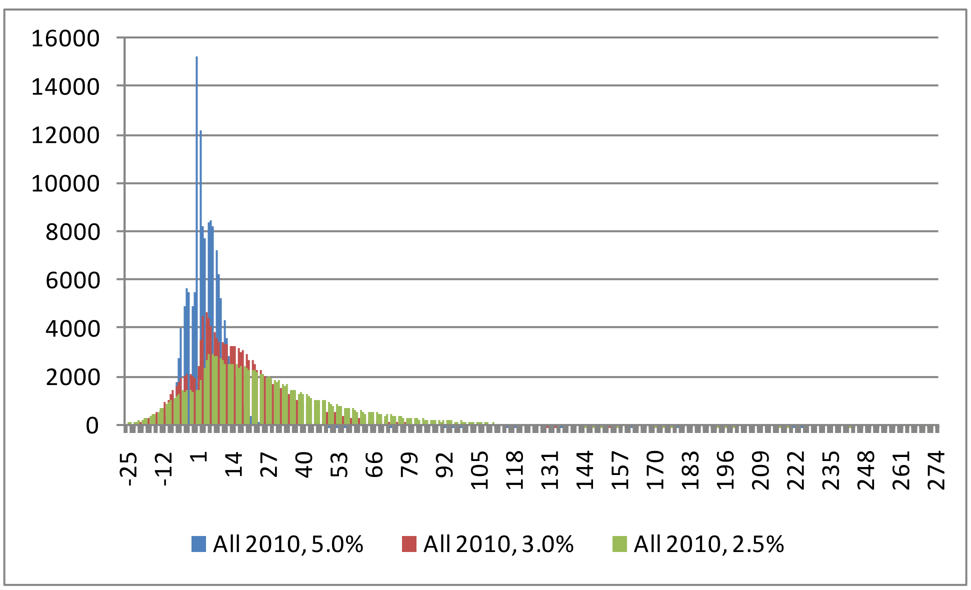

Figure 14A.9.9 Histogram of Global SCC Estimates in 2010 (2007$/ton CO_2), by discount rate

* The distribution of SCC values ranges from -$5,192 to $66,116, but the X-axis has been truncated at approximately the 1st and 99th percentiles to better show the data.

Table 14A.9.5 Additional Summary Statistics of 2010 Global SCC Estimates

Discount Rate		Scenario		
		DICE	PAGE	FUND
5%	Mean	9	6.5	-1.3
	Variance	13.1	136	70.1
	Skewness	0.8	6.3	28.2
	Kurtosis	0.2	72.4	1,479.00
3%	Mean	28.3	29.8	6
	Variance	209.8	3,383.70	16,382.50
	Skewness	1.1	8.6	128
	Kurtosis	0.9	151	18,976.50
2.50%	Mean	42.2	49.3	13.6
	Variance	534.9	9,546.00	#######
	Skewness	1.2	8.7	149
	Kurtosis	1.1	143.8	23,558.30

APPENDIX 14B. TECHNICAL UPDATE OF SOCIAL COST OF CARBON FOR REGULATORY IMPACT ANALYSIS UNDER EXECUTIVE ORDER 12866

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APPENDIX 14B. TECHNICAL UPDATE OF SOCIAL COST OF CARBON FOR REGULATORY IMPACT ANALYSIS UNDER EXECUTIVE ORDER 12866

14B.1 PREFACE

The following text is reproduced almost verbatim from the May 2013 report (revised July 2015) of the Interagency Working Group on the Social Cost of Carbon of the United States Government. Minor changes were made to the report's format to make it more consistent with the rest of this technical support document.

14B.2 EXECUTIVE SUMMARY

Under Executive Order 12866, agencies are required, to the extent permitted by law, "to assess the costs and the benefits of the intended regulation and, recognizing that some costs and benefits are difficult to quantify, propose or adopt a regulation only upon a reasoned determination that the benefits of the intended regulation justify its costs." The purpose of the "social cost of carbon" (SCC) estimates presented here is to allow agencies to incorporate the social benefits of reducing carbon dioxide (CO_2) emissions into cost-benefit analyses of regulatory actions that impact cumulative global emissions. The SCC is an estimate of the monetized damages associated with an incremental increase in carbon emissions in a given year. It is intended to include (but is not limited to) changes in net agricultural productivity, human health, property damages from increased flood risk, and the value of ecosystem services due to climate change.

The interagency process that developed the original U.S. government's SCC estimates is described in the 2010 interagency technical support document (2010 TSD) (Interagency Working Group on Social Cost of Carbon 2010). Through that process the interagency group selected four SCC values for use in regulatory analyses. Three values are based on the average SCC from three integrated assessment models (IAMs), at discount rates of 2.5, 3, and 5 percent. The fourth value, which represents the 95th percentile SCC estimate across all three models at a 3 percent discount rate, is included to represent higher-than-expected impacts from temperature change further out in the tails of the SCC distribution.

While acknowledging the continued limitations of the approach taken by the interagency group in 2010, this document provides an update of the SCC estimates based on new versions of each IAM (DICE, PAGE, and FUND). It does not revisit other interagency modeling decisions (e.g., with regard to the discount rate, reference case socioeconomic and emission scenarios, or equilibrium climate sensitivity). Improvements in the way damages are modeled are confined to those that have been incorporated into the latest versions of the models by the developers themselves in the peer-reviewed literature.

The SCC estimates using the updated versions of the models are higher than those reported in the 2010 TSD. By way of comparison, the four 2020 SCC estimates reported in the 2010 TSD were $7, $26, $42 and $81 (2007$). The corresponding four updated SCC estimates for 2020 are $12, $43, $64, and $128 (2007$). The model updates that are relevant to the SCC estimates include: an explicit representation of sea level rise damages in the DICE and PAGE models; updated adaptation assumptions, revisions to ensure damages are constrained by GDP, updated regional scaling of damages, and a revised treatment of potentially abrupt shifts in climate damages in the PAGE model; an updated carbon cycle in the DICE model; and updated damage functions for sea level rise impacts, the agricultural sector, and reduced space heating requirements, as well as changes to the transient response of temperature to the buildup of GHG concentrations and the inclusion of indirect effects of methane emissions in the FUND model. The SCC estimates vary by year, and the following table summarizes the revised SCC estimates from 2010 through 2050.

14B.3 PURPOSE

The purpose of this document is to update the schedule of SCC [a] estimates from the 2010 TSD[1] E.O. 13563 commits the Administration to regulatory decision making "based on the best available science."[b] Additionally, the interagency group recommended in 2010 that the SCC estimates be revisited on a regular basis or as model updates that reflect the growing body of scientific and economic knowledge become available.[c] New versions of the three integrated assessment models used by the U.S. government to estimate the SCC (DICE, FUND, and PAGE), are now available and have been published in the peer reviewed literature. While acknowledging the continued limitations of the approach taken by the interagency group in 2010 (documented in the original 2010 TSD), this document provides an update of the SCC estimates based solely on the latest peer-reviewed version of the models, replacing model versions that were developed up to ten years ago in a rapidly evolving field. It does not revisit other assumptions with regard to the discount rate, reference case socioeconomic and emission scenarios, or equilibrium climate sensitivity. Improvements in the way damages are modeled are confined to those that have been incorporated into the latest versions of the models by the developers themselves in the peer-reviewed literature. The Environmental Protection Agency (EPA), in collaboration with other Federal agencies such as the Department of Energy (DOE), continues to investigate potential improvements to the way in which economic damages associated with changes in CO_2 emissions are quantified.

Section 14B.4 summarizes the major updates relevant to SCC estimation that are contained in the new versions of the integrated assessment models released since the 2010 interagency report. Section 14B.5 presents the updated schedule of SCC estimates for 2010 – 2050 based on these versions of the models.

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[a] In this document, we present all values of the SCC as the cost per metric ton of CO_2 emissions. Alternatively, one could report the SCC as the cost per metric ton of carbon emissions. The multiplier for translating between mass of CO_2 and the mass of carbon is 3.67.

[b] http://www.whitehouse.gov/sites/default/files/omb/inforeg/eo12866/eo13563_01182011.pdf

[c] See p. 1, 3, 4, 29, and 33 (Interagency Working Group on Social Cost of Carbon 2010).[1]

14B.4 SUMMARY OF MODEL UPDATES

This section briefly summarizes changes integrated into the most recent versions of the three integrated assessment models (IAMs) used by the interagency group in 2010. We focus on describing those model updates that are relevant to estimating the social cost of carbon. For example, both the DICE and PAGE models now include an explicit representation of sea level rise damages. Other revisions to PAGE include: updated adaptation assumptions, revisions to ensure damages are constrained GDP, updated regional scaling of damages, and a revised treatment of potentially abrupt shifts in climate damages. In the most recent version of DICE, the model's simple carbon cycle has been updated to be more consistent with a relatively more complex climate model. The FUND model includes updated damage functions for sea level rise impacts, the agricultural sector, and reduced space heating requirements, as well as changes to the response of temperature to the buildup of GHG concentrations and the inclusion of indirect effects of methane emissions. Changes made to parts of the models that are superseded by the interagency working group's modeling assumptions – regarding climate sensitivity, discounting, and socioeconomic variables – are not discussed.

Table 14B.4.1 Summary of Key Model Revisions Relevant to the Interagency SCC

IAM	Version used in 2010 Interagency Analysis	New Version	Key changes relevant to interagency SCC
DICE	2007	2010	Updated calibration of the carbon cycle model and explicit representation of seal level rise (SLR) and associated damages.
FUND	3.5 (2009)	3.8 (2012)	Updated damage functions for space heating, SLR, agricultural impacts, changes to transient response of temperature to buildup of GHG concentrations, and inclusion of indirect climate effects of methane.
PAGE	2002	2009	Explicit representation of SLR damages, revisions to damage function to ensure damages do not exceed 100 percent of GDP, change in regional scaling of damages, revised treatment of potential abrupt damages, and updated adaptation assumptions.

14B.4.1 DICE

Changes in the DICE model relevant for the SCC estimates developed by the interagency working group include: 1) updated parameter values for the carbon cycle model, 2) an explicit representation of sea level dynamics, and 3) a re-calibrated damage function that includes an explicit representation of economic damages from sea level rise. Changes were also made to other parts of the DICE model—including the equilibrium climate sensitivity parameter, the rate of change of total factor productivity, and the elasticity of the marginal utility of consumption—

but these components of DICE are superseded by the interagency working group's assumptions and so will not be discussed here. More details on DICE2007 can be found in Nordhaus (2008)[2] and on DICE2010 in Nordhaus (2010)[3] and the associated on-line appendix containing supplemental information.

14B.4.1.1 Carbon Cycle Parameters

DICE uses a three-box model of carbon stocks and flows to represent the accumulation and transfer of carbon among the atmosphere, the shallow ocean and terrestrial biosphere, and the deep ocean. These parameters are "calibrated to match the carbon cycle in the Model for the Assessment of Greenhouse Gas Induced Climate Change (MAGICC)" (Nordhaus 2008 p 44).[2d] Carbon cycle transfer coefficient values in DICE2010 are based on re-calibration of the model to match the newer version of MAGICC (Nordhaus 2010 p 2).[3] For example, in DICE2010 in each decade, 12 percent of the carbon in the atmosphere is transferred to the shallow ocean, 4.7 percent of the carbon in the shallow ocean is transferred to the atmosphere, 94.8 percent remains in the shallow ocean, and 0.5 percent is transferred to the deep ocean. For comparison, in DICE 2007, 18.9 percent of the carbon in the atmosphere is transferred to the shallow ocean each decade, 9.7 percent of the carbon in the shallow ocean is transferred to the atmosphere, 85.3 percent remains in the shallow ocean, and 5 percent is transferred to the deep ocean.

The implication of these changes for DICE2010 is in general a weakening of the ocean as a carbon sink and therefore a higher concentration of carbon in the atmosphere than in DICE2007, for a given path of emissions. All else equal, these changes will generally increase the level of warming and therefore the SCC estimates in DICE2010 relative to those from DICE2007.

14B.4.1.2 Sea Level Dynamics

A new feature of DICE2010 is an explicit representation of the dynamics of the global average sea level anomaly to be used in the updated damage function (discussed below). This section contains a brief description of the sea level rise (SLR) module; a more detailed description can be found on the model developer's website.[e] The average global sea level anomaly is modeled as the sum of four terms that represent contributions from: 1) thermal expansion of the oceans, 2) melting of glaciers and small ice caps, 3) melting of the Greenland ice sheet, and 4) melting of the Antarctic ice sheet.

The parameters of the four components of the SLR module are calibrated to match consensus results from the IPCC's Fourth Assessment Report.[4,f] The rise in sea level from

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[d] MAGICC is a simple climate model initially developed within the U.S. National Center for Atmospheric Research that has been used heavily by the Intergovernmental Panel on Climate Change (IPCC) to emulate projections from much more sophisticated state of the art earth system simulation models (Randall et al. 2007).[4]

[e] Documentation on the new sea level rise module of DICE is available on William Nordhaus' website at: http://www.econ.yale.edu/~nordhaus/homepage/documents/SLR_021910.pdf.

[f] For a review of post-IPCC AR4 research on sea level rise, see Nicholls et al. (2011)[5] and NAS (2011).[6]

thermal expansion in each time period (decade) is 2 percent of the difference between the sea level in the previous period and the long run equilibrium sea level, which is 0.5 meters per degree Celsius (°C) above the average global temperature in 1900. The rise in sea level from the melting of glaciers and small ice caps occurs at a rate of 0.008 meters per decade per °C above the average global temperature in 1900.

The contribution to sea level rise from melting of the Greenland ice sheet is more complex. The equilibrium contribution to SLR is 0 meters for temperature anomalies less than 1 ^{o}C and increases linearly from 0 meters to a maximum of 7.3 meters. The contribution to SLR in each period is proportional to the difference between the previous period's sea level anomaly and the equilibrium sea level anomaly, where the constant of proportionality increases with the temperature anomaly in the current period.

The contribution to SLR from the melting of the Antarctic ice sheet is -0.001 meters per decade when the temperature anomaly is below 3 °C and increases linearly to a maximum rate of 0.025 meters per decade at a temperature anomaly of 6 °C.

14B.4.1.3 Re-calibrated Damage Function

Economic damages from climate change in the DICE model are represented by a fractional loss of gross economic output in each period. A portion of the remaining economic output in each period (net of climate change damages) is consumed and the remainder is invested in the physical capital stock to support future production, so each period's climate damages will reduce consumption in that period and in all future periods due to the lost investment. The fraction of output in each period that is lost due to climate change impacts is represented as one minus a fraction, which is one divided by a quadratic function of the temperature anomaly, producing a sigmoid ("S"-shaped) function. The loss function in DICE2010 has been expanded by adding a quadratic function of SLR to the quadratic function of temperature. In DICE2010 the temperature anomaly coefficients have been recalibrated to avoid double-counting damages from sea level rise that were implicitly included in these parameters in DICE2007.

The aggregate damages in DICE2010 are illustrated by Nordhaus (2010 p 3),[3] who notes that "…damages in the uncontrolled (baseline) (*i.e.*, reference) case … in 2095 are $12 trillion, or 2.8 percent of global output, for a global temperature increase of 3.4 ^{o}C above 1900 levels." This compares to a loss of 3.2 percent of global output at 3.4 ^{o}C in DICE2007. However, in DICE2010 (as downloaded from the homepage of William Nordhaus), annual damages are lower in most of the early periods but higher in later periods of the time horizon than would be calculated using the DICE2007 damage function. Specifically, the percent difference between damages in the base run of DICE2010 and those that would be calculated using the DICE2007 damage function starts at +7 percent in 2005, decreases to a low of -14 percent in 2065, then continuously increases to +20 percent by 2300 (the end of the interagency analysis time horizon), and to +160 percent by the end of the model time horizon in 2595. The large increases in the far future years of the time horizon are due to the permanence associated with damages from sea level rise, along with the assumption that the sea level is projected to continue to rise long after the global average temperature begins to decrease. The changes to the loss function generally decrease the interagency working group SCC estimates slightly, all else equal.

14B.4.2 FUND

FUND version 3.8 includes a number of changes over the previous version 3.5 used in the interagency report. Documentation supporting FUND and the model's source code for all versions of the model is available from the model authors.[g] Notable changes, due to their impact on the estimates of expected SCC, are adjustments to the space heating, agriculture, and sea level rise damage functions in addition to changes to the temperature response function and the inclusion of indirect effects from methane emissions.[h] We discuss each of these in turn.

14B.4.2.1 Space Heating

In FUND, the damages associated with the change in energy needs for space heating are based on the estimated impact due to one degree of warming. These baseline damages are scaled based on the forecasted temperature anomaly's deviation from the one degree benchmark and adjusted for changes in vulnerability due to economic and energy efficiency growth. In FUND 3.5, the function that scales the base year damages adjusted for vulnerability allows for the possibility that in some simulations the benefits associated with reduced heating needs may be an unbounded convex function of the temperature anomaly. In FUND 3.8, the form of the scaling has been modified to ensure that the function is everywhere concave, meaning that for every simulation there will exist an upper bound on the benefits a region may receive from reduced space heating needs. The new formulation approaches a value of two in the limit as the temperature anomaly increases, or in other words, assuming no decrease in vulnerability, the reduced expenditures on space heating at any level of warming will not exceed two times the reductions experienced at one degree of warming. Since the reduced need for space heating represents a benefit of climate change in the model, or a negative damage, this change will increase the estimated SCC. This update accounts for a significant portion of the difference in the expected SCC estimates reported by the two versions of the model when run probabilistically.

14B.4.2.2 Sea Level Rise and Land Loss

The FUND model explicitly includes damages associated with the inundation of dry land due to sea level rise. The amount of land lost within a region is dependent upon the proportion of the coastline being protected by adequate sea walls and the amount of sea level rise. In FUND 3.5 the function defining the potential land lost in a given year due to sea level rise is linear in the rate of sea level rise for that year. This assumption implicitly assumes that all regions are well represented by a homogeneous coastline in length and a constant uniform slope moving

[g] http://www.fund-model.org/. This report uses version 3.8 of the FUND model, which represents a modest update to the most recent version of the model to appear in the literature (version 3.7) (Anthoff and Tol, 2013).[7] For the purpose of computing the SCC, the relevant changes are associated with improving consistency with IPCC AR4 by adjusting the atmospheric lifetimes of CH4 and N2O and incorporating the indirect forcing effects of CH4, along with making minor stability improvements in the sea wall construction algorithm.

[h] The other damage sectors (water resources, space cooling, land loss, migration, ecosystems, human health, and extreme weather) were not the subject of significant updates.

inland. In FUND 3.8 the function defining the potential land lost has been changed to be a non-linear function of sea level rise, thereby assuming that the slope of the shore line is not constant moving inland, with a positive first derivative. The effect of this change is to typically reduce the vulnerability of some regions to sea level rise based land loss, therefore having an effect of lowering the expected SCC estimate. The model has also been updated to assume that the value of dry land at risk of inundation is not uniform across a region but will be a decreasing function of protection measure, thereby implicitly assuming that the most valuable land will be protected first.

14B.4.2.3 Agriculture

In FUND, the damages associated with the agricultural sector are measured as proportional to the sector's value. The fraction is made up of three additively separable components that represent the effects from carbon fertilization, the rate of temperature change, and the level of the temperature anomaly. In both FUND 3.5 and FUND 3.8, the fraction of the sector's value lost due to the level of the temperature anomaly is modeled as a quadratic function with an intercept of zero. In FUND 3.5, the linear and quadratic coefficients are modeled as the ratio of two normal distributions. Within this specification, as draws from the distribution in the denominator approached zero the share of the sector's value "lost" approaches (+/-) infinity independent of the temperature anomaly itself. In FUND 3.8, the linear and quadratic coefficients are drawn directly from truncated normal distributions so that they remain in the range $[0,\infty)$ and $(-\infty,0]$, respectively, where the means for the new distributions are set equal to the ratio of the means from the normal distributions used in the previous version. In general the impact of this change has been to increase the likelihood that increases in the temperature level will have either larger positive or negative effects on the agricultural sector relative to the previous version (through eliminating simulations in which the "lost" value approached (+/-) infinity). The net effect of this change on the SCC estimates is difficult to predict.

14B.4.2.4 Temperature Response Model

The temperature response model translates changes in global levels of radiative forcing into the current expected temperature anomaly. In FUND, a given year's increase in the cumulative temperature anomaly is based on a mean reverting function where the mean equals the equilibrium temperature anomaly that would eventually be reached if that year's level of radiative forcing were sustained. The rate of mean reversion defines the rate at which the transient temperature approaches the equilibrium. In FUND 3.5, the rate of temperature response is defined as a decreasing linear function of equilibrium climate sensitivity to capture the fact that the progressive heat uptake of the deep ocean causes the rate to slow at higher values of the equilibrium climate sensitivity. In FUND 3.8, the rate of temperature response has been updated to a quadratic function of the equilibrium climate sensitivity. This change reduces the sensitivity of the rate of temperature response to the level of the equilibrium climate sensitivity. Therefore in FUND 3.8, the temperature response will typically be faster than in the previous version. The overall effect of this change is likely to increase estimates of the SCC as higher temperatures are reached during the timeframe analyzed and as the same damages experienced in the previous version of the model are now experienced earlier and therefore discounted less.

14B.4.2.5 Methane

The IPCC notes a series of indirect effects of methane emissions, and has developed methods for proxying such effects when computing the global warming potential of methane (Forster et al. 2007).[8] FUND 3.8 now includes the same methods for incorporating the indirect effects of methane emissions. Specifically, the average atmospheric lifetime of methane has been set to 12 years to account for the feedback of CH4 emissions on its own lifetime. The radiative forcing associated with atmospheric methane has also been increase by 40 percent to account for its net impact on ozone production and increase in stratospheric water vapor. The general effect of this increased radiative forcing will be to increase the estimated SCC values, where the degree to which this occurs will be dependent upon the relative curvature of the damage functions with respect to the temperature anomaly.

14B.4.3 PAGE

PAGE09 (Hope 2012)[9] includes a number of changes from PAGE2002, the version used in the 2009 SCC interagency report. The changes that most directly affect the SCC estimates include: explicitly modeling the impacts from sea level rise, revisions to the damage function to ensure damages are constrained by GDP, a change in the regional scaling of damages, a revised treatment for the probability of a discontinuity within the damage function, and revised assumptions on adaptation. The model also includes revisions to the carbon cycle feedback and the calculation of regional temperatures. More details on PAGE2009 can be found in three working papers (Hope 2011a, 2011b, 2011c).[10, 11, 12] A description of PAGE2002 can be found in Hope (2006).[13]

14B.4.3.1 Sea Level Rise

While PAGE2002 aggregates all damages into two categories – economic and non-economic impacts - PAGE2009 adds a third explicit category: damages from sea level rise. In the previous version of the model, damages from sea level rise were subsumed by the other damage categories. PAGE09 models damages from sea level rise as increasing less than linearly with sea level based on the assumption that low-lying shoreline areas will be associated with higher damages than current inland areas. Damages from the economic and non-economic sector were adjusted to account for the introduction of this new category.

14B.4.3.2 Revised Damage Function to Account for Saturation

In PAGE09, small initial economic and non-economic benefits (negative damages) are modeled for small temperature increases, but all regions eventually experience positive economic damages from climate change, where damages are the sum of additively separable polynomial functions of temperature and sea level rise. Damages transition from this polynomial function to a logistic path once they exceed a certain proportion of remaining Gross Domestic Product (GDP) to ensure that damages do not exceed 100 percent of GDP. This differs from PAGE2002, which allowed Eastern Europe to potentially experience large benefits from temperature increases, and which also did not bound the possible damages that could be experienced.

14B.4.3.3 Regional Scaling Factors

As in the previous version of PAGE, the PAGE09 model calculates the damages for the European Union (EU) and then, assumes that damages for other regions are proportional based on a given scaling factor. The scaling factor in PAGE09 is based on the length of a region's coastline relative to the EU (Hope 2011b).[11] Because of the long coastline in the EU, other regions are, on average, less vulnerable than the EU for the same sea level and temperature increase, but all regions have a positive scaling factor. PAGE2002 based its scaling factors on four studies reported in the IPCC's third assessment report, and allowed for benefits from temperature increase in Eastern Europe, smaller impacts in developing countries, and higher damages in developing countries.

14B.4.3.4 Probability of a Discontinuity

In PAGE2002, the damages associated with a "discontinuity" were modeled as an expected value. That is, additional damages from an extreme event, such as extreme melting of the Greenland ice sheet, were multiplied by the probability of the event occurring and added to the damage estimate. In PAGE09, the probability of "discontinuity" is treated as a discrete event for each year in the model. The damages for each model run are estimated with or without a discontinuity occurring, rather than as an expected value. A large-scale discontinuity becomes possible when the temperature rises beyond some threshold value between 2 and 4°C. The probability that a discontinuity will occur beyond this threshold then increases by between 10 and 30 percent for every 1°C rise in temperature beyond the threshold. If a discontinuity occurs, the EU loses an additional 5 to 25 percent of its GDP (drawn from a triangular distribution with a mean of 15 percent) in addition to other damages, and other regions lose an amount determined by the regional scaling factor. The threshold value for a possible discontinuity is lower than in PAGE2002, while the rate at which the probability of a discontinuity increases with the temperature anomaly and the damages that result from a discontinuity are both higher than in PAGE2002. The model assumes that only one discontinuity can occur and that the impact is phased in over a period of time, but once it occurs, its effect is permanent.

14B.4.3.5 Adaptation

As in PAGE2002, adaptation is available to increase the tolerable level of temperature change and can help mitigate any climate change impacts that still occur. In PAGE this adaptation is the same regardless of the temperature change or sea level rise and is therefore akin to what is more commonly considered a reduction in vulnerability. It is modeled by modifying the temperature change and sea level rise used in the damage function or by reducing the damages by some percentage. PAGE09 assumes a smaller decrease in vulnerability than the previous version of the model and assumes that it will take longer for this change in vulnerability to be realized. In the aggregated economic sector, at the time of full implementation, this adaptation will mitigate all damages up to a temperature increase of 1°C, and for temperature anomalies between 1°C and 3°C, it will reduce damages by 15-30 percent (depending on the region). However, it takes 20 years to fully implement this adaptation. In PAGE2002, adaptation was assumed to reduce economic sector damages up to 3°C by 50-90 percent after 20 years. Beyond 3°C, no adaptation is assumed to be available to mitigate the impacts of climate change.

For the non-economic sector, in PAGE09 adaptation is available to reduce 15 percent of the damages due to a temperature increase between 0°C and 2°C and is assumed to take 40 years to fully implement, instead of 25 percent of the damages over 20 years assumed in PAGE2002. Similarly, adaptation is assumed to alleviate 25-50 percent of the damages from the first 0.20 to 0.25 meters of sea level rise but is assumed to be ineffective thereafter. Hope (2011c)[12] estimates that the less optimistic assumptions regarding the ability to offset impacts of temperature and sea level rise via adaptation increase the SCC by approximately 30 percent.

14B.4.3.6 Other Noteworthy Changes

Two other changes in the model are worth noting. A revised carbon cycle feedback is introduced to simulate decreased CO_2 absorption by the terrestrial biosphere and ocean as the temperature rises. This feedback is linear in the average global and annual temperature anomaly but is capped at a maximum value. In the previous version of PAGE, an additional amount was added to the CO_2 emissions each period to account for a decrease in ocean absorption and a loss of soil carbon. Also updated is the method by which the average global and annual temperature anomaly is downscaled to determine annual average regional temperature anomalies to be used in the regional damage functions. In the previous version of PAGE, the scaling was determined solely based on regional difference in emissions of sulfate aerosols. In PAGE09, this regional temperature anomaly is further adjusted using an additive factor that is based on the average absolute latitude of a region relative to the area weighted average absolute latitude of the Earth's landmass.

14B.5 REVISED SCC ESTIMATES

The updated versions of the three integrated assessment models were run using the same methodology detailed in the 2010 TSD.[1] The approach along with the inputs for the socioeconomic emissions scenarios, equilibrium climate sensitivity distribution, and discount rate remains the same. This includes the five reference scenarios based on the EMF-22 modeling exercise, the Roe and Baker equilibrium climate sensitivity distribution calibrated to the Fourth Assessment Report of the IPCC, and three constant discount rates of 2.5, 3, and 5 percent.

As was previously the case, the use of three models, three discount rates, and five scenarios produces 45 separate distributions for the SCC. The approach laid out in the TSD applied equal weight to each model and socioeconomic scenario in order to reduce the dimensionality down to three separate distributions representative of the three discount rates. The interagency group selected four values from these distributions for use in regulatory analysis. Three values are based on the average SCC across models and socio-economic-emissions scenarios at the 2.5, 3, and 5 percent discount rates, respectively. The fourth value was chosen to represent the higher-than-expected economic impacts from climate change further out in the tails of the SCC distribution. For this purpose, the 95th percentile of the SCC estimates at a 3 percent discount rate was chosen. (A detailed set of percentiles by model and scenario combination is available in the Annex.) As noted in the original TSD, "the 3 percent discount rate is the central value, and so the central value that emerges is the average SCC across models at the 3 percent discount rate" (TSD, p. 25). However, for purposes of capturing the uncertainties involved in regulatory impact analysis, the interagency group emphasizes the importance and value of including all four SCC values.

Table 14B.5.1 shows the four selected SCC estimates in five year increments from 2010 to 2050. Values for 2010, 2020, 2030, 2040, and 2050 are calculated by first combining all outputs (10,000 estimates per model run) from all scenarios and models for a given discount rate. Values for the years in between are calculated using basic linear interpolation. The full set of annual SCC estimates between 2010 and 2050 is reported in the Annex.

Table 14B.5.1 Revised Social Cost of CO_2, 2010 – 2050 (in 2007 dollars per ton of CO_2)

Discount Rate Year	5.0% Avg	3.0% Avg	2.5% Avg	3.0% 95th
2010	10	31	50	86
2015	11	36	56	105
2020	12	42	62	123
2025	14	46	68	138
2030	16	50	73	152
2035	18	55	78	168
2040	21	60	84	183
2045	23	64	89	197
2050	26	69	95	212

The SCC estimates using the updated versions of the models are higher than those reported in the TSD due to the changes to the models outlined in the previous section. Figure 14B.5.1 illustrates where the four SCC values for 2020 fall within the full distribution for each discount rate based on the combined set of runs for each model and scenario (150,000 estimates in total for each discount rate). In general, the distributions are skewed to the right and have long tails. The Figure also shows that the lower the discount rate, the longer the right tail of the distribution.

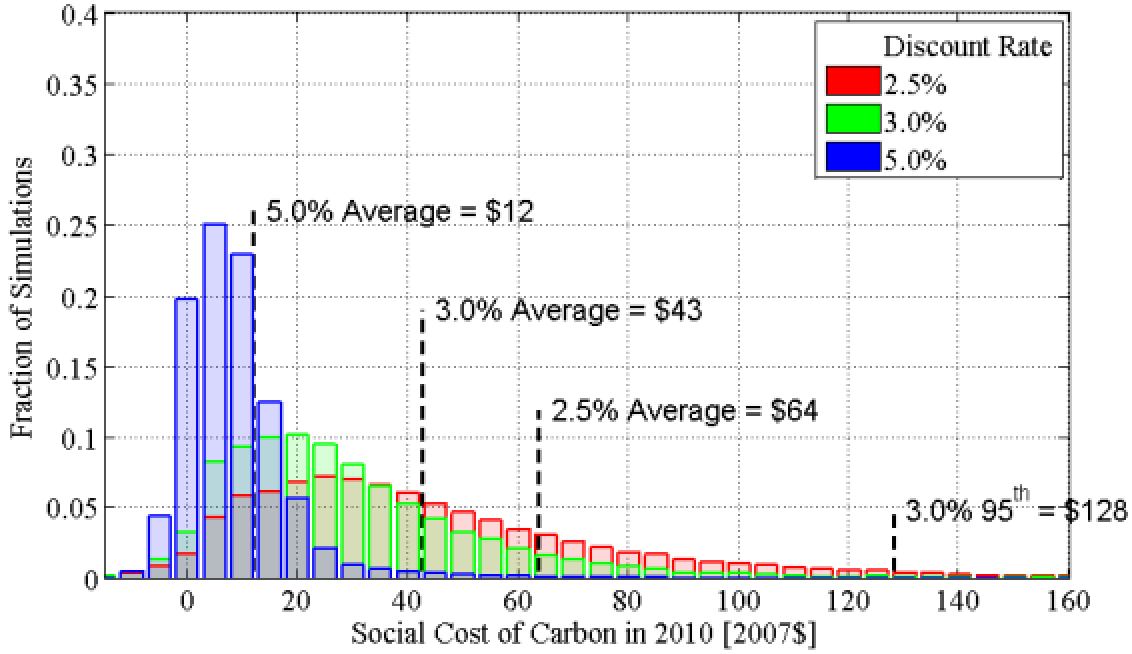

Figure 14B.5.1 Distribution of SCC Estimates for 2010 (in 2007$ per ton CO_2)

As was the case in the original TSD, the SCC increases over time because future emissions are expected to produce larger incremental damages as physical and economic systems become more stressed in response to greater climatic change. The approach taken by the interagency group is to allow the growth rate to be determined endogenously by the models through running them for a set of perturbation years out to 2050. Table 14B.5.2 illustrates how the growth rate for these four SCC estimates varies over time.

Table 14B.5.2 Average Annual Growth Rates of SCC Estimates between 2010 and 2050

Average Annual Rate (%)	5.0% Avg	3.0% Avg	2.5% Avg	3.0% 95th
2010-2020	1.2%	3.2%	2.4%	4.4%
2020-2030	3.4%	2.1%	1.7%	2.3%
2030-2040	3.0%	1.9%	1.5%	2.0%
2040-2050	2.6%	1.6%	1.3%	1.6%

The future monetized value of emission reductions in each year (the SCC in year *t* multiplied by the change in emissions in year *t*) must be discounted to the present to determine its total net present value for use in regulatory analysis. As previously discussed in the original TSD, damages from future emissions should be discounted at the same rate as that used to calculate the SCC estimates themselves to ensure internal consistency – *i.e.*, future damages from climate change, whether they result from emissions today or emissions in a later year, should be discounted using the same rate.

14B.6 OTHER MODEL LIMITATIONS OR RESEARCH GAPS

The 2010 interagency SCC technical support report discusses a number of important limitations for which additional research is needed. In particular, the document highlights the need to improve the quantification of both non-catastrophic and catastrophic damages, the treatment of adaptation and technological change, and the way in which inter-regional and inter-sectoral linkages are modeled. It also discusses the need to more carefully assess the implications of risk aversion for SCC estimation as well as the inability to perfectly substitute between climate and non-climate goods at higher temperature increases, both of which have implications for the discount rate used. EPA, DOE, and other agencies continue to engage in long-term research work on modeling and valuation of climate impacts that we expect will inform improvements in SCC estimation in the future.

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14B.7 ANNEX A

Table 14B.7.1 Annual SCC Values: 2010-2050 (2007$/ton CO_2)

Discount Rate Year	5.0% Avg	3.0% Avg	2.5% Avg	3.0% 95th
2010	10	31	50	86
2011	11	32	51	90
2012	11	33	53	93
2013	11	34	54	97
2014	11	35	55	101
2015	11	36	56	105
2016	11	38	57	108
2017	11	39	59	112
2018	12	40	60	116
2019	12	41	61	120
2020	12	42	62	123
2021	12	42	63	126
2022	13	43	64	129
2023	13	44	65	132
2024	13	45	66	135
2025	14	46	68	138
2026	14	47	69	141
2027	15	48	70	149
2028	15	49	71	146
2029	15	49	72	149
2030	16	50	73	152
2031	16	51	74	155
2032	17	52	75	158
2033	17	53	76	161
2034	18	54	77	164
2035	18	55	78	168
2036	19	56	79	171
2037	19	57	81	174
2038	20	58	82	177
2039	20	59	83	180
2040	21	60	84	183
2041	21	61	85	186
2042	22	61	86	189
2043	22	62	87	192
2044	23	63	88	194
2045	23	64	89	197
2046	24	65	90	200
2047	24	66	92	203
2048	25	67	93	206
2049	25	68	94	209
2050	26	69	95	212

Table 14B.7.2 202 Global SCC Estimates at 2.5 Percent Discount Rate (2007$/ton CO_2)

Percentile	1st	5th	10th	25th	50th	Avg	75th	90th	95th	99th
Scenario					PAGE					
IMAGE	6	10	15	26	55	123	133	313	493	949
MERGE	4	6	8	15	32	75	79	188	304	621
MESSAGE	4	7	10	19	41	104	103	266	463	879
MiniCAM Base	5	8	12	21	45	102	108	255	412	835
5th Scenario	2	4	6	11	24	81	66	192	371	915
Scenario					DICE					
IMAGE	25	31	37	47	64	72	92	123	139	161
MERGE	14	18	20	26	36	40	50	65	74	85
MESSAGE	20	24	28	37	51	58	71	95	109	221
MiniCAM Base	20	25	29	38	53	61	76	102	117	135
5th Scenario	17	22	25	33	45	52	65	91	106	126
Scenario					FUND					
IMAGE	-14	-2	4	15	31	39	55	86	107	157
MERGE	-6	1	6	14	27	35	46	70	87	141
MESSAGE	-16	-5	1	11	24	31	43	67	83	126
MiniCAM Base	-7	2	7	16	32	39	55	83	103	158
5th Scenario	-29	-13	-6	4	16	21	32	53	69	103

Table 14B.7.3 SCC Estimates at 3 Percent Discount Rate (2007$/ton CO2)

Percentile	1st	5th	10th	25th	50th	Avg	75th	90th	95th	99th
Scenario					PAGE					
IMAGE	4	7	9	17	36	87	91	228	369	696
MERGE	2	4	6	10	22	54	55	136	222	461
MESSAGE	3	5	7	13	28	72	71	188	316	614
MiniCAM Base	3	5	7	13	29	70	72	177	288	597
5th Scenario	1	3	4	7	16	55	46	130	252	632
Scenario					DICE					
IMAGE	16	21	24	32	43	48	60	79	90	102
MERGE	10	13	15	19	25	28	35	44	50	58
MESSAGE	14	18	20	26	35	40	49	64	73	83
MiniCAM Base	13	17	20	26	35	39	49	65	73	85
5th Scenario	12	15	17	22	30	34	43	58	67	79
Scenario					FUND					
IMAGE	-13	-4	0	8	18	23	33	51	65	99
MERGE	-7	-1	2	8	17	21	29	45	57	95
MESSAGE	-14	-6	-2	5	14	18	26	41	52	82
MiniCAM Base	-7	-1	3	9	19	23	33	50	63	101
5th Scenario	-22	-11	-6	1	8	11	18	31	40	62

Table 14B.7.4 2020 Global SCC Estimates at 5 Percent Discount Rate (2007$/ton CO_2)

Percentile	1st	5th	10th	25th	50th	Avg	75th	90th	95th	99th
Scenario	PAGE									
IMAGE	1	2	2	4	10	27	26	68	118	234
MERGE	1	1	2	3	6	17	17	43	72	149
MESSAGE	1	1	2	4	8	23	22	58	102	207
MiniCAM Base	1	1	2	3	8	20	20	52	90	182
5th Scenario	0	1	1	2	5	17	14	39	75	199
Scenario	DICE									
IMAGE	6	8	9	11	14	15	18	22	25	27
MERGE	4	5	6	7	9	10	12	15	16	18
MESSAGE	6	7	8	10	12	13	16	20	22	25
MiniCAM Base	5	6	7	8	11	12	14	18	20	22
5th Scenario	5	6	6	8	10	11	14	17	19	21
Scenario	FUND									
IMAGE	-9	-5	-4	-1	2	3	6	10	14	24
MERGE	-6	-4	-2	0	3	4	6	11	15	26
MESSAGE	-10	-6	-4	-1	1	2	5	9	12	21
MiniCAM Base	-7	-4	-2	0	3	4	6	11	14	25
5th Scenario	-11	-7	-5	-3	0	0	3	5	7	13

Table 14B.7.5 Additional Summary Statistics of 2020 Global SCC Estimates

Discount Rate	5.0%				3.0%				2.5%			
Statistic:	Mean	Variance	Skewness	Kurtosis	Mean	Variance	Skewness	Kurtosis	Mean	Variance	Skewness	Kurtosis
DICE	12	26	2	15	38	409	3	24	57	1097	3	30
PAGE	21	1481	5	32	68	13712	4	22	97	26878	4	23
FUND	3	41	5	179	19	1452	-42	8727	33	6154	-73	14931

14B.8 ANNEX B

The November 2013 revision of this technical support document is based on two corrections to the runs based on the FUND model. First, the potential dry land loss in the algorithm that estimates regional coastal protections was misspecified in the model's computer code. This correction is covered in an erratum to Anthoff and Tol (2013) published in the same journal (Climatic Change) in October 2013 (Anthoff and Tol (2013b)). Second, the equilibrium climate sensitivity distribution was inadvertently specified as a truncated Gamma distribution (the default in FUND) as opposed to the truncated Roe and Baker distribution as was intended. The truncated Gamma distribution used in the FUND runs had approximately the same mean and upper truncation point, but lower variance and faster decay of the upper tail, as compared to the intended specification based on the Roe and Baker distribution. The difference between the original estimates reported in the May 2013 version of this technical support document and this revision are generally one dollar or less.

The July 2015 revision of this technical support document is based on two corrections. First, the DICE model had been run up to 2300 rather than through 2300, as was intended, thereby leaving out the marginal damages in the last year of the time horizon. Second, due to an indexing error, the results from the PAGE model were in 2008 U.S. dollars rather than 2007 U.S. dollars, as was intended. In the current revision, all models have been run through 2300, and all estimates are in 2007 U.S. dollars. On average the revised SCC estimates are one dollar less than the mean SCC estimates reported in the November 2013 version of this technical support document. The difference between the 95th percentile estimates with a 3 percent discount rate is slightly larger, as those estimates are heavily influenced by results from the PAGE model.

APPENDIX 15A. UTILITY IMPACT ANALYSIS METHODOLOGY

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APPENDIX 15A. UTILITY IMPACT ANALYSIS METHODOLOGY

15A.1 INTRODUCTION

In the utility impact analysis, the U.S. Department of Energy (DOE) analyzes the changes in electric installed capacity and power generation that result for each trial standard level (TSL). These changes are estimated by multiplying the site savings of electricity by a set of *impact factors* which measure the corresponding change in generation by fuel type, installed capacity, and power sector emissions. This Appendix describes the methods that DOE used to calculate these impact factors. The methodology is more fully described in Coughlin (2014).[1]

DOE's analysis uses output of the DOE/Energy Information Administration (EIA)'s *Annual Energy Outlook* (*AEO*). The *AEO* includes a reference case and a set of side cases that implement a variety of economic and policy scenarios. In 2015 EIA announced the adoption of a two-year release cycle for the *AEO*, alternating between a full set of scenarios and a shorter edition containing only five scenarios.[2] DOE adapts its calculation methodology according to the number and type of scenarios available with each *AEO* publication.

15A.2 METHODOLOGY

Marginal reductions in electricity demand lead to marginal reductions in power sector generation, emissions, and installed capacity. Generally, DOE quantifies these reductions using marginal impact factors, which are time series defining the change in some power sector quantity that results from a unit change in site electricity demand. Because load shapes affect the mix of generation types on the margin, these impact factors depend on end-use and sector.

DOE's approach examines a series of *AEO* side cases related to efficiency policy to estimate the relationship between marginal demand reductions and power sector variables. In *AEO2016* most published side cases do not incorporate changes in demand. Consequently DOE has adapted it's methodology to use grid-average, rather than marginal, data for the utility impacts estimation. DOE continues to use marginal emissions intensity factors for the emissions analysis, as described in appendix 13A.

The purpose of the utility impacts analysis is to relate changes in electricity demand to the corresponding changes in three quantities: power sector generation (TWh) by fuel type, power sector fuel consumption (quads) by fuel type, and power sector installed capacity (GW) by fuel and technology type.

For this analysis, DOE used the AEO projections of generation, fuel consumption and installed capacity by Electricity Market Module (EMM) region. DOE aggregated the data for the 22 EMM regions into 5 regions which are also aggregations of the NERC reliability regions: region 1 consists of NERC regions NPCC and RFC, region 2 contains the SERC and FRCC regions, region 3 is MRO, region 4 ERCOT plus SPP, and region 5 is WECC.

The relationship between fuel consumption and generation is defined by the heat rate (quads/TWh). DOE's approach to calculating heat rates is described in appendix 10B of this

TSD. DOE defined a heat rate *H(f,r,y)* for each fuel type *f*, region *r* and year *y*. The fuel types are coal, natural gas, nuclear, oil and renewables. DOE's uses the EIA convention assigning a heat rate of 10.5 Btu/Wh to nuclear power and 9.5 Btu/Wh to electricity from renewable sources. The heat rates include the transmission and distribution loss factor.

The relationship between installed capacity and generation is defined by a capacity factor (GW/TWh). For each of the five aggregated EMM regions, and each year, DOE used the ratio of total installed capacity by technology type to total annual generation by fuel type to define capacity factors. The technology types are coal, natural gas combined-cycle (NGCC), oil and gas steam (OGS), combustion turbine-diesel (CTD), nuclear and renewable sources. For NGCC the capacity factor is defined as the ration of NGCC capacity to natural gas generation. For both CTD and OGS DOE defined a *peak* capacity type, with capacity factor equal to the ratio of the sum of CTD plus OGS capacity to oil-fired generation. The AEO projections of nuclear generation and installed capacity are nearly the same for all scenarios, which implies that the installed capacity for nuclear is not affected by small changes in demand; hence DOE assumed a capacity factor of zero for nuclear power in its utility impacts estimates. The result is a set of capacity factors C*(p,r,y)* for each power plant technology type *p*, region *r* and year *y*.

Within each region, DOE calculated the fraction of generation allocated to each fuel type based on AEO projections of generation by EMM region, for the major fuel types: coal, natural gas, nuclear, oil, and renewables. This grid-average calculation shows that approximately 15-20% of generation is allocated to nuclear. As the grid-average calculation is an approximation to the marginal calculation, and all DOE's previous marginal calculations have shown that within NEMS nuclear power is never on the margin, DOE zeroed out the nuclear portion of the generation fraction and redistributed the nuclear share proportionally across the other fuel types. The result is a set of factors *G(r,f,y)* defining the fraction of generation by fuel type for marginal reductions in demand that vary by region and year.

To relate the regional supply-side data to demand-side electricity use by sector and end-use DOE calculated regional weighting factors. These weights define the distribution of electricity consumption for sector/end-use *u* over the five regions *r*. This calculation uses the AEO projection of end-use electricity consumption by census division, and a matrix provided with the NEMS code that cross-tabulates sectoral electricity use by both EMM region and census division. This calculation provides regional weights *w(u,r,y)* .

The regional weights are combined with the supply side generation fuel shares and capacity factors to define impact factors as a function of sector/end-use and year. In equation form,

$$G'(u, f, y) = \sum_r w(u, r, y)\, G(r, f, y),$$

$$C'(u, p, y) = \sum_r w(u, r, y)\, C(r, p, y).$$

Eq. 15A.1

Where:

u = an index representing the sector/end-use (e.g. commercial cooling)
r = the region

y = the analysis year
f = the fuel type
p = the power plant technology type
w(u,r,y) = the regional weight
G(r,f,y) = the fraction of generation provided by fuel type *f* in region *r* and year *y*
G'(u,f,y) = the fraction of generation provided by fuel type *f* for end-use *u* in year y
C(r,f,y) = the capacity factor for plant type *p* in region *r* and year *y*
C'(u,f,y) = the capacity factor for plant type *p* for end-use *u* in year

15A.3 MODEL RESULTS

Representative values of the impact factors for fuel share by fuel type, and capacity by technology type are provided in the tables below. The tables show the factors for two years, 2025 and 2040. The marginal heat rates are presented in appendix 10B and emissions factors are presented in in appendix 13A.

15A.3.1 Electricity Generation

Table 15A.3.1 and Table 15A.3.2 show the distribution across fuel types of a unit reduction in electricity demand by sector and end-use, referred to above as fuel-share weights. The fuel types are coal, natural gas, petroleum, renewables and nuclear. The values for cooling are representative of peaking loads, while the values for refrigeration are representative of flat loads. The data are shown for 2025 and 2040.

Table 15A.3.1. Fuel-Share Weights by Sector and End-Use (Values for 2025)

	Coal	Natural Gas	Nuclear	Oil	Renewables
Commercial Sector					
cooking	43.5%	36.9%	0.0%	0.2%	19.3%
lighting	42.8%	35.7%	0.0%	0.2%	21.2%
office equipment (non-pc)	41.6%	34.7%	0.0%	0.2%	23.5%
office equipment (pc)	42.9%	35.6%	0.0%	0.2%	21.2%
other uses	42.8%	35.5%	0.0%	0.2%	21.5%
refrigeration	43.7%	35.9%	0.0%	0.2%	20.2%
space cooling	42.2%	37.1%	0.0%	0.2%	20.4%
space heating	43.9%	34.3%	0.0%	0.2%	21.6%
ventilation	43.3%	35.9%	0.0%	0.2%	20.6%
water heating	42.9%	36.5%	0.0%	0.2%	20.4%
Industrial Sector					
all uses	43.3%	34.3%	0.0%	0.2%	22.2%
Residential Sector					
ceiling fans	44.5%	35.7%	0.0%	0.2%	19.5%
clothes dryers	42.8%	36.2%	0.0%	0.2%	20.8%
cooking	42.6%	35.9%	0.0%	0.2%	21.3%
electronics	42.2%	35.3%	0.0%	0.2%	22.3%
freezers	43.2%	35.1%	0.0%	0.2%	21.5%
furnace fans	44.8%	34.0%	0.0%	0.2%	20.9%
lighting	41.9%	35.2%	0.0%	0.2%	22.6%
other uses	42.9%	36.2%	0.0%	0.2%	20.6%
refrigeration	42.1%	35.0%	0.0%	0.2%	22.7%
space cooling	42.7%	37.3%	0.0%	0.2%	19.7%
space heating	43.1%	36.4%	0.0%	0.2%	20.3%
water heating	43.4%	37.1%	0.0%	0.2%	19.3%

Table 15A.3.2 Fuel-Share Weights by Sector and End-Use (Values for 2040)

	Coal	Natural Gas	Nuclear	Oil	Renewables
Commercial Sector					
cooking	34.9%	42.9%	0.0%	0.2%	22.1%
lighting	34.6%	41.2%	0.0%	0.2%	24.0%
office equipment (non-pc)	33.8%	39.6%	0.0%	0.2%	26.5%
office equipment (pc)	34.7%	41.1%	0.0%	0.2%	24.0%
other uses	34.7%	41.0%	0.0%	0.2%	24.2%
refrigeration	35.4%	41.7%	0.0%	0.2%	22.7%
space cooling	33.6%	42.8%	0.0%	0.2%	23.5%
space heating	36.3%	39.8%	0.0%	0.2%	23.7%
ventilation	35.0%	41.7%	0.0%	0.2%	23.2%
water heating	34.5%	42.0%	0.0%	0.2%	23.3%
Industrial Sector					
all uses	35.2%	39.7%	0.0%	0.2%	24.9%
Residential Sector					
ceiling fans	36.0%	41.7%	0.0%	0.2%	22.1%
clothes dryers	34.2%	41.7%	0.0%	0.2%	24.0%
cooking	34.2%	41.3%	0.0%	0.2%	24.4%
electronics	34.2%	40.6%	0.0%	0.2%	25.1%
freezers	35.0%	40.5%	0.0%	0.2%	24.3%
furnace fans	37.2%	39.7%	0.0%	0.2%	22.9%
lighting	33.8%	40.3%	0.0%	0.2%	25.7%
other uses	34.6%	41.9%	0.0%	0.2%	23.3%
refrigeration	34.1%	40.1%	0.0%	0.2%	25.6%
space cooling	33.5%	42.7%	0.0%	0.2%	23.6%
space heating	34.7%	42.2%	0.0%	0.2%	22.9%
water heating	34.5%	42.8%	0.0%	0.2%	22.5%

15A.3.2 Installed Capacity

Table 15A.3.3 and Table 15A.3.4 show the total change in installed capacity (GW) per unit of site electricity demand reduction for the five principal capacity types: coal, natural gas, peaking, renewables, and nuclear. The peaking category is the sum of the two NEMS categories oil and gas steam and combustion turbine/diesel. Data are shown for 2025 and 2040.

Table 15A.3.3. Capacity Impact Factors in GW per TWh Reduced Site Electricity Demand (Values for 2025)

	Coal	Natural Gas	Nuclear	Peaking	Renewables
Commercial Sector					
cooking	6.99E-02	8.06E-02	0.00E+00	6.95E-02	6.42E-02
lighting	6.88E-02	7.90E-02	0.00E+00	6.83E-02	6.96E-02
office equipment (non-pc)	6.67E-02	7.79E-02	0.00E+00	6.66E-02	7.64E-02
office equipment (pc)	6.88E-02	7.87E-02	0.00E+00	6.82E-02	6.94E-02
other uses	6.87E-02	7.87E-02	0.00E+00	6.82E-02	7.04E-02
refrigeration	7.02E-02	7.89E-02	0.00E+00	6.91E-02	6.63E-02
space cooling	6.78E-02	8.20E-02	0.00E+00	6.92E-02	6.86E-02
space heating	7.05E-02	7.62E-02	0.00E+00	6.82E-02	7.00E-02
ventilation	6.95E-02	7.91E-02	0.00E+00	6.90E-02	6.76E-02
water heating	6.89E-02	8.03E-02	0.00E+00	6.88E-02	6.76E-02
Industrial Sector					
all uses	6.94E-02	7.68E-02	0.00E+00	6.76E-02	7.28E-02
Residential Sector					
ceiling fans	7.15E-02	7.83E-02	0.00E+00	6.99E-02	6.39E-02
clothes dryers	6.86E-02	7.98E-02	0.00E+00	6.81E-02	6.90E-02
cooking	6.83E-02	7.93E-02	0.00E+00	6.78E-02	7.03E-02
electronics	6.77E-02	7.85E-02	0.00E+00	6.73E-02	7.30E-02
freezers	6.94E-02	7.78E-02	0.00E+00	6.79E-02	7.04E-02
furnace fans	7.20E-02	7.52E-02	0.00E+00	6.93E-02	6.66E-02
lighting	6.73E-02	7.85E-02	0.00E+00	6.70E-02	7.42E-02
other uses	6.89E-02	8.00E-02	0.00E+00	6.83E-02	6.86E-02
refrigeration	6.75E-02	7.81E-02	0.00E+00	6.70E-02	7.42E-02
space cooling	6.85E-02	8.20E-02	0.00E+00	6.92E-02	6.65E-02
space heating	6.90E-02	8.01E-02	0.00E+00	6.84E-02	6.76E-02
water heating	6.96E-02	8.08E-02	0.00E+00	6.90E-02	6.45E-02

Table 15A.3.4 Capacity Impact Factors in GW per TWh Reduced Site Electricity Demand (Values for 2040)

	Coal	Natural Gas	Nuclear	Peaking	Renewables
Commercial Sector					
cooking	5.92E-02	9.06E-02	0.00E+00	5.88E-02	7.89E-02
lighting	5.84E-02	8.82E-02	0.00E+00	5.84E-02	8.41E-02
office equipment (non-pc)	5.67E-02	8.59E-02	0.00E+00	5.74E-02	9.09E-02
office equipment (pc)	5.85E-02	8.79E-02	0.00E+00	5.84E-02	8.34E-02
other uses	5.84E-02	8.79E-02	0.00E+00	5.86E-02	8.42E-02
refrigeration	5.98E-02	8.87E-02	0.00E+00	5.92E-02	7.98E-02
space cooling	5.71E-02	9.16E-02	0.00E+00	5.83E-02	8.46E-02
space heating	6.08E-02	8.55E-02	0.00E+00	5.96E-02	8.16E-02
ventilation	5.91E-02	8.89E-02	0.00E+00	5.90E-02	8.11E-02
water heating	5.84E-02	8.96E-02	0.00E+00	5.84E-02	8.29E-02
Industrial Sector					
all uses	5.92E-02	8.58E-02	0.00E+00	5.86E-02	8.65E-02
Residential Sector					
ceiling fans	6.07E-02	8.87E-02	0.00E+00	6.01E-02	7.69E-02
clothes dryers	5.80E-02	8.89E-02	0.00E+00	5.77E-02	8.52E-02
cooking	5.78E-02	8.83E-02	0.00E+00	5.77E-02	8.61E-02
electronics	5.76E-02	8.73E-02	0.00E+00	5.78E-02	8.71E-02
freezers	5.90E-02	8.69E-02	0.00E+00	5.85E-02	8.49E-02
furnace fans	6.19E-02	8.50E-02	0.00E+00	6.07E-02	7.68E-02
lighting	5.69E-02	8.70E-02	0.00E+00	5.74E-02	8.97E-02
other uses	5.86E-02	8.94E-02	0.00E+00	5.82E-02	8.36E-02
refrigeration	5.75E-02	8.66E-02	0.00E+00	5.77E-02	8.85E-02
space cooling	5.71E-02	9.13E-02	0.00E+00	5.78E-02	8.55E-02
space heating	5.89E-02	8.97E-02	0.00E+00	5.83E-02	8.23E-02
water heating	5.87E-02	9.05E-02	0.00E+00	5.81E-02	8.13E-02

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APPENDIX 17A. REGULATORY IMPACT ANALYSIS: SUPPORTING MATERIALS

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APPENDIX 17A. REGULATORY IMPACT ANALYSIS: SUPPORTING MATERIALS

17A.1 INTRODUCTION

This appendix contains sections discussing the following topics:

- Projections of annual market share increases for the alternative policies;
- NIA-RIA Integrated Model;
- Market penetration curves used to analyze consumer rebates and voluntary energy efficiency targets, including:
  - Background material on XENERGY’s approach,
  - DOE’s adjustment of these curves for this analysis, and
  - The method DOE used to derive interpolated, customized curves;
- Background material on Federal and State tax credits for appliances.

17A.2 MARKET SHARE ANNUAL INCREASES BY POLICY

Table 17A.2.1 shows the annual increases in market shares of portable air conditioners (ACs) meeting the target efficiency level for the selected TSL (TSL 2). DOE used these market share increases as inputs to the NIA-RIA spreadsheet model.

Table 17A.2.1 Annual Increases in Market Shares Attributable to Alternative Policy Measures for Portable Air Conditioners (TSL 2)

Year	Consumer Rebates	Consumer Tax Credits	Manufacturer Tax Credits	Vol Energy Eff Targets	Bulk Govt Purchases
2022	9.1%	5.5%	2.7%	1.5%	0.5%
2023	9.1%	5.5%	2.7%	3.4%	1.0%
2024	9.1%	5.5%	2.7%	12.3%	1.4%
2025	9.1%	5.5%	2.7%	18.6%	1.9%
2026	9.1%	5.5%	2.7%	23.2%	2.4%
2027	9.1%	5.5%	2.7%	27.0%	2.9%
2028	9.1%	5.5%	2.7%	30.3%	3.4%
2029	9.1%	5.5%	2.7%	33.3%	3.9%
2030	9.1%	5.5%	2.7%	36.1%	4.3%
2031	9.1%	5.5%	2.7%	38.7%	4.8%
2032	9.1%	5.5%	2.7%	39.1%	4.8%
2033	9.1%	5.5%	2.7%	39.4%	4.8%
2034	9.1%	5.5%	2.7%	39.8%	4.8%
2035	9.1%	5.5%	2.7%	40.1%	4.8%
2036	9.1%	5.5%	2.7%	40.5%	4.8%
2037	9.1%	5.5%	2.7%	40.9%	4.8%
2038	9.1%	5.5%	2.7%	41.2%	4.8%
2039	9.1%	5.5%	2.7%	41.5%	4.8%
2040	9.1%	5.5%	2.7%	41.9%	4.8%
2041	9.1%	5.5%	2.7%	42.2%	4.8%
2042	9.1%	5.5%	2.7%	42.6%	4.8%
2043	9.1%	5.5%	2.7%	42.9%	4.8%
2044	8.2%	4.9%	2.5%	42.3%	4.8%
2045	6.9%	4.1%	2.1%	41.3%	4.7%
2046	5.6%	3.4%	1.7%	40.4%	4.6%
2047	4.3%	2.6%	1.3%	39.4%	4.5%
2048	3.0%	1.8%	0.9%	38.4%	4.4%
2049	1.7%	1.0%	0.5%	37.4%	4.3%
2050	0.4%	0.2%	0.1%	36.4%	4.2%
2051	0.0%	0.0%	0.0%	35.4%	4.1%

17A.3 NIA-RIA INTEGRATED MODEL

For this analysis, DOE used its integrated NIA-RIA[a] model approach that the Department built on the NIA model discussed in Chapter 10 and documented in Appendix 10-A.The resulting integrated NIA-RIA model features both the NIA and RIA inputs, analyses and results. It has the capability to generate results, by product class and TSL, for the mandatory standards and each of the RIA policies. Separate modules estimate increases in market penetration of more efficient equipment for consumer rebates, voluntary energy efficiency targets and bulk government purchases.[b] The consumer rebates module calculates benefit-cost (B/C) ratios and market barriers, and generates customized market penetration curves for each product class; the voluntary energy efficiency targets module relies on the market barriers calculated in the consumer rebates module to project a reduction in those barriers over the first ten years of the forecast period and estimate the market effects of such a reduction; and the bulk government purchases module scales down the market for portable ACs to housing units in public housing authority. A separate module summarizes the market impacts from mandatory standards and all policy alternatives, and an additional module produces all tables and figures presented in Chapter 17 as well as the table of market share increases for each policy reported in Section 17A.2 of this Appendix.

17A.4 MARKET PENETRATION CURVES

This section first discusses the theoretical basis for the market penetration curves that DOE used to analyze the Consumer Rebates and Voluntary Energy Efficiency Targets policies. Next it discusses the adjustments it made to the maximum penetration rates. It then refers to the method it used to develop interpolated penetration curves for portable ACs that meet the target efficiency level at each TSL. The resulting curve is presented in Chapter 17.

17A.4.1 **Introduction**

XENERGY, Inc.[c], developed a re-parameterized, mixed-source information diffusion model to estimate market impacts induced by financial incentives for purchasing energy efficient appliances.[1] The basic premise of the mixed-source model is that information diffusion drives the adoption of technology.

Extensive economic literature describes the diffusion of new products as technologies evolve. Some research focuses primarily on developing analytical models of diffusion patterns applicable to individual consumers or to technologies from competing firms.[2, 3, 4] One study records researchers' attempts to investigate the factors that drive diffusion processes.[5] Because a new product generally has its own distinct characteristics, few studies have been able to conclusively develop a universally applicable model. Some key findings, however, generally are accepted in academia and industry.

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[a] NIA = National Impact Analysis; RIA = Regulatory Impact Analysis

[b] As mentioned in Chapter 17, the increase in market penetrations for consumer tax credits and manufacturer tax credits are estimated as a fraction of the increase in market penetration of consumer rebates.

[c] XENERGY is now owned by KEMA, Inc. (www.kema.com)

One accepted finding is that, regardless of their economic benefits and technological merits, new technologies are unlikely to be adopted by all potential users. For many products, a ceiling must be placed on the adoption rate. A second conclusion is that not all adopters purchase new products at the same time: some act quickly after a new product is introduced; others wait for the product to mature. Third, diffusion processes can be characterized approximately by asymmetric S-curves that depict three stages of diffusion: starting, accelerating, and decreasing (as the adoption ceiling is approached).

A so-called epidemic model of diffusion is used widely in marketing and social studies. The epidemic model assumes that (1) all consumers place identical value on the benefits of a new product, and (2) the cost of a new product is constant or declines monotonically over time. What induces a consumer to purchase a new product is information about the availability and benefits of the product. In other words, information diffusion drives consumers' adoption of a new product.[3] The model incorporates information diffusion from both internal sources (spread by word of mouth from early adopters to prospective adopters) and external sources (the "announcement effect" produced by government agencies, institutions, or commercial advertising). The model incorporates both internal and external sources by combining a logistic function with an exponential function.[4,5]

The relative degree of influence from the internal and external sources determines the general shape of the diffusion curve for a specific product.[4,5] If adoption of a product is influenced primarily by external sources of information (the announcement effect), for instance, a high rate of diffusion occurs at the beginning of the process. In this scenario, external sources provide immediate information exposure to a significant number of prospective adopters. In contrast, internal sources (such as a network of prospective adopters) are relatively small in size and reach, producing a more gradual exposure to prospective adopters. Graphically speaking, information diffusion dominated by external sources is represented by a concave curve (the exponential curve in Figure 17A.4.1). If adoption of a new product is influenced most strongly by internal sources of information, the number of adopters increases gradually, forming a convex curve (the logistic curve in Figure 17A.4.1).

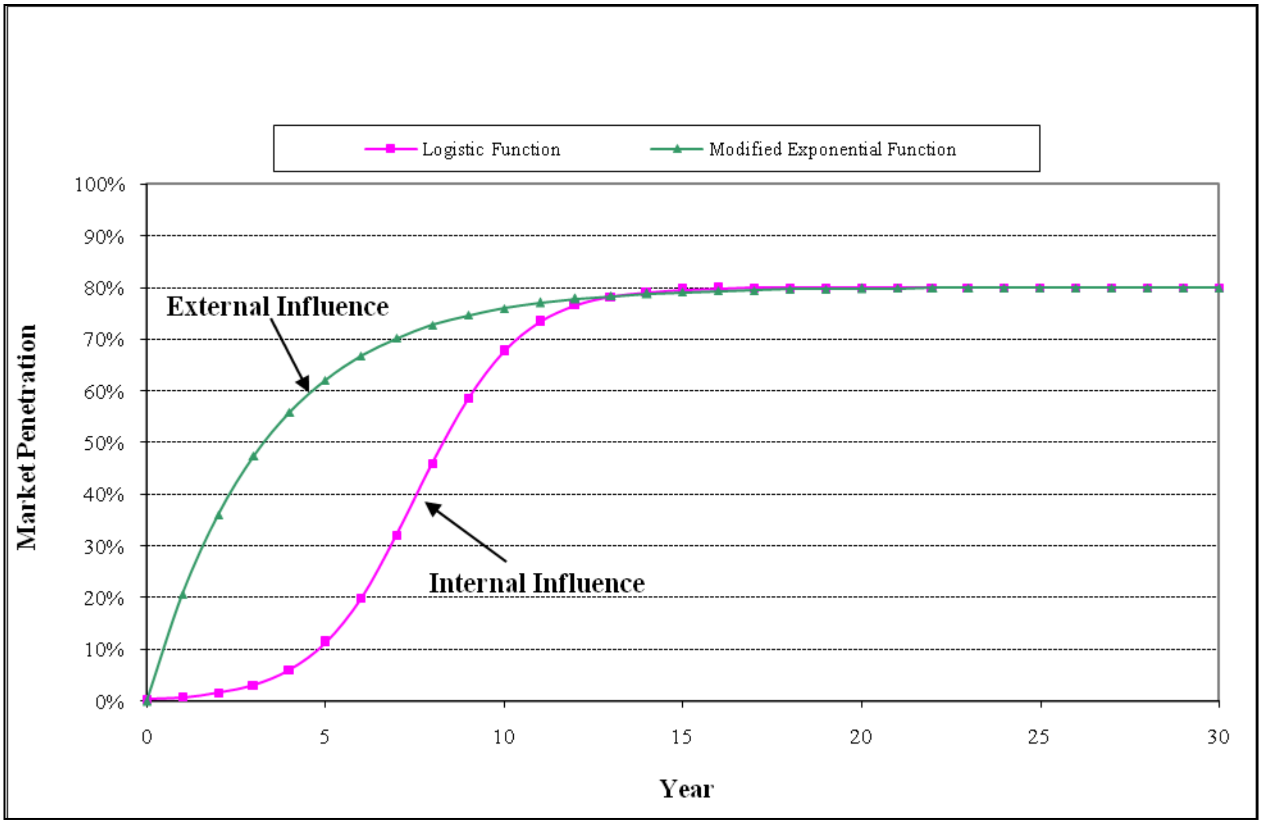

Figure 17A.4.1 S-Curves Showing Effects of External and Internal Sources on Adoption of New Technologies

17A.4.2 **Adjustment of XENERGY Penetration Curves**

In consultation with the primary authors of the 2002 XENERGY study who later conducted similar California studies, DOE made some adjustments to XENERGY's original implementation (penetration) curves.[6] The experiences with utility programs since the XENERGY study indicate that incentive programs have difficulty achieving penetration rates as high as 80 percent. Consumer response is limited by barriers created by consumer utility issues and other non-economic factors. DOE therefore adjusted the maximum penetration parameters for some of the curves from 80 percent to the following levels:

Moderate Barriers:	70%
High Barriers:	60%
Extremely High Barriers:	50%

The *low barriers* and *no barriers* curves (the latter used only when a product has a very high base-case-market share) remained, respectively, with 80 percent and 100 percent as their maximum penetration rates. For the interpolated penetration curves (discussed below), DOE set the *no barriers* and *extremely high barriers* curves as the upper and lower bounds, respectively, for any benefit/cost ratio points higher or lower than the curves. It set another constraint such that the policy case market share cannot be great than 100 percent, as might occur for products with high no-new-standards case market shares of the target-level technology.

17A.4.3 **Interpolation of Penetration Curves**

As discussed above, the XENERGY penetration (implementation) curves followed a functional form to estimate the market implementation rate caused by energy efficiency measures such as consumer rebates.[d] The XENERGY report presents five reference market implementation curves that vary according to the level of market barriers to technology penetration.[1] Such curves have been used by DOE in the Regulatory Impact Analyses for rulemakings for appliance energy efficiency standards to estimate market share increases in response to rebate programs.[e] They provide a framework for evaluating technology penetration, yet require matching the studied market to the curve that best represents it. This approximate matching can introduce some inaccuracy to the analysis.

Blum et al (2011, Appendix A)[7] presents an alternative approach to such evaluation: a method to estimate market implementation rates more accurately by performing interpolations of the reference curves. The referred report describes the market implementation rate function and the reference curves, the method to calibrate the function to a given market, and the limitations of the method.

DOE used the above referred method to interpolate market implementation curves, to generate customized curves that were used to estimate the effects of consumer rebates and voluntary energy efficiency targets for each product class covered by this RIA. For consumer rebates, DOE derived such curves based on an algorithm that finds the market implementation curve that best fits, for the first year of the analysis period, the B/C ratio of the target efficiency level and the market penetration of equipment with that level of energy efficiency in the no-new-standards case. For the analysis of voluntary energy efficiency targets, DOE departs from the market barriers level corresponding to the market implementation curve it derived for consumer rebates, to linearly decrease it over the ten initial years of the analysis period. For each year, as market barriers decline, the corresponding market implementation curve leads – for the same B/C ratio – to higher market penetrations.

17A.5 FEDERAL AND STATE TAX CREDITS

This section summarizes the Federal and State tax credits available to consumers who purchase energy efficient appliances. This section also describes tax credits available to manufacturers who produce certain energy efficient appliances.

17A.5.1 **Federal Tax Credits for Consumers**

EPACT 2005 included Federal tax credits for consumers who installed efficient air conditioners or heat pumps; gas, oil and propane furnaces and boilers; furnace fans; and/or gas,

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[d] The RIA chapter refers to these curves as *penetration curves*. This section, in references to the original source, uses the term *implementation curve*.

[e] DOE has also used this method to estimate market share increases resulting from consumer tax credit and manufacturer tax credit programs, since the effects of tax credits on markets are considered in this RIA proportional to the impacts from rebates.

oil, or electric heat pump water heaters in new or existing homes.[8, 9] These tax credits were in effect in 2006 and 2007, expired in 2008, and were reinstated for 2009–2010 by the American Recovery and Reinvestment Act (ARRA).[10] There was a $1,500 cap on the credit per home, including the amount received for insulation, windows, and air and duct sealing. Congress extended this provision for 2011, with some modifications to eligibility requirements, and reductions in the cap to $500 per home. The American Taxpayer Relief Act of 2012 extended, with some modifications, residential tax credits for air conditioners, heat pumps, furnaces, and water heaters placed in service between January 1, 2012 and December 31, 2013.[8, 11]
The tax credit for furnace fans was $50 in 2011, after which it expired.

The importance of the Federal tax credits has been emphasized in research in the residential heating industry on the impacts of the relatively large credits that were available for HVAC (heating, ventilating, and air conditioning) equipment. In a survey of HVAC distributors conducted by Vermont Energy Investment Corporation, respondents indicated that the ample credit had had a notable impact on sales of higher-efficiency heating and cooling equipment. Some distributors combined the Federal tax credits with manufacturer rebates and utility program rebates for a greater consumer incentive. However, when the amount of the Federal tax credit was reduced, smaller utility rebate incentives had not induced the same levels of equipment sales increases. The decrease in incentive size from a $1,500 cap in 2009-2010 to a $500 cap in 2011, during a period when the economy continued to be sluggish, resulted in a decline in total sales of residential HVAC products. Distributors stated that an incentive needed to cover 25 to 75 percent of the incremental cost of the efficient equipment to influence consumer choice. The industry publication "2011 HVAC Review and Outlook" noted a decline in sales of air conditioning units with >14 SEER in 2011 and a return in sales of units with >16 SEER to 2009 levels (after an increase in 2010). The large majority of distributors observed no impacts from the utility programs with their lower rebate amounts available in 2011. Distributors also commented on the advantages of the Federal tax credit being nationwide in contrast to utility rebate programs that target regional markets.[12, 13]

In an effort to evaluate the potential impact of a Federal appliance tax credit program, DOE reviewed Internal Revenue Service (IRS) data on the numbers of taxpayers who claimed the tax credits during tax years 2006 and 2007. It estimated the percentage of taxpayers who filed Form 5695, *Residential Energy Credits.*[14] It also estimated the percentage of taxpayers with entries under Form 5695's section 3, *Residential energy property costs*, line 3b, *qualified natural gas, propane, or oil furnace or hot water boiler*. DOE reasoned that the percentage of taxpayers with an entry on Line 3b could serve as a rough indication of the potential of taxpayer participation in a Federal tax credit program for furnaces during the initial program years. DOE found that of all residential taxpayers filing tax returns, 0.8 percent in 2006 and 0.6 percent in 2007, claimed a credit for a furnace or boiler. DOE further found that the percentages of those filing Form 5695 for <u>any</u> qualifying energy property expenditure (which also included installation of efficient windows, doors and roofs) were 3.1 and 3.2 percent in 2006 and 2007 respectively.

DOE also reviewed data from an earlier Federal energy conservation tax credit program in place in the 1980s. While this tax credit was available from 1979 through 1985, DOE located data for only the first three years of the program.[15, 16, 17] For those three years - 1979, 1980, and

1981 - the percentages of taxpayers filing Form 5695 were 6.4 percent, 5.2 percent, and 4.9 percent. Given that the data from this earlier tax credit program were not disaggregated by type of energy property, this data series served only to indicate a possible trend of greater participation in the initial program year, followed by slightly smaller participation in subsequent years. However, DOE did not find detailed analysis of this program to indicate the possible reasons for such a trend. Also, this trend varies from the more stable trend shown in the EPAct 2005 energy tax credit program data for its first two program years.

As discussed in Chapter 17, DOE analyzed the percentage of participation in consumer tax credit programs using its estimates of consumer participation in rebate programs that was based on benefit/cost data specific to each product class of portable ACs covered by this RIA. Hence it was difficult to compare these detailed estimates to the more general data analysis described above from the existing Federal tax credit program, or to use the IRS data analysis in its consumer tax credit analysis.

17A.5.2 **Federal Tax Credits for Manufacturers**

EPACT 2005 provided Federal Energy Efficient Appliance Credits to manufacturers that produced high-efficiency refrigerators, clothes washers, and dishwashers in 2006 and 2007.[18] The Emergency Economic Stabilization Act of 2008[19] amended the credits and extended them through 2010. The credits were extended again to 2011 with modifications in the eligibility requirements. Manufacturer tax credits were extended again, by the American Taxpayer Relief Act of 2012, for clothes washers, refrigerators, and dishwashers manufactured between January 1, 2012 and December 31, 2013.

Manufacturers who produce these appliances receive the credits for increasing their production of qualifying appliances. These credits had several efficiency tiers in 2011. For 2012-2013, credits for the higher tiers remain but were eliminated for the lowest (least efficient) tiers for clothes washers and dishwashers.[11] The credit amounts applied to each unit manufactured. The credit to manufacturers of qualifying clothes washers, refrigerators and dishwashers was capped at $75 million for the period of 2008-2010. However, the most efficient refrigerator (30%) and clothes washer (2.2 MEF/4.5 wcf) models was not subject to the cap. The credit to manufacturers was capped at $25 million for 2011, with the most efficient refrigerators (35%) and clothes washers (2.8 MEF/3.5 WCF) exempted from this cap.[20]

17A.5.3 **State Tax Credits**

The States of Oregon and Montana have offered consumer tax credits for efficient appliances for several years, and the States of Kentucky, Michigan and Indiana began offering such credits in 2009. The Oregon Department of Energy (ODOE) has disaggregated data on taxpayer participation in credits for eligible products. (See the discussion in Chapter 17, Section 17.3.3, on tax credit data for clothes washers.) Montana’s Department of Revenue does not disaggregate participation data by appliance, although DOE reviewed Montana's overall participation trends and found them congruent with its analysis of Oregon's clothes washer tax credits.

Oregon's Residential Energy Tax Credit (RETC) was created in 1977. The Oregon legislature expanded the RETC program in 1997 to include residential refrigerators, clothes washers, and dishwashers, which significantly increased participation in the program. The program subsequently added credits for high-efficiency heat pump systems, air conditioners, and water heaters (2001); furnaces and boilers (2002); and duct/air sealing, fuel cells, heat recovery, and renewable energy equipment. Beginning in 2012 a Tax Credit Extension Bill (HB3672) eliminated refrigerators, clothes washers, dishwashers, air conditioners, and boilers from the RETC program, leaving credits for water heaters, furnaces, heat pumps, tankless water heaters, and heat pump water heaters.[21, 22] Those technologies recognized by the Oregon Department of Energy as "premium efficiency" are eligible for tax credit of $0.60 per kWh saved in the first year (up to $1,500).[21, 23]

Montana has had an Energy Conservation Tax Credit for residential measures since 1998.[24] The tax credit covers various residential energy and water efficient products, including split system central air conditioning; package system central air conditioning; split system air source heat pumps; package system heat pumps; natural gas, propane, or oil furnaces; hot water boilers; advanced main air circulating fans; heat recovery ventilators; gas, oil, or propane water heaters; electric heat pump water heaters; low-flow showerheads and faucets; light fixtures; and controls. In 2002 the amount of the credit was increased from 5 percent of product costs (up to $150) to 25 percent (up to $500) per taxpayer. The credit can be used for products installed in new construction or remodeling projects. The tax credit covers only that part of the cost and materials that exceed established standards of construction.

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