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

## RESIDENTIAL DISHWASHERS

**December 2014**

**U.S. Department of Energy**
Assistant Secretary
Office of Energy Efficiency and Renewable Energy
Building Technologies Program
Appliances and Commercial Equipment Standards
Washington, DC 20585

This Document was prepared for the Department of Energy
by staff members of
Navigant Consulting, Inc.
and
Ernest Orlando Lawrence Berkeley National Laboratory

# CHAPTER 1. INTRODUCTION

## TABLE OF CONTENTS

## LIST OF TABLES

# 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 notice of proposed rulemaking (NOPR) for residential dishwashers.

## 1.2 SUMMARY OF NATIONAL BENEFITS

DOE's analyses indicate that the proposed standards would save a significant amount of energy. The lifetime savings for residential dishwashers purchased in the 30-year period that begins in the year of compliance with amended standards (2019–2048) amount to 1.06 quadrillion Btu (quads)[a] and 0.24 trillion gallons of water. The annual energy savings in 2030 are equivalent to 0.17 percent of total U.S. residential energy use in 2013.

The cumulative net present value (NPV) of total consumer costs and savings of the proposed standards for residential dishwashers ranges from $0.23 billion (at a 7-percent discount rate) to $ 2.14 billion (at a 3-percent discount rate). This NPV expresses the estimated total value of future operating-cost savings minus the estimated increased product costs for products purchased in 2019–2048.

In addition, the proposed standards would have significant environmental benefits. The energy savings would result in cumulative emission reductions of 61.9 million metric tons (Mt)[b] of carbon dioxide ($CO_2$), 345.1 thousand tons of methane, 42.9 thousand tons of sulfur dioxide ($SO_2$), 126.7 thousand tons of nitrogen oxides ($NO_X$), 0.7 thousand tons of nitrous oxide ($N_2O$), and 0.1 tons of mercury (Hg).[c] The cumulative reduction in $CO_2$ emissions through 2030 amounts to 14.6 Mt.

The value of the $CO_2$ reductions is calculated using a range of values per metric ton of $CO_2$ (otherwise known as the Social Cost of Carbon, or SCC) developed by a recent Federal interagency process.[d] The derivation of the SCC values is discussed in section IV.L of this

---

[a] A quad is equal to $10^{15}$ British thermal units (Btu).

[b] A metric ton is equivalent to 1.1 short tons. Results for emissions other than $CO_2$ are presented in short tons.

[c] DOE calculated emissions reductions relative to the Annual Energy Outlook 2014 (AEO 2014) Reference case, which generally represents current legislation and environmental regulations for which implementing regulations were available as of October 31, 2013.

[d] 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 November 2013. http://www.whitehouse.gov/sites/default/files/omb/assets/inforeg/technical-update-social-cost-of-carbon-for-regulator-impact-analysis.pdf.

notice. Using discount rates appropriate for each set of SCC values, DOE estimates the present monetary value of the $CO_2$ emissions reduction is between \$0.4 billion and \$6.1 billion. DOE also estimates the present monetary value of the $NO_X$ emissions reduction is \$0.08 billion at a 7-percent discount rate and \$0.17 billion at a 3-percent discount rate.[e]

Table 1.2.1 summarizes the national economic costs and benefits expected to result from the proposed standards for residential dishwashers.

---

[e] DOE is currently investigating valuation of avoided Hg and $SO_2$ emissions.

**Table 1.2.1 Summary of National Economic Benefits and Costs of Proposed Energy Conservation Standards for Residential Dishwashers***

| Category | Present Value Billion 2013$ | Discount Rate |
|---|---|---|
| **Benefits** | | |
| Operating Cost Savings | 4.1 | 7% |
| | 9.2 | 3% |
| $CO_2$ Reduction Monetized Value ($11.8/t case)** | 0.4 | 5% |
| $CO_2$ Reduction Monetized Value ($39.7/t case)** | 2.0 | 3% |
| $CO_2$ Reduction Monetized Value ($61.2/t case)** | 3.1 | 2.5% |
| $CO_2$ Reduction Monetized Value ($117/t case)** | 6.1 | 3% |
| $NO_X$ Reduction Monetized Value (at $2,684/ton) | 0.1 | 7% |
| | 0.2 | 3% |
| Total Benefits† | 6.2 | 7% |
| | 11.4 | 3% |
| **Costs** | | |
| Incremental Installed Costs | 3.9 | 7% |
| | 7.1 | 3% |
| **Total Net Benefits** | | |
| Including Emissions Reduction Monetized Value† | 2.3 | 7% |
| | 4.3 | 3% |

* This table presents the costs and benefits associated with residential dishwashers shipped in 2019−2048. These results include benefits to consumers which accrue after 2048 from the products purchased in 2019−2048. The results account for the incremental variable and fixed costs incurred by manufacturers due to the standard, some of which may be incurred in preparation for the rule.

** The $CO_2$ values represent global monetized values of the SCC, in 2013$, in 2015 under several scenarios of the updated SCC values. The first three cases use the averages of SCC distributions calculated using 5%, 3%, and 2.5% discount rates, respectively. The fourth case represents the 95th percentile of the SCC distribution calculated using a 3% discount rate. The SCC time series used by DOE incorporate an escalation factor.

† Total Benefits for both the 3% and 7% cases are derived using the series corresponding to average SCC with 3-percent discount rate.

The benefits and costs of today's proposed standards, for products sold in 2019–2048, can also be expressed in terms of annualized values. The annualized monetary values are the sum of (1) the annualized national economic value of the benefits from consumer operation of products that meet the new or amended standards (consisting primarily of operating cost savings from using less energy, minus increases in equipment purchase and installation costs, which is another way of representing consumer NPV), and (2) the annualized monetary value of the benefits of emission reductions, including $CO_2$ emission reductions.[f]

Although combining the values of operating savings and $CO_2$ emission reductions provides a useful perspective, two issues should be considered. First, the national operating savings are domestic U.S. consumer monetary savings that occur as a result of market transactions, whereas the value of $CO_2$ reductions is based on a global value. Second, the assessments of operating cost savings and $CO_2$ savings are performed with different methods that use different time frames for analysis. The national operating cost savings is measured for the lifetime of residential dishwashers shipped in 2019-2048. The SCC values, on the other hand, reflect the present value of some future climate-related impacts resulting from the emission of one ton of carbon dioxide in each year. These impacts continue well beyond 2100.

Estimates of annualized benefits and costs of the proposed standards are shown in Table I.2.2. The results under the primary estimate are as follows. Using a 7-percent discount rate for benefits and costs other than $CO_2$ reduction, for which DOE used a 3-percent discount rate along with the average SCC series that has a value of $40.5/t in 2015, the cost of the standards proposed in today's rule is $413million per year in increased equipment costs, while the benefits are $437 million per year in reduced equipment operating costs, $113 million in $CO_2$ reductions, and $8.37 million in reduced $NO_X$ emissions. In this case, the net benefit amounts to $146 million per year. Using a 3-percent discount rate for all benefits and costs and the average SCC series that has a value of $40.5/t in 2015, the cost of the standards proposed in today's rule is $406 million per year in increased equipment costs, while the benefits are $529 million per year in reduced operating costs, $113 million in $CO_2$ reductions, and $9.95 million in reduced $NO_X$ emissions. In this case, the net benefit amounts to $246 million per year.

---

[f] To convert the time-series of costs and benefits into annualized values, DOE calculated a present value in 2014, the year used for discounting the NPV of total consumer costs and savings. For the benefits, DOE calculated a present value associated with each year's shipments in the year in which the shipments occur (i.e., 2020, 2030, etc.), and then discounted the present value from each year to 2014. The calculation uses discount rates of 3 and 7 percent for all costs and benefits except for the value of $CO_2$ reductions, for which DOE used case-specific discount rates, as shown in Table I.2. Using the present value, DOE then calculated the fixed annual payment over a 30-year period, starting in the compliance year, that yields the same present value.

**Table 1.2.2 Annualized Benefits and Costs of Proposed Energy Conservation Standards for Residential Dishwashers**

| | Discount Rate | Primary Estimate* | Low Net Benefits Estimate* | High Net Benefits Estimate* |
|---|---|---|---|---|
| | | **million 2013$/year** | | |
| **Benefits** | | | | |
| Operating Cost Savings | 7% | 437 | 388 | 506 |
| | 3% | 529 | 462 | 624 |
| $CO_2$ Reduction Monetized Value ($11.8/t case)* | 5% | 34 | 30 | 39 |
| $CO_2$ Reduction Monetized Value ($39.7/t case)* | 3% | 113 | 100 | 131 |
| $CO_2$ Reduction Monetized Value ($61.2/t case)* | 2.5% | 165 | 146 | 191 |
| $CO_2$ Reduction Monetized Value ($117/t case)* | 3% | 351 | 311 | 406 |
| $NO_X$ Reduction Monetized Value (at $2,684/ton) | 7% | 8.37 | 7.53 | 9.49 |
| | 3% | 9.95 | 8.86 | 11.43 |
| Total Benefits† | 7% plus $CO_2$ range | 479 to 796 | 425 to 706 | 555 to 921 |
| | 7% | 558 | 496 | 647 |
| | 3% plus $CO_2$ range | 572 to 890 | 501 to 782 | 674 to 1,041 |
| | 3% | 652 | 572 | 766 |
| **Costs** | | | | |
| Consumer Incremental Product Costs | 7% | 413 | 468 | 371 |
| | 3% | 406 | 465 | 361 |
| **Net Benefits** | | | | |
| Total† | 7% plus $CO_2$ range | 66 to 383 | -43 to 238 | 183 to 550 |
| | 7% | 146 | 28 | 275 |
| | 3% plus $CO_2$ range | 167 to 484 | 36 to 317 | 313 to 680 |
| | 3% | 246 | 106 | 405 |

* This table presents the annualized costs and benefits associated with residential dishwashers shipped in 2019−2048. These results include benefits to consumers which accrue after 2048 from the products purchased in 2019−2048. The results account for the incremental variable and fixed costs incurred by manufacturers due to the standard, some of which may be incurred in preparation for the rule. The Primary, Low Benefits, and High Benefits Estimates utilize projections of energy prices from the AEO 2014 Reference case, Low Estimate, and High Estimate, respectively. In addition, incremental product costs reflect a medium decline rate for projected product prices in the Primary Estimate, a low decline rate for projected product prices in the Low Benefits Estimate, and a high decline rate for projected product prices in the High Benefits Estimate.

** The $CO_2$ values represent global monetized values of the SCC, in 2013$, in 2015 under several scenarios of the updated SCC values. The first three cases use the averages of SCC distributions calculated using 5%, 3%, and 2.5% discount rates, respectively. The fourth case represents the 95th percentile of the SCC distribution calculated using a 3% discount rate. The SCC time series used by DOE incorporate an escalation factor.

† Total Benefits for both the 3% and 7% cases are derived using the series corresponding to the average SCC with 3-percent discount rate. In the rows labeled "7% plus $CO_2$ range" and "3% plus $CO_2$ range," the operating cost and $NO_X$ benefits are calculated using the labeled discount rate, and those values are added to the full range of $CO_2$ values.

## 1.3 OVERVIEW OF STANDARDS FOR RESIDENTIAL DISHWASHERS

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. The National Energy Conservation Policy Act of 1978 (NECPA), Pub. L. 95-619, amended EPCA to add Part C[g] of Title III (42 U.S.C. 6311–6317), which established an energy conservation program for certain industrial equipment. Additional amendments to EPCA give DOE the authority to regulate the energy efficiency of several products, including residential dishwashers—the products that are the focus of this document. The amendments to EPCA in the National Appliance Energy Conservation Act of 1987 (NAECA), Pub. L. 100-12, established standards for residential dishwashers, as well as requirements for determining whether these standards should be amended. (42 U.S.C. 6295(g))

NAECA established the first prescriptive standards for residential dishwashers, requiring that dishwashers be equipped with an option to dry without heat, and further required that DOE conduct two cycles of rulemakings to determine if more stringent standards are justified.[h] (42 U.S.C. 6295 (g)(1) and (4)) On May 14, 1991, DOE published a final rule in the *Federal Register* (FR) establishing the first set of performance standards for residential dishwashers; the compliance date of the new standards was May 14, 1994. 56 FR 22250. DOE initiated a second standards rulemaking for residential dishwashers, publishing an advance notice of proposed rulemaking (ANOPR) on November 14, 1994, to consider amending the energy conservation standards for clothes washers, dishwashers, and clothes dryers. 59 FR 56423. However, as a

---

[g] Part C has been redesignated Part A-1 in the United States Code for editorial reasons.

[h] DOE defines "dishwasher" under EPCA as "a cabinet-like appliance which with the aid of water and detergent, washes, rinses, and dries (when a drying process is included) dishware, glassware, eating utensils, and most cooking utensils by chemical, mechanical and/or electrical means and discharges to the plumbing drainage system." 10 CFR 430.2.

result of the priority-setting process outlined in its *Procedures for Consideration of New or Revised Energy Conservation Standards for Consumer Products* (the "Process Rule") (61 FR 36974 (July 15, 1996); 10 CFR part 430, subpart C, appendix A), DOE suspended the standards rulemaking for dishwashers.

To complete the second rulemaking cycle required by NAECA, on March 15, 2006, DOE published on its website the *Rulemaking Framework for Commercial Clothes Washers and Residential Dishwashers, Dehumidifiers, and Cooking Products*, and a notice announcing the availability of this framework document. On November 15, 2007, DOE published an ANOPR addressing energy conservation standards for these products. 72 FR 64432. On December 19, 2007, however, Congress enacted the Energy Independence and Security Act of 2007 (EISA 2007), Pub. L. 110-140, which, among other things, established maximum energy and water use levels for residential dishwashers manufactured on or after January 1, 2010. (42 U.S.C. 6295(g)(10)) Because EISA 2007 established standards for residential dishwashers, DOE codified the statutory standards for these products in a final rule published March 23, 2009. 74 FR 12058.

The current energy conservation standards for residential dishwashers were submitted to DOE by groups representing manufacturers, energy and environmental advocates, and consumer groups. This collective set of comments, titled "Agreement on Minimum Federal Efficiency Standards, Smart Appliances, Federal Incentives and Related Matters for Specified Appliances" (the "Joint Petition"[i]), recommended specific energy conservation standards for residential dishwashers that, in the commenters' view, would satisfy the EPCA requirements in 42 U.S.C. 6295(o). DOE conducted its rulemaking analyses on multiple residential dishwasher efficiency levels, including those suggested in the Joint Petition. In a direct final rule published on May 30, 2012, DOE established energy conservation standards for residential dishwashers manufactured on or after May 30, 2013, consistent with the levels suggested in the Joint Petition. 77 FR 31918.

## 1.4 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;

---

[i] DOE Docket No. EERE–2011–BT–STD–0060, Comment 1.

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) and 42 U.S.C. 6316(e).

DOE considers interested party 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 interested parties during the comment period in each stage of the rulemaking. Throughout the entire duration of the rulemaking process, interactions among interested parties 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. Any new or amended standard must be designed to achieve significant additional conservation of energy and be technologically feasible and economically justified. 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.

The energy conservation standards rulemaking process involves two formal public notices, which DOE publishes in the *Federal Register*. The first notice is the NOPR, which presents the analyses of the impacts of potential amended energy conservation standards on consumers, manufacturers, and the Nation; DOE's weighting of these impacts of amended energy conservation standards; and the proposed energy conservation standards for the equipment. The second 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 amended energy conservation standards DOE is adopting for each product; and the effective dates of the amended energy conservation standards.

**Table 1.4.1 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 | |

* In the current rulemaking, DOE conducted the analyses listed under Preliminary Analyses as part of the NOPR analysis.

DOE developed spreadsheets for the engineering, Life-Cycle Cost (LCC) Payback Period (PBP), and national impact analyses for each product. The LCC spreadsheet calculates the LCC and PBP at various energy efficiency levels. The national impact analysis spreadsheet calculates the national energy savings and national net present values at various energy efficiency levels. This spreadsheet includes a model that forecasts the impacts of amended energy conservation standards at various levels on product shipments. All of these spreadsheets are available on the DOE website for residential dishwashers at: http://www1.eere.energy.gov/buildings/appliance_standards/product.aspx/productid/67.

DOE can also provide quantitative outputs from its analyses in machine-readable format upon request. For example, outputs from trial runs of the LCC Monte Carlo simulations can be provided in such a format.

## 1.5 STRUCTURE OF THE DOCUMENT

This TSD outlines the analytical approaches used in this rulemaking. The TSD consists of the following chapters and 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 price and increased efficiency. |
| Chapter 6 | Markups for Equipment Price Determination: discusses the methods used for establishing markups for converting manufacturer prices to customer product costs. |
| Chapter 7 | Energy and Water Use Analysis: discusses the process used for generating energy and water 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 higher 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 three pollutants—sulfur dioxide ($SO_2$), nitrogen oxides ($NO_x$), and mercury—as well as carbon dioxide emissions. |
| Chapter 14 | Monetization of Emission Reductions Benefits. |

| | |
|---|---|
| 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 8-A | User Instructions for Life-Cycle Cost and Payback Period Spreadsheets |
| Appendix 8-B | Uncertainty and Variability |
| Appendix 8-C | Estimating Product Price Trends for Residential Dishwashers |
| Appendix 8-D | Lifetime Distributions |
| Appendix 8-E | Distributions Used for Discount Rates |
| Appendix 9-A | Relative Price Elasticity of Demand for Appliances |
| Appendix 10-A | User Instructions for Shipments and National Impact Analysis Spreadsheets |
| Appendix 10-B | Full-Fuel-Cycle Multipliers |
| Appendix 10-C | National Net Present Value of Consumer Benefits Using Alternative Product Price Forecasts |
| Appendix 10-D | National Impacts Analysis Using Alternative Economic Growth Scenarios |
| Appendix 12-A | Manufacturer Impact Analysis Interview Guide |
| Appendix 12-B | Government Regulatory Impact Model |
| Appendix 14-A | Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866 |
| Appendix 14-B | Technical Update of Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866 |
| Appendix 17-A | Regulatory Impact Analysis: Supporting Materials |

# CHAPTER 2. ANALYTICAL FRAMEWORK

## TABLE OF CONTENTS

## LIST OF FIGURES

# 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 set forth 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, amended energy conservation standards for residential dishwashers. 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.

Figure 2.1.1 summarizes the analytical components of the standards-setting process. The focus of this figure is the center column, identified as “Analyses.” The columns labeled “Key Inputs” and “Key Outputs” show how the analyses fit into the rulemaking process, and how the analyses relate to each other. Key inputs are the types of data and information that the analyses require. Some key inputs exist in public databases; DOE collects other inputs from interested parties or other knowledgeable experts within the field. Key outputs are analytical results that feed directly into the standards-setting process. Arrows connecting analyses show types of information that feed from one analysis to another.

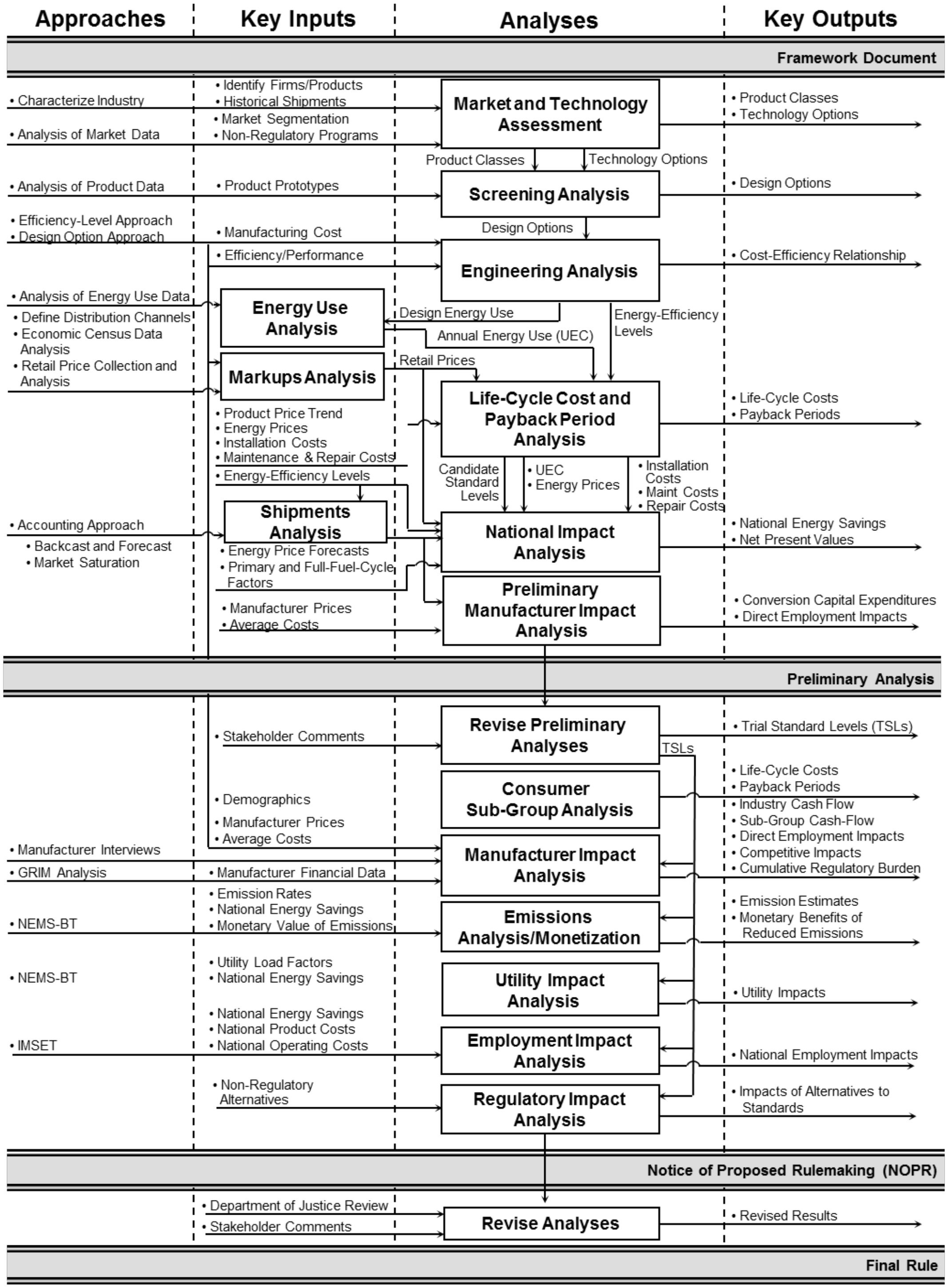


**Figure 2.1 Flow Diagram of Analyses for the Rulemaking Process[a]**

---

[a] Note: This rulemaking bypassed the framework and preliminary analysis stages and went straight to the NOPR analysis stage.

The analyses performed for this notice of proposed rulemaking (NOPR) and reported in this technical support document (TSD) are listed below.

- A market and technology assessment to characterize the relevant product markets and existing technology options, including prototype designs.
- A screening analysis to review each technology option to decide whether 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, which indicate the manufacturer's cost of achieving increased efficiency.
- A markups analysis to develop distribution channel markups that relate 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 in a representative set 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 covered 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 are then 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 potential 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 customer characteristics that might cause a standard to disproportionately affect particular customer 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 analysis to assess the impacts of amended energy conservation standards on the environment.
- An emissions monetization to assess the benefits associated with emissions reductions.

- A utility impact analysis to estimate the effects of potential standards on electric, gas, or oil utilities.

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

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

## 2.2 MARKET AND TECHNOLOGY ASSESSMENT

The market and technology assessment characterizes the relevant product markets and existing technology options, including 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 assesses the industry and products both quantitatively and qualitatively based on publicly available information and encompasses the following: (1) manufacturer market share and characteristics, (2) existing regulatory and non-regulatory efficiency improvement initiatives, and (3) trends in product characteristics and retail markets. This information serves as resource material throughout the rulemaking.

The subjects addressed in the market assessment for residential dishwashers included 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 residential dishwasher manufacturers. DOE also examined publicly available data from the key trade association for this product category, the Association of Home Appliance Manufacturers (AHAM). DOE reviewed shipment data collected by AHAM and *Appliance* magazine to evaluate annual shipment trends. Finally, DOE reviewed other energy efficiency programs from utilities, individual States, and other organizations. Chapter 3 of the NOPR TSD provides additional details on the market and technology assessment.

### 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 residential dishwashers from trade publications and technical papers, and a review of the TSD published in support of the direct final rule published on May 30, 2012 (May 2012 direct final rule). 77 FR 31918. Because many options for improving product efficiency are available in existing units, product literature and direct examination provided additional information.

Chapter 3 of the NOPR TSD includes the detailed list of all technology options identified for residential dishwashers.

## 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 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 the NOPR TSD contains details on the screening analysis for residential dishwashers.

## 2.4 ENGINEERING ANALYSIS

The engineering analysis (chapter 5 of the NOPR TSD) establishes the relationship between the MPC and the efficiency for each class of residential dishwashers. This relationship serves as the basis for cost/benefit calculations in terms of individual consumers, manufacturers, and the nation. The engineering analysis 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, 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 hybrid approach of all three methods in developing cost estimates at each efficiency level for residential dishwashers, focusing on the design-option and reverse-engineering approaches. This approach involved physically disassembling commercially available products, reviewing publicly available cost and performance information, and modeling equipment cost. From this information, DOE estimated the MPC for a range of products currently available on the market. DOE then considered the incremental steps manufacturers may take to reach efficiency level. In its modeling, DOE started with the baseline MPC and added the expected design options at each higher efficiency level to estimate incremental MPCs. By doing this, the engineering analysis did not factor in the additional higher-cost features with no impact on efficiency that are included in some models. However, at efficiency levels where the product designs significantly deviated from the baseline product, DOE used the efficiency-level approach to determine an MPC estimate, while removing the costs associated with non-efficiency-related components or features. Chapter 5 of the NOPR TSD describes the methodology and results of the analysis used to derive the cost-efficiency relationships.

## 2.5 MARKUPS ANALYSIS

DOE performed a markups analysis to convert the manufacturer costs estimated in the engineering analysis to consumer prices, which then were used in the LCC and PBP and manufacturer impact analyses. DOE calculated markups for baseline products (baseline markups) and for more efficient products (incremental markups). The 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 consumer. After establishing appropriate distribution channels, DOE relied on economic data from the U.S. Census Bureau and other sources to determine how prices are marked up as the products pass from the manufacturer to the consumer. Chapter 6 of the NOPR TSD provides details on DOE’s development of markups for residential dishwashers.

## 2.6 ENERGY AND WATER USE ANALYSIS

DOE performed an energy and water use analysis to assess the energy and water savings potential from higher efficiency levels, providing the basis for the energy and water savings values used in the LCC and subsequent analyses. The goal of the energy and water use characterization is to generate a range of energy and water use values that reflects actual product use in American homes. Chapter 7 of the NOPR TSD provides more detail about DOE’s approach for characterizing energy and water use of residential dishwashers.

DOE determined a range of annual energy and per-cycle water consumption of dishwashers by multiplying the per-cycle energy use and per-cycle water use of each considered design by the number of cycles per year in a representative sample of U.S. households.

DOE estimated the per-cycle energy use by subtracting the annual energy use associated with standby power from the total annual energy use and dividing the result by the national average number of dishwasher cycles per year. DOE used data provided by AHAM for the 2012 Direct Final Rule data submission on the total annual dishwasher energy use and the standby power use for each considered efficiency level. DOE analyzed per-cycle energy consumption based on two components: (1) water-heating energy, and (2) machine (motor) and drying energy.

To estimate the number of cycles per year in a representative sample of U.S. households, DOE analyzed data from the Energy Information Administration (EIA)'s 2009 *Residential Energy Consumption Survey* (*RECS*), which was the most recent such survey available at the time of DOE's analysis. RECS reported dishwasher use at 174 cycles per year for U.S. households. DOE also analyzed a review of survey data to estimate the number of cycles per year. This data was also used to develop the 2003 dishwasher amendments, which included a reduction in the average use cycles per year, from 264 to 215 cycles per year. Because the survey is more comprehensive than the *RECS* data, DOE chose an average usage of 215 cycles per year as the most representative value for average dishwasher use. To estimate the annual number of cycles for each *RECS* household in the dishwasher sample, DOE multiplied the assigned specific numerical value by the ratio of 215 cycles to 174 cycles.

## 2.7 LIFE-CYCLE COST AND PAYBACK PERIOD ANALSYIS

In determining whether an energy efficiency standard is economically justified, DOE considers the economic impact of potential standards on consumers. The effect of new or amended standards on individual consumers usually includes a reduction in operating cost and an increase in purchase cost. DOE used the following two metrics to measure consumer impacts:

- LCC (life-cycle cost) is the total consumer cost of an appliance or product, generally over the life of the appliance or product. The LCC calculation includes total installed cost (equipment manufacturer selling price, distribution chain markups, sales tax, and installation costs), operating costs (energy, repair, and maintenance costs), equipment lifetime, and discount rate. Future operating costs are discounted to the time of purchase and summed over the lifetime of the appliance or product.
- PBP (payback period) measures the amount of time it takes consumers to recover the assumed higher purchase price of a more energy-efficient product through reduced operating costs. Inputs to the payback period calculation include the installed cost to the consumer and first-year operating costs.

DOE analyzed the net effect of potential amended dishwasher standards on consumers by determining the LCC and PBP using the engineering performance data, the energy and water use data, and the markups. Inputs to the LCC calculation include the installed cost to the consumer (purchase price plus installation cost), operating expenses (energy and water expenses, repair costs, and maintenance costs), the lifetime of the product, and a discount rate. Inputs to the payback period calculation include the installed cost to the consumer and first-year operating costs.

DOE generated LCC and PBP results as probability distributions using a simulation approach based on Monte Carlo analysis methods, in which certain key inputs to the analysis consist of probability distributions rather than single-point values. Therefore, the outcomes of the Monte Carlo analysis can also be expressed as probability distributions. As a result, the analysis produces a range of LCC and PBP results which allows DOE to identify the fraction of customers achieving LCC savings or incurring net cost at the considered efficiency levels.

Chapter 8 of the NOPR TSD describes the results from the LCC and PBP analyses.

## 2.8 SHIPMENTS ANALYSIS

Forecasts of product shipments are needed to calculate the national impacts of standards on energy use, NPV, and future manufacturer cash flows. DOE developed shipment forecasts based on an analysis of key market drivers for residential dishwashers. In DOE’s shipments model, shipments of products are driven by new construction, stock replacements, and other types of purchases.

The shipments models take an accounting approach, tracking market shares of each product class and the vintage of units in the existing stock. Stock accounting uses product shipments as inputs to estimate 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 operating costs for any year depend on the age distribution of the stock.

DOE also considers the impacts on shipments from changes in product purchase price and operating cost associated with higher energy efficiency levels. Chapter 9 of the NOPR TSD provides additional details on the shipments analysis.

## 2.9 NATIONAL IMPACT ANALYSIS

The national impact analysis (NIA) assesses the net present value (NPV), to the nation, of total consumer life-cycle cost (LCC) and net energy savings (NES). DOE determined both the NPV and NES for the efficiency levels considered for the product classes analyzed. To make the analysis more accessible and transparent to all interested parties, DOE prepared a Microsoft Excel spreadsheet model to forecast NES and the national consumer economic costs and savings resulting from 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 may conduct sensitivity analyses by running scenarios on specific input variables. Chapter 10 of the NOPR TSD provides additional details regarding the national impact analysis.

Several of the inputs for determining NES and NPV depend on the forecast trends in product energy efficiency. For the base case, DOE uses the efficiency distributions developed for the LCC analysis, and assumes some rate of change over the forecast period. In this analysis, DOE has used a roll-up scenario in developing its forecasts of efficiency trends after standards take effect. Under a roll-up scenario, all products that perform at levels below a prospective standard are moved, or rolled-up, to the minimum performance level allowed under the standard. Product efficiencies above the standard level under consideration would remain the same as before the revised standard takes effect.

### 2.9.1 National Energy and Water Savings

The inputs for determining the national energy and water savings for each product class are: (1) annual energy and water consumption per unit, (2) shipments, (3) product stock, (4) national energy and water consumption, and (5) site-to-source conversion factors for energy. DOE calculated national energy and water consumption by multiplying the number of units, or stock, of each product class (by vintage, or age) by the unit energy and water consumption (also by vintage). DOE calculated annual NES based on the difference in national energy and water consumption for the base case (without new efficiency standards) and for each efficiency standard being considered. DOE estimated energy consumption and savings based on site energy consumption, which it then converted to source energy. DOE estimated water consumption and savings based on site water use. DOE did not use a conversion factor for water because no such factor has been developed. Cumulative energy and water savings are the sum of the NES for each year.

### 2.9.2 Net Present Value of Consumer Benefit

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 base 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 base 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 base 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 base 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.

## 2.10 CONSUMER SUBGROUP ANALYSIS

The consumer subgroup analysis evaluates economic impacts on selected groups of consumers who might be adversely affected by a change in the national energy conservation standards for the considered products. DOE evaluates impacts on particular subgroups of consumers primarily by analyzing the LCC impacts and PBP for those particular consumers using the LCC spreadsheet model.

For this rulemaking, DOE analyzed as subgroups: (1) low-income households; and (2) households solely occupied by senior citizens. Chapter 11 of NOPR TSD describes the consumer subgroup analysis.

## 2.11 MANUFACTURER IMPACT ANALYSIS

The manufacturer impact analysis (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 conducts the MIA in three phases, and will tailor the analytical framework based on interested parties' comments. In Phase I, DOE created a dishwasher manufacturing industry profile and analyzed publicly available financial information to derive preliminary inputs for the GRIM. In Phase II, DOE prepared an industry cash flow model. In Phase III, industry and subgroup cash flow and NPV were assessed through the use of the Government Regulatory Impact Model (GRIM). Then, DOE assessed impacts on competition, manufacturing capacity, employment, and cumulative regulatory burden. DOE discusses its findings from the MIA in chapter 12 of the NOPR TSD.

## 2.12 EMISSIONS IMPACT ANALYSIS

In the emissions analysis, DOE estimated the reduction in power sector emissions of carbon dioxide ($CO_2$), nitrogen oxides ($NO_X$), sulfur dioxide ($SO_2$) and mercury (Hg) from potential energy conservation standards for the considered products. In addition, DOE estimated emissions impacts in production activities (extracting, processing, and transporting fuels) that provide the energy inputs to power plants. These 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 FFC analysis includes impacts on emissions of methane and nitrous oxide, both of which are recognized as greenhouse gases.

DOE primarily conducted the emissions analysis using emissions factors for $CO_2$ and most of the other gases derived from data in the latest version of EIA's *Annual Energy Outlook (AEO)*. Combustion emissions of $CH_4$ and $N_2O$ were estimated using emissions intensity factors published by the Environmental Protection Agency (EPA), GHG Emissions Factors Hub.[b]

EIA prepares the *Annual Energy Outlook* using the National Energy Modeling System (NEMS). Each annual version of NEMS incorporates the projected impacts of existing air quality regulations on emissions. The text below refers to *AEO 2014*, which generally represents current legislation and environmental regulations, including recent government actions, for which implementing regulations were available as of October 31, 2013.

Because the on-site water heating operation of residential dishwashers requires use of fossil fuels and results in emissions of $CO_2$, $NO_X$, and $SO_2$ at the sites where these appliances are used, DOE also accounted for the reduction in these site emissions and the associated upstream emissions due to potential standards.

$SO_2$ 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 it remained in effect.[c] On July 6, 2011 EPA issued a replacement for CAIR, the Cross-State Air Pollution Rule (CSAPR). 76 FR 48208 (Aug. 8, 2011). On August 21, 2012, the D.C. Circuit issued a decision to vacate CSAPR.[d] The court ordered EPA to continue administering CAIR. *AEO 2014* assumes that CAIR remains a binding regulation through 2040.[e]

The attainment of emissions caps is typically flexible among 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

---

[b] *http://www.epa.gov/climateleadership/inventory/ghg-emissions.html*

[c] See North Carolina v. EPA, 550 F.3d 1176 (D.C. Cir. 2008); North Carolina v. EPA, 531 F.3d 896 (D.C. Cir. 2008).

[d] See EME Homer City Generation, LP v. EPA, 696 F.3d 7, 38 (D.C. Cir. 2012).

[e] 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. 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. See *EPA v. EME Homer City Generation*, No 12-1182, slip op. at 32 (U.S. April 29, 2014). Because DOE is using emissions factors based on AEO 2014, the analysis assumes that CAIR, not CSAPR, is the regulation in force. The difference between CAIR and CSAPR is not relevant for the purpose of DOE's analysis of $SO_2$ emissions.

adoption 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 HCl 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 2014* 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 that would be established by CAIR, 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 energy efficiency standards will reduce $SO_2$ emissions in 2016 and beyond.

CAIR established a cap on $NO_X$ emissions in eastern States and the District of Columbia. Energy conservation standards are expected to have little or no physical effect on these emissions in those States covered by CAIR because excess $NO_X$ emissions allowances resulting from the lower electricity demand could be used to permit offsetting increases in $NO_X$ emissions. However, standards would be expected to reduce $NO_X$ emissions in the States not affected by the caps, so DOE estimated $NO_X$ emissions reductions from potential standards in the States where emissions are not capped.

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 mercury emissions reduction using emissions factors based on *AEO 2014*, which incorporates the MATS.

Power plants may emit particulates from the smoke stack, which are known as direct particulate matter (PM) emissions. NEMS does not account for direct PM emissions from power plants. DOE is investigating the possibility of using other methods to estimate reduction in PM emissions due to standards. The great majority of ambient PM associated with power plants is in the form of secondary sulfates and nitrates, which are produced at a significant distance from power plants by complex atmospheric chemical reactions that often involve the gaseous emissions of power plants, mainly $SO_2$ and $NO_X$. The monetary benefits that DOE estimated for reductions in $SO_2$ and $NO_X$ emissions resulting from standards are in fact primarily related to the health benefits of reduced ambient PM.

Further detail is provided in chapter 13 of the NOPR TSD.

## 2.13 MONETIZING REDUCED $CO_2$ AND OTHER EMISSIONS

DOE considered the estimated monetary benefits likely to result from the reduced emissions of $CO_2$ 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 used the most current Social Cost of Carbon (SCC) values developed and/or agreed to by an interagency process. The SCC is intended to be a monetary measure of the 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 SCC can be used to provide estimates of the social benefits of reductions in GHG emissions.

The Interagency Working Group on Social Cost of Carbon released an update of its previous report in 2013.[f] The most recent estimates of the SCC in 2015, expressed in 2013$, are $12.0, $40.5, $62.4, and $119 per metric ton of $CO_2$ avoided. For emissions reductions that occur in later years, these 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, although DOE gives preference to consideration of the global benefits of reducing $CO_2$ emissions.

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 discount rates that had been used to obtain the SCC values in each case.

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 estimated the potential monetary benefit of reduced $NO_X$ emissions resulting from the standard levels it considers. Estimates of monetary value for reducing $NO_X$ from stationary sources range from $476 to $4,893 per ton in 2013$.[g] DOE calculated monetary

---

[f] *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; revised November 2013. [www.whitehouse.gov/sites/default/files/omb/assets/inforeg/technical-update-social-cost-of-carbon-for-regulator-impact-analysis.pdf](www.whitehouse.gov/sites/default/files/omb/assets/inforeg/technical-update-social-cost-of-carbon-for-regulator-impact-analysis.pdf)

[g] U.S. Office of Management and Budget, Office of Information and Regulatory Affairs, *2006 Report to Congress on the Costs and Benefits of Federal Regulations and Unfunded Mandates on State, Local, and Tribal Entities*, Washington, DC.

benefits using a medium value for $NO_X$ emissions of $2,684 per short ton (2013$), and real discount rates of 3 percent and 7 percent.

DOE is investigating appropriate valuation of Hg and $SO_2$ emissions. DOE has not monetized estimates of $SO_2$ and Hg reduction in this rulemaking.

Further detail on the emissions monetization is provided in chapter 14 of the NOPR TSD.

## 2.14 UTILITY IMPACT ANALYSIS

In the utility impact analysis, DOE analyzes the changes in electric installed capacity and 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). 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. As of 2014, DOE is using a new methodology based on results published for the *Annual Energy Outlook 2014 (AEO 2014)* Reference case and a set of side cases that implement a variety of efficiency-related policies.

Further detail is provided in chapter 15 of the NOPR TSD.

## 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.

Indirect employment impacts are investigated in the employment impact analysis using the Pacific Northwest National Laboratory's "Impact of Sector Energy Technologies" (ImSET) model.[h] The ImSET model was developed for DOE's Office of Planning, Budget, and Analysis

---

[h] M.J. Scott, O.V. Livingston, P.J. Balducci, J.M. Roop, and R.W. Schultz, *ImSET 3.1: Impact of Sector Energy Technologies*, PNNL-18412, Pacific Northwest National Laboratory (2009) (Available at: *www.pnl.gov/main/publications/external/technical_reports/PNNL-18412.pdf*).

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. Further detail is provided in chapter 16 of the NOPR TSD.

## 2.16 REGULATORY IMPACT ANALYSIS

In the NOPR stage, DOE prepared a regulatory impact analysis (RIA) pursuant to Executive Order 12866, Regulatory Planning and Review, 58 FR 51735, October 4, 1993. The RIA addresses the potential for non-regulatory approaches to supplant or augment energy conservation standards in order to improve the energy efficiency or reduce the energy consumption of the product covered under this rulemaking. DOE recognizes that voluntary or other non-regulatory efforts by manufacturers, utilities, and other interested parties 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 impacts existing initiatives might have in the future. Further detail is provided in chapter 17 of the NOPR TSD.

# CHAPTER 3. MARKET AND TECHNOLOGY ASSESSMENT

## TABLE OF CONTENTS

## LIST OF TABLES

## LIST OF FIGURES

# CHAPTER 3. MARKET AND TECHNOLOGY ASSESSMENT

## 3.1 INTRODUCTION

This chapter provides a profile of the residential dishwasher 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 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.

## 3.2 PRODUCT DEFINITION

DOE defines "dishwasher" under the Energy Policy and Conservation Act (EPCA) of 1975 (42 U.S.C. 6291–6309) as "a cabinet-like appliance which with the aid of water and detergent, washes, rinses, and dries (when a drying process is included) dishware, glassware, eating utensils, and most cooking utensils by chemical, mechanical and/or electrical means and discharges to the plumbing drainage system." (10 CFR 430.2)

## 3.3 PRODUCT CLASSES

DOE separates residential dishwashers into two product classes. The criteria for separation into different classes are: (1) type of energy used, and (2) capacity or other performance-related features such as those that provide utility to the consumer or others deemed appropriate by the Secretary that would justify the establishment of a separate energy conservation standard. (42 U.S.C. 6295(q))

For residential dishwashers, the size of the unit impacts the energy consumed. Because standard residential dishwashers offer enhanced consumer utility over compact units (*i.e.*, the ability to wash more dishes), DOE has established the following product classes, which are based on the size of the dishwasher (as specified in American National Standards Institute (ANSI)/Association of Home Appliance Manufacturers (AHAM) Standard DW-1-2010, *Household Electric Dishwashers*):

- Compact, (capacity less than eight place settings plus six serving pieces); and
- Standard, (capacity equal to or greater than eight place settings plus six serving pieces).

## 3.4 PRODUCT TEST PROCEDURES

DOE's test procedure for residential dishwashers is found in the Code of Federal Regulations (CFR) at 10 CFR part 430, subpart B, appendix C1 (appendix C1). DOE originally established its test procedure for residential dishwashers in 1977. 42 FR 39964 (Aug. 3, 1977). In 1983, DOE amended the test procedure to revise the representative average-use cycles to reflect consumer use and to address dishwashers that use 120 degree Fahrenheit (°F) inlet water. 48 FR 9202 (Mar. 3, 1983). DOE amended the test procedure again in 1984 to redefine "water heating dishwasher." 49 FR 46533 (Nov. 27, 1984). In 1987, DOE amended the test procedure to address models that use 50 °F inlet water. 52 FR 47551 (Dec. 15, 1987). In 2001, DOE revised the test procedure's testing specifications to improve repeatability, change the definitions of "compact dishwasher" and "standard dishwasher," and reduce the average number of use cycles per year from 322 to 264. 66 FR 65091, 65095–97 (Dec. 18, 2001).

In 2003, DOE again revised the test procedure to more accurately measure residential dishwasher efficiency, energy use, and water use. The 2003 test procedure amendments included the following revisions: (1) the addition of a method to rate the efficiency of soil-sensing products; (2) the addition of a method to measure standby power; and (3) a reduction in the average-use cycles per year from 264 to 215. 68 FR 51887, 51899–903 (Aug. 29, 2003).

In 2012, DOE established a new test procedure at appendix C1 for residential dishwashers that updated the existing test procedure to: (1) revise the provisions for measuring energy consumption in standby mode or off mode; (2) add requirements for dishwashers with water softeners to account for regeneration cycles; (3) require an additional preconditioning cycle; (4) include clarifications regarding certain definitions, test conditions, and test setup; and (5) replace obsolete test load items and soils. 77 FR 65942, 65982–87 (Oct. 31, 2012). The current version of the additional test procedure at 10 CFR 430.23(c) includes provisions for determining annual energy use expressed in kilowatt-hours (kWh) per year, water consumption expressed in gallons per cycle, and estimated annual operating cost.

## 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 dishwasher 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 room air conditioners, dehumidifiers and room air cleaners; an active communications program; and technical services and research.

---

[a] For more information, please visit *http://www.aham.org*.

In addition, AHAM conducts other market and consumer research studies and periodically publishes a *Major Appliance Fact Book*. 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 manufacturers of dishwashers, 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). DOE primarily used the manufacturer information gathered in support of the direct final rule published on May 30, 2012 (77 FR 31918), (May 2012 direct final rule) for this market assessment.

### 3.6.1 Manufacturers and Market Shares

Using publicly available data (*e.g.*, *Appliance Magazine* and market assessments done by third parties), DOE estimates the domestic market shares for dishwasher manufacturers. Manufacturers may offer multiple brand names. Some of the brand names come from independent appliance manufacturers that have been acquired over time, and domestic manufacturers may put their brand on a product manufactured overseas.

For residential dishwashers, DOE estimates that there are approximately 18 manufacturers supplying the domestic market. In 2008 (the most recent year for which market share data were available), nearly the entire market, or 94 percent, was controlled by three domestic manufacturers: Whirlpool, General Electric (GE), and AB Electrolux (under the Frigidaire brand[b]). The merger between Whirlpool and Maytag resulted in the combined company accounting for 49 percent of the domestic dishwasher market in 2008. BSH Home Appliances Corporation (BSH) accounted for five percent of the total market in 2008, and the remaining one percent is made up of companies including ASKO Appliances, Inc. (ASKO), Dacor Inc. (Dacor), Equator Corporation (Equator), Fagor America Inc. (Fagor), Fisher & Paykel Appliances Limited (Fisher & Paykel), Haier America Trading, LLC (Haier), Miele, Inc. (Miele), Viking Range Corporation (Viking) and others. More recently, AGA Rangemaster Group plc (AGA), Bonferraro SpA (Bonferraro), Foshan Shunde Midea Washing Appliances Manufacturing Company, Ltd. (Midea), Merloni Elettrodomestici (Merloni), Samsung Electronics, Inc. (Samsung) and LG Electronics, Inc. (LG) have also entered the domestic market. Table 3.6.1 lists these manufacturers. Figure 3.6.1 illustrates the 2008 market shares for the domestic residential dishwasher market.

---

[b] AB Electrolux also markets residential dishwashers in much smaller volumes under the Electrolux brand.

**Table 3.6.1 Major and Other Dishwasher Manufacturers**

| Major Manufacturers | Other Manufacturers |
|---|---|
| Whirlpool | AGA |
| GE | ASKO |
| Electrolux | Bonferraro |
| | BSH |
| | Dacor |
| | Equator |
| | Fagor |
| | Fisher & Paykel |
| | Haier |
| | LG |
| | Merloni |
| | Midea |
| | Miele |
| | Samsung |
| | Viking |

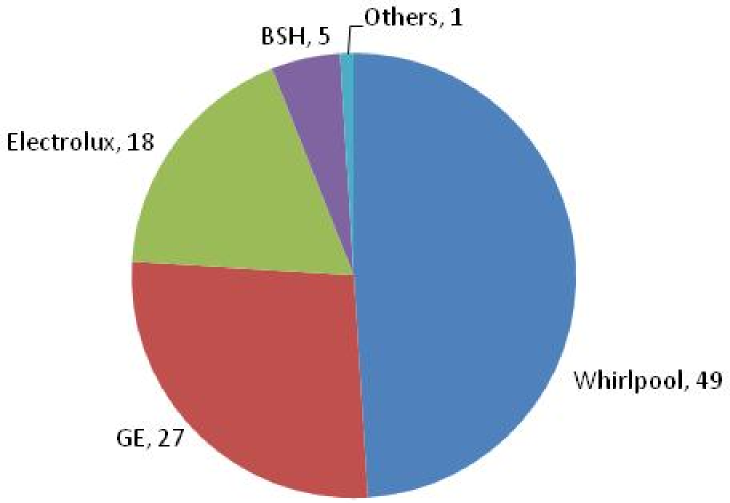


**Figure 3.6.1 2008 Market Shares for the Domestic Residential Dishwasher Market[1]**

### 3.6.2 Mergers and Acquisitions

Due to mergers and acquisitions, the home appliance industry continues to consolidate. While this phenomenon varies from product to product within the industry, the large market shares of a few companies provide evidence in support of this characterization.

According to the January 2010 *Appliance Market Research Report,* three manufacturers comprised 85 percent of the core major appliance market share in 2008. The term "core major appliance" includes dishwashers, dryers, freezers, ranges, refrigerators, and clothes washers. Figure 3.6.2 illustrates the breakdown of 2008 market shares in the core appliance category.

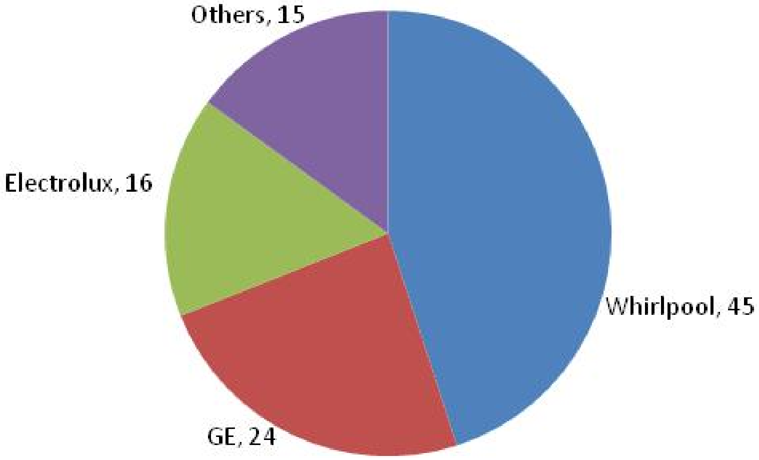


**Figure 3.6.2 2008 Core Appliance Market Shares**[2]

On August 22, 2005, Whirlpool, headquartered in Benton Harbor, Michigan, and Maytag, based in Newton, Iowa, announced plans to merge in a deal worth $2.7 billion.[3] Maytag shareholders approved the merger on December 22, 2005. Shortly after announcing the merger, Whirlpool submitted a pre-merger notification to the U.S. Department of Justice (DOJ). The DOJ Antitrust Division initiated an investigation, scheduled to end February 27, 2006, into the effects of the merger, including potential lessening of competition or the creation of a monopoly. Following this initial review, the DOJ asked for additional materials from each company and extended the review to March 30, 2006.

Opponents of the merger asserted that the combined companies would control as much as 70 percent of the residential laundry market and as much as 50 percent of the residential dishwasher market.[4] Whirlpool claimed that their large potential residential laundry market share was skewed because the company produces washing machines for Sears, which sells them under their Kenmore in-house brand. Whirlpool went on to say that they must periodically bid with other manufacturers to keep the Kenmore contract and that Sears controls the pricing of the Kenmore units.[5]

In early January 2006, U.S. Senator Tom Harkin and U.S. Representative Leonard Boswell, both of Iowa, called upon the DOJ to block the merger, claiming it would give Whirlpool an unfair advantage in the home appliance industry. The Congressmen wrote, that if the DOJ does not block the deal, the agency should at least "require that Whirlpool divest the washer and dryer portions of Maytag to a viable purchaser who will have the financial capability and desire to continue to operate that business."[6]

On March 29, 2006, DOJ closed its investigation and approved the merger. DOJ claims "that the proposed transaction is not likely to reduce competition substantially. The combination of strong rival suppliers with the ability to expand sales significantly and large cost savings and other efficiencies that Whirlpool appears likely to achieve indicates that this transaction is not likely to harm consumer welfare."[7]

The DOJ Antitrust Division focused its investigation on residential laundry, although it considered impacts across all products offered by the two companies. DOJ determined that the merger would not give Whirlpool excessive market power in the sale of its products and that any attempt to raise prices would likely be unsuccessful. In support of this claim, DOJ noted: (1) other U.S. brands, including Kenmore, GE, and Frigidaire, are well established; (2) foreign manufacturers, including LG and Samsung, are gaining market share; (3) existing U.S. manufacturers are below production capacity; (4) the large home appliance retailers have alternatives available to resist price increase attempts; and (5) Whirlpool and Maytag substantiated large cost savings and other efficiencies that would benefit consumers.[8]

Whirlpool and Maytag completed the merger on March 31, 2006. This large merger followed several other mergers and acquisitions in the home appliance industry. For example, Maytag acquired Jenn-Air Corporation (Jenn-Air) in 1982, Magic Chef, Inc. (Magic Chef) in 1986, and Amana Appliances (Amana) in 2001. Whirlpool acquired the KitchenAid division of Hobart Corporation (KitchenAid) in 1986. White Consolidated Industries (WCI) acquired the Frigidaire division of General Motors Corporation in 1979, and AB Electrolux acquired WCI (and therefore Frigidaire) in 1986.

More recently, Gorenje, a Slovenian company, acquired ASKO in 2010, which had been previously acquired by Antonia Merloni S.p.A. of Italy in 2000. In addition, Haier Group acquired Fisher & Paykel in 2012.

### 3.6.3 Small Business Impacts

DOE considers the possibility of small businesses being impacted by the promulgation of energy conservation standards. At this time, DOE is not aware of any small manufacturers, defined by the Small Business Association as having 500 employees or fewer,[9] who produce dishwashers and who therefore would be impacted by a minimum efficiency standard.

### 3.6.4 Distribution Channels

Understanding the distribution channels of dishwashers is an important facet of the market assessment. DOE gathered information regarding the distribution channels for dishwashers from publicly available sources.

The distribution chain for dishwashers, and most residential appliances, differs from commercial products, as the majority of consumers purchase their appliances directly from retailers. These retailers include: (1) home improvement, appliance, and department stores; (2) internet retailers; (3) membership warehouse clubs; and (4) kitchen remodelers. The AHAM *2005 Fact Book* reports that home improvement stores claim nearly one out of every four dollars spent on appliances.[10]

Home appliance retailers generally obtain products directly from manufacturers. The AHAM *2003 Fact Book* shows that over 93 percent of residential appliances are distributed from the manufacturer directly to a retailer.[11]

## 3.7 REGULATORY PROGRAMS

The following section details current regulatory programs mandating energy conservation standards for dishwashers. Section 3.7.1 discusses Federal energy conservation standards, and section 3.7.2 reviews standards in Canada that may impact the companies servicing the North American market.

### 3.7.1 Federal Energy Conservation Standards

Current Federal standards exist for residential dishwashers. The National Appliance Energy Conservation Act of 1987 (NAECA) (42 U.S.C. 6291–6309) amended EPCA to establish prescriptive standards for dishwashers, requiring that they be equipped with an option to dry without heat and further requiring that DOE conduct two cycles of rulemakings to determine if more stringent standards are justified. (42 U.S.C. 6295 (g)(1), (4) and (5)) On May 14, 1991, DOE issued a final rule establishing the first set of performance standards for dishwashers (56 FR 22250); those standards became effective on May 14, 1994. (10 CFR 430.32(f)) DOE initiated a second standards rulemaking for dishwashers by issuing an advance notice of proposed rulemaking (ANOPR) on November 14, 1994. 59 FR 56423. However, as a result of the priority-setting process outlined in its *Procedures for Consideration of New or Revised Energy Conservation Standards for Consumer Products* (the “Process Rule”) (61 FR 36974 (July 15, 1996); 10 CFR part 430, subpart C, appendix A), DOE suspended the standards rulemaking for dishwashers.

The Energy Independence and Security Act of 2007[c] (EISA 2007) further amended EPCA to establish new energy conservation standards for residential dishwashers manufactured on or after January 1, 2010. (42 U.S.C. 6295(g)(10)(A); 10 CFR 430.32(f)(2)) The amendments also required the Secretary to publish a final rule not later than January 1, 2015, determining whether to amend the standards for dishwashers manufactured on or after January 1, 2018. (42 U.S.C. 6295(g)(10)(B))

---

[c] Pub. L. 110-140 (enacted Dec. 19, 2007).

On July 30, 2010, AHAM and the American Council for an Energy Efficient Economy (ACEEE), additionally representing manufacturers (Whirlpool, GE, Electrolux, LG, BSH, Alliance Laundry Systems (ALS), Viking Range, Sub-Zero Wolf, Friedrich A/C, U-Line, Samsung, Sharp Electronics, Miele, Heat Controller, AGA Marvel, Brown Stove, Haier, Fagor America, Airwell Group, Arcelik, Fisher & Paykel, Scotsman Ice, Indesit, Kuppersbusch, Kelon, and DeLonghi); energy and environmental advocates (Appliance Standards Awareness Project (ASAP), Natural Resources Defense Council (NRDC), Alliance to Save Energy (ASE), Alliance for Water Efficiency (AWE), Northwest Power and Conservation Council (NPCC), and Northeast Energy Efficiency Partnerships (NEEP)); and consumer groups (Consumer Federation of America (CFA) and the National Consumer Law Center (NCLC)) submitted to DOE a multi-product standards agreement (Consensus Agreement) that addresses negotiated standards for multiple products, including residential dishwashers. In response to the Consensus Agreement, DOE conducted a rulemaking analysis based on the recommended levels for residential dishwashers. DOE published the May 2012 direct final rule to establish energy conservation standards consistent with the Consensus Agreement levels for dishwashers manufactured on or after May 30, 2013. 77 FR 31918. Table 3.7.1 shows the current dishwasher energy conservation standards.

**Table 3.7.1 Current Federal Energy Conservation Standards for Residential Dishwashers**

| **Dishwasher Classification** | **Maximum Annual Energy Use** *(kWh/year)* | **Maximum Water Consumption** *(gallons/cycle)* |
|---|---|---|
| Standard dishwasher | 307 | 5.0 |
| Compact dishwasher | 222 | 3.5 |

### 3.7.2 Canadian Energy Conservation Standards

Canada's Energy Efficiency Regulations (hereinafter Regulations) establish energy conservation standards for residential dishwashers.

Canadian Regulations include maximum energy use requirements and definitions for residential dishwashers that are identical to the EISA 2007 energy conservation standards required for residential dishwashers manufactured on or after January 1, 2010. These Regulations set a maximum annual energy use of 355 kWh/year for standard dishwashers and 260 kWh/year for compact dishwashers; however, the Canadian Regulations do not include any requirements for water consumption. Canadian Regulations have the same definitions for compact and standard dishwashers as in the United States.

## 3.8 VOLUNTARY PROGRAMS

DOE reviewed several voluntary programs promoting energy-efficient dishwashers in the United States. Many programs, including ENERGY STAR, the Consortium for Energy Efficiency (CEE), and the Federal Energy Management Program (FEMP), establish voluntary energy conservation standards for these products.

### 3.8.1 ENERGY STAR

ENERGY STAR, a voluntary labeling program backed by the U.S. Environmental Protection Agency (EPA) and DOE, identifies energy efficient products through a qualification process.[d] To qualify, a product must exceed Federal minimum standards by a specified amount, or if no Federal standard exists, exhibit selected energy-saving features. The ENERGY STAR program works to recognize the top quartile of products on the market, meaning that approximately 25 percent of products on the market should meet or exceed the ENERGY STAR levels. ENERGY STAR specifications exist for several products, including residential dishwashers.

On January 20, 2012, the current ENERGY STAR residential dishwasher qualifying criteria took effect. The ENERGY STAR program originally established performance requirements for both standard and compact dishwashers; however, ENERGY STAR eliminated the compact criteria after December 31, 2013 because the DOE energy conservation standards for these products effective as of May 30, 2013 were at the same level as the ENERGY STAR criteria. The current ENERGY STAR criteria for residential dishwashers are listed in Table 3.8.1.

**Table 3.8.1 ENERGY STAR Qualifying Criteria for Residential Dishwashers**

| | **Current Criteria Levels** | |
|---|---|---|
| **Dishwasher Classification** | **Maximum Annual Energy Use** *(kWh/year)* | **Maximum Water Consumption** *(gallons/cycle)* |
| Standard dishwasher | 295 | 4.25 |
| Compact dishwasher | N/A | N/A |

DOE notes that the ENERGY STAR program references the DOE test procedure in appendix C1 to determine annual energy use and per-cycle water consumption. As part of future qualification criteria, ENERGY STAR may require that dishwashers meet minimum cleaning performance requirements; however, the DOE test procedure does not include any measure of cleaning performance. In preparation for these potential requirements, ENERGY STAR developed a Test Method for Determining Residential Dishwasher Cleaning Performance (Rev. Feb-2014) (Cleaning Performance Test Method). This Cleaning Performance Test Method is based on the DOE test procedure in appendix C1, with added requirements for grading test load items at the end of a test cycle, and calculations to determine a per-cycle cleaning index. The

---

[d] For more information, please visit http://www.energystar.gov.

grading requirements and cleaning index calculations are based on the methods included in ANSI/AHAM Standard DW-1-2010. Chapter 5 of this notice of proposed rulemaking (NOPR) technical support document (TSD) includes additional information on the ENERGY STAR Cleaning Performance Test Method.

### 3.8.2 Consortium for Energy Efficiency

CEE[e] develops initiatives for its North American members to promote the manufacture and purchase of energy efficient products and services. The goal of the organization is to induce lasting structural and behavioral changes in the marketplace, resulting in the increased adoption of energy efficient technologies.

CEE issues voluntary specifications for standard-size and compact residential dishwashers. Table 3.8.2 presents the dishwasher efficiency specifications, effective January 20, 2012, under its Super-Efficient Home Appliances Initiative.

**Table 3.8.2 CEE Criteria for Residential Dishwashers**

| **Level** | **Minimum Energy Factor (EF)*** *(cycles/kWh)* | **Maximum Annual Energy Use** *(kWh/year)* | **Maximum Water Consumption** *(gallons/cycle)* |
|---|---|---|---|
| Standard CEE Tier 1 | 0.75 | 295 | 4.25 |
| Compact CEE Tier 1 | 1.00 | 222 | 3.5 |

* Prior to January 1, 2010, energy conservation standards were based on EF, defined in cycles/kWh. The current DOE test procedure for residential dishwashers no longer include a calculation of EF, as the current standards are based on annual energy use and per-cycle water consumption.

The annual energy use and water consumption CEE Tier 1 criteria for standard dishwashers are identical to the criteria for the ENERGY STAR program, with the added requirement for a minimum EF. The compact criteria equal the maximum allowable DOE energy conservation standards, with an added requirement for a minimum EF.

### 3.8.3 Federal Energy Management Program

DOE’s Federal Energy Management Program[f] (FEMP) works to reduce the cost and environmental impact of the Federal government by advancing energy efficiency and water conservation, promoting the use of distributed and renewable energy, and improving utility management decisions at Federal sites. FEMP helps Federal buyers identify and purchase energy efficient equipment, including residential dishwashers.

---

[e] For more information, please visit *http://www.cee1.org*.

[f] For more information, please visit *http://www.eere.energy.gov/femp*.

On March 13, 2009, FEMP issued a final rule covering the Federal procurement of energy-efficiency products. 74 FR 10830. The final rule establishes guidelines requiring that Federal agencies procure ENERGY STAR-qualified products and FEMP-designated product categories for energy-consuming products and systems.

## 3.9 HISTORICAL SHIPMENTS

Awareness of annual product shipment trends is an important aspect of the market assessment and in the development of the standards rulemaking. DOE reviewed data collected by the U.S. Census Bureau, EPA, and AHAM to evaluate residential dishwasher shipment trends and the value of these shipments. Knowledge of such trends will be used during the shipments analysis (chapter 9 of this NOPR TSD).

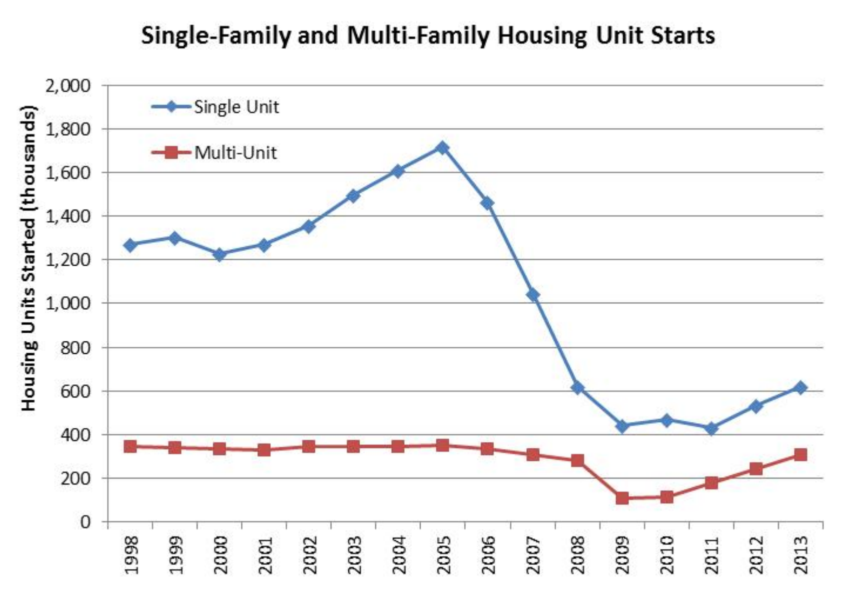
### 3.9.1 New Home Starts

Trends in new home starts may directly affect shipments of certain home appliances. While there is certainly both a replacement and remodeling market for some appliances, including residential dishwashers, these products are also fixtures in virtually all new homes.

Table 3.9.1 presents the number of new single-family and multi-family housing units started in the United States from 1998–2013. Over the period from 2000–2005, single-family home starts increased nearly 40 percent, to 1,716,000 units annually. However, between 2005 and 2010, single-family home starts decreased 73 percent, to 471,000 units annually. Multi-family unit starts remained relatively stable during the period 1998–2005 at around 340,000 units annually. Between 2005 and 2010, multi-family units decreased 67.1 percent to 116,000 units annually. Over the period from 2010–2013, multi-family units have rebounded to near their pre-2005 levels, while single-family units remain significantly lower.

**Table 3.9.1 New Privately Owned Single-Family and Multi-Family Housing Unit Starts in the United States from 1998–2013 (Thousands)**[12]

| Year | Single Unit | Multi-Unit |
|---|---|---|
| 2013 | 618 | 307 |
| 2012 | 535 | 245 |
| 2011 | 431 | 178 |
| 2010 | 471 | 116 |
| 2009 | 445 | 109 |
| 2008 | 622 | 284 |
| 2007 | 1046 | 309 |
| 2006 | 1465 | 336 |
| 2005 | 1716 | 353 |
| 2004 | 1611 | 345 |
| 2003 | 1499 | 349 |
| 2002 | 1359 | 346 |
| 2001 | 1273 | 329 |
| 2000 | 1231 | 338 |
| 1999 | 1302 | 339 |
| 1998 | 1271 | 346 |

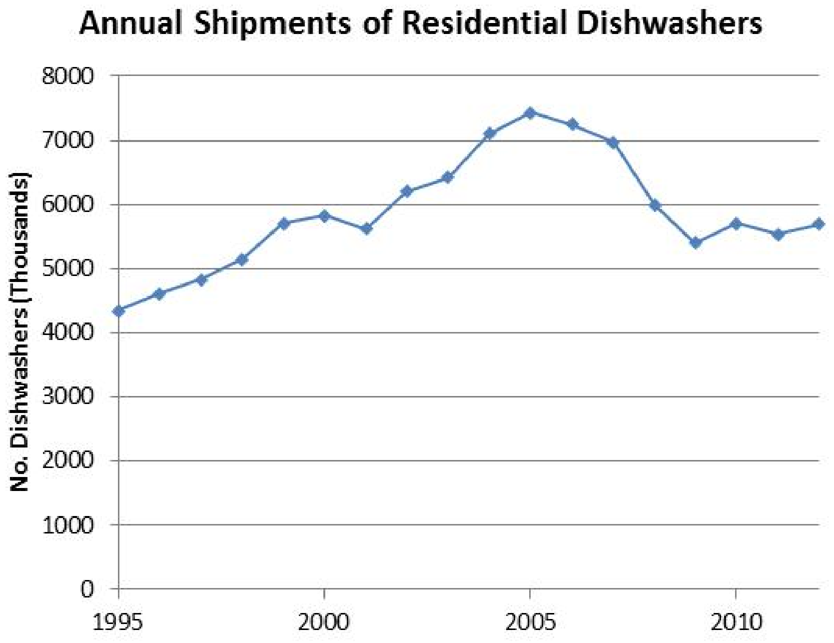


### 3.9.2 Unit Shipments

AHAM's *2005 Fact Book* provides annual unit shipments for residential dishwashers from 1995 to 2005. Shipments for 2006 through 2010 were obtained from the January 2011 *Appliance Market Research Report*'s "U.S. Appliance Shipment Statistics January 2011." The two sources contain consistent shipment values for the overlapping years 2000 through 2005. Shipments for 2011 and 2012 were taken from Appliance Magazine's "Full-Year Appliance Industry Shipment Statistics" reports for the respective years. Table 3.9.2 presents the annual shipments of dishwashers for the period from 1995 to 2012.

Shipments of residential dishwashers peaked in 2005 at around 7.4 million units before declining every year through 2009. The decline in shipments corresponds to the decline in new multi-family and single-family housing starts over the same time period, shown in Table 3.9.1. Residential dishwasher shipments increased slightly from 2009 to 2012, corresponding to the small increase in multi-family and single-family housing starts for those years.

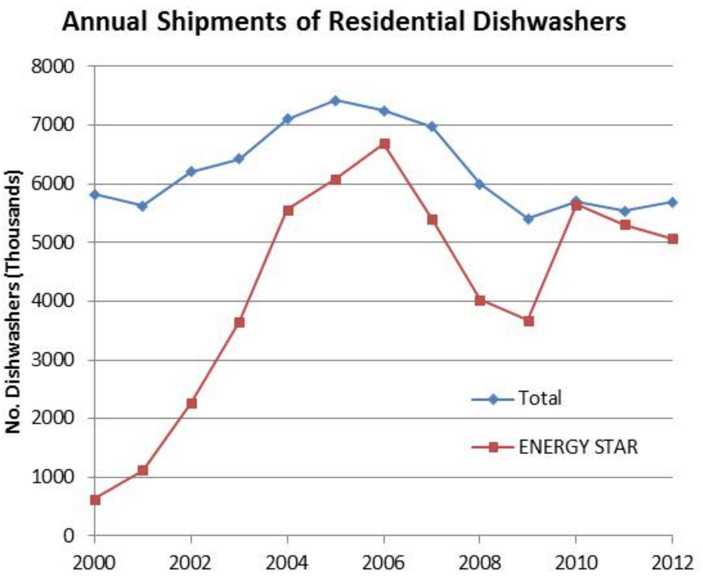
**Table 3.9.2 Industry Shipments of Residential Dishwashers (Domestic and Import)[13, 14, 15, 16]**

| Year | Shipments *(Thousands)* |  |
|---|---|---|
| 2012 | 5,689 | |
| 2011 | 5,535 | |
| 2010 | 5,708 | |
| 2009 | 5,404 | |
| 2008 | 5,995 | |
| 2007 | 6,977 | |
| 2006 | 7,252 | |
| 2005 | 7,428 | |
| 2004 | 7,106 | |
| 2003 | 6,428 | |
| 2002 | 6,207 | |
| 2001 | 5,627 | |
| 2000 | 5,827 | |
| 1999 | 5,712 | |
| 1998 | 5,144 | |
| 1997 | 4,826 | |
| 1996 | 4,606 | |
| 1995 | 4,346 | |

ENERGY STAR also provides shipments data and market share for qualified residential dishwashers. Table 3.9.3 presents the breakdown of ENERGY STAR versus non-ENERGY STAR shipments for residential dishwashers from 2000 to 2012 from data provided on the ENERGY STAR website.

**Table 3.9.3 ENERGY STAR Residential Dishwasher Shipments and Market Share (Domestic and Import)**[17]

| | | **Shipments** *(Thousands)* | |
|---|---|---|---|
| **Year** | **% ENERGY STAR** | **Total** | **ENERGY STAR** |
| 2012[a] | 89.2% | 5,689 | 5,072 |
| 2011 | 95.9% | 5,535 | 5,309 |
| 2010 | 98.9% | 5,708 | 5,644 |
| 2009[b] | 68.0% | 5,404 | 3,672 |
| 2008 | 67.2% | 5,995 | 4,030 |
| 2007[c] | 77.4% | 6,977 | 5,401 |
| 2006 | 92.3% | 7,252 | 6,691 |
| 2005 | 82.0% | 7,428 | 6,092 |
| 2004 | 78.2% | 7,106 | 5,557 |
| 2003 | 56.9% | 6,428 | 3,656 |
| 2002 | 36.4% | 6,207 | 2,262 |
| 2001 | 19.9% | 5,627 | 1,119 |
| 2000[d] | 10.9% | 5,827 | 632 |



a) Current ENERGY STAR criteria effective January 20, 2012
b) ENERGY STAR criteria effective August 11, 2009: Standard ≤ 324 kWh/year, 5.8 gal/cycle; Compact ≤ 234 kWh/year, 4.0 gal/cycle
c) ENERGY STAR criteria effective January 1, 2007: Standard – EF ≥ 0.65, Compact – EF ≥ 0.88
d) ENERGY STAR criteria: Standard – EF ≥ 0.46, Compact – EF ≥ 0.62

### 3.9.3 Value of Shipments

Table 3.9.4 provides the value of shipments for the manufacturers in the North American Industry Classification System (NAICS) category of major household appliances (product class code 33522) from 1997 to 2010. The values are based on data from the U.S. Census Bureau's *Current Industrial Reports*[g] (*CIR*) and *Annual Survey of Manufacturers*[h] (*ASM*). This NAICS category includes companies primarily engaged in manufacturing household appliances such as cooking appliances, laundry equipment, refrigerators, upright and chest freezers, dishwashers, water heaters, and garbage disposal units. The U.S. Census Bureau reports all shipment values in nominal dollars, *i.e.*, 2010 data are expressed in 2010 dollars and 2009 data are expressed in 2009 dollars. Using the Gross Domestic Product Implicit Price Deflator (GDPIPD) published by the U.S. Bureau of Economic Analysis,[i] DOE converted each year's value of shipments to 2013 dollars.

---

[g] Available online at *www.census.gov/manufacturing/cir/index.html*
[h] Available online at *www.census.gov/manufacturing/asm/index.html*
[i] Available online at *www.bea.gov/iTable/*

**Table 3.9.4 Annual Shipment Value of Major Household Appliances**[18, 19, 20, 21, 22]

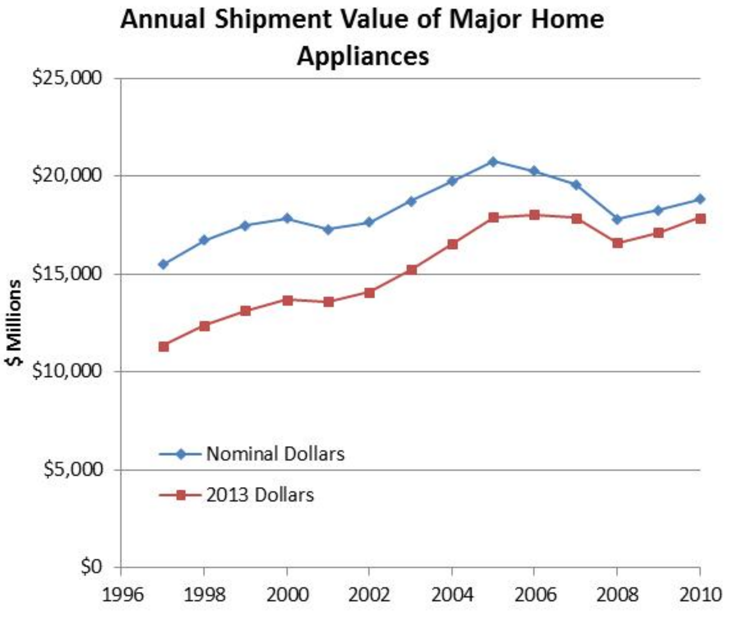
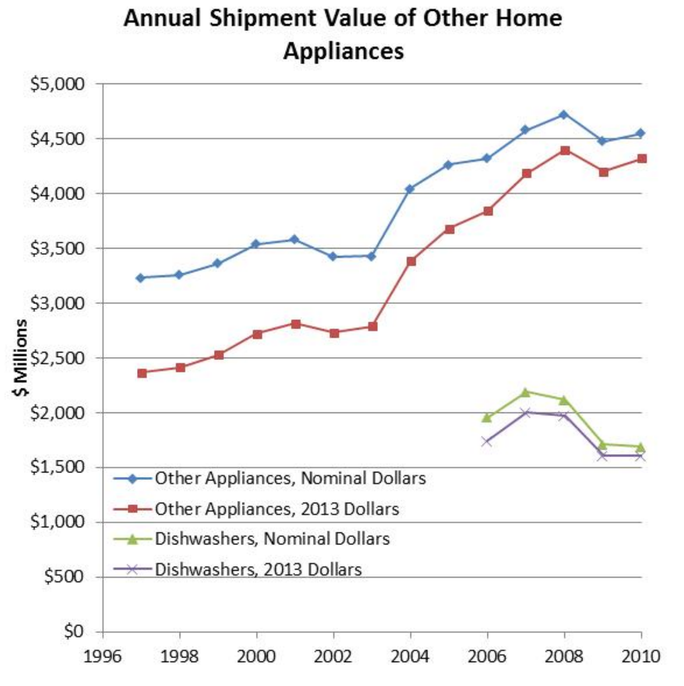
| | **Annual Shipment Value** *($ millions)* | |  |
|---|---|---|---|
| **Year** | **Nominal Dollars** | **2013 Dollars** | |
| 2010 | 18,823.6 | 17,874.0 | |
| 2009 | 18,253.8 | 17,125.6 | |
| 2008 | 17,808.0 | 16,579.7 | |
| 2007 | 19,575.0 | 17,875.7 | |
| 2006 | 20,255.0 | 18,018.3 | |
| 2005 | 20,730.0 | 17,891.1 | |
| 2004 | 19,747.4 | 16,513.4 | |
| 2003 | 18,721.7 | 15,237.9 | |
| 2002 | 17,645.9 | 14,080.9 | |
| 2001 | 17,295.5 | 13,592.3 | |
| 2000 | 17,836.1 | 13,703.4 | |
| 1999 | 17,479.6 | 13,131.1 | |
| 1998 | 16,713.9 | 12,379.1 | |
| 1997 | 15,487.1 | 11,347.2 | |

Table 3.9.5 provides the annual shipment value for the NAICS product class for “Other Household Appliances” (product class code 335228), which includes dishwashers, food waste disposal units, garbage disposal units, water heaters, and trash compactors, from 1997 to 2010 based upon data from the U.S. Census Bureau’s *CIR* and *ASM*. Also included in Table 3.9.5 are dishwasher shipment values from 2006 to 2010—the only years that dishwashers are reported separately in the *CIR*. Over these 4 years, dishwashers represented slightly less than half of the total annual shipments value for the Other Household Appliances product category. The U.S. Census Bureau shipment values are expressed in nominal dollars. DOE used the GDPIPD to convert each year’s value of shipments to 2013 dollars.

**Table 3.9.5 Annual Shipment Value of Other Major Household Appliances[23, 24, 25, 26, 27, 28, 29, 30]**

| | **Annual Shipment Value** *($ millions)* | | | |
|---|---|---|---|---|
| | **Other Home Appliances** | | **Dishwashers** | |
| **Year** | **Nominal Dollars** | **2013 Dollars** | **Nominal Dollars** | **2013 Dollars** |
| 2010 | 4,553.1 | 4,323.4 | 1,690.4 | 1,605.1 |
| 2009 | 4,479.9 | 4,203.0 | 1,709.5 | 1,603.9 |
| 2008 | 4,722.9 | 4,397.1 | 2,114.2 | 1,968.4 |
| 2007 | 4,581.7 | 4,184.0 | 2,189.0 | 1,999.0 |
| 2006 | 4,319.4 | 3,842.4 | 1,954.4 | 1,738.6 |
| 2005 | 4,263.5 | 3,679.6 | N/A | N/A |
| 2004 | 4,042.9 | 3,380.8 | N/A | N/A |
| 2003 | 3,428.1 | 2,790.2 | N/A | N/A |
| 2002 | 3,422.7 | 2,731.2 | N/A | N/A |
| 2001 | 3,579.7 | 2,813.2 | N/A | N/A |
| 2000 | 3,540.7 | 2,720.3 | N/A | N/A |
| 1999 | 3,362.3 | 2,525.8 | N/A | N/A |
| 1998 | 3,255.1 | 2,410.9 | N/A | N/A |
| 1997 | 3,232.1 | 2,368.1 | N/A | N/A |

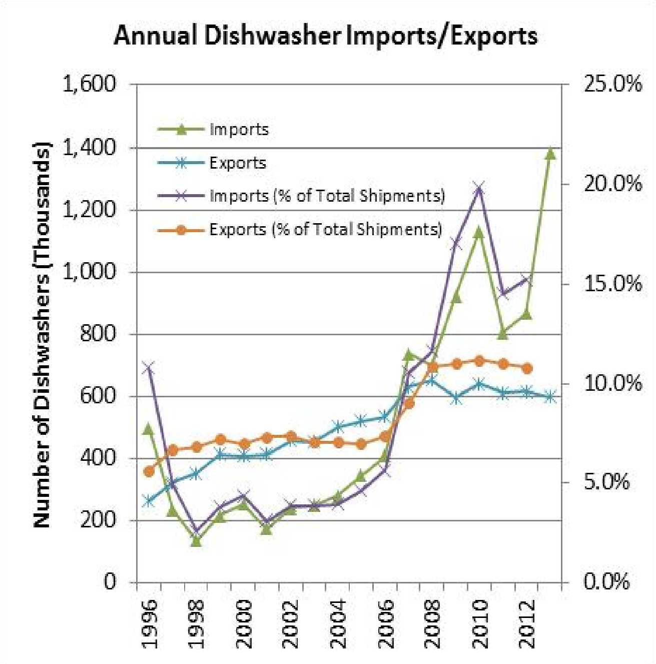


## 3.9.4 Imports and Exports

There is a large market for the import and export of home appliances. The U.S. International Trade Commission (ITC) publishes import and export data for certain home appliances, which includes annual summaries. Table 3.9.6 shows ITC's import/export data for Harmonized Tariff Schedule (HTS) 8422110000, *Dishwashing Machines, Household Type*, for 1996–2013. Beginning in 2006, both imports and exports rose as a share of total shipments, with imports in particular increasing substantially. Prior to 2007, the United States generally exported more dishwashers than it imported. Since that time, imports have exceeded exports.

**Table 3.9.6 Annual Dishwasher Imports/Exports**[31]

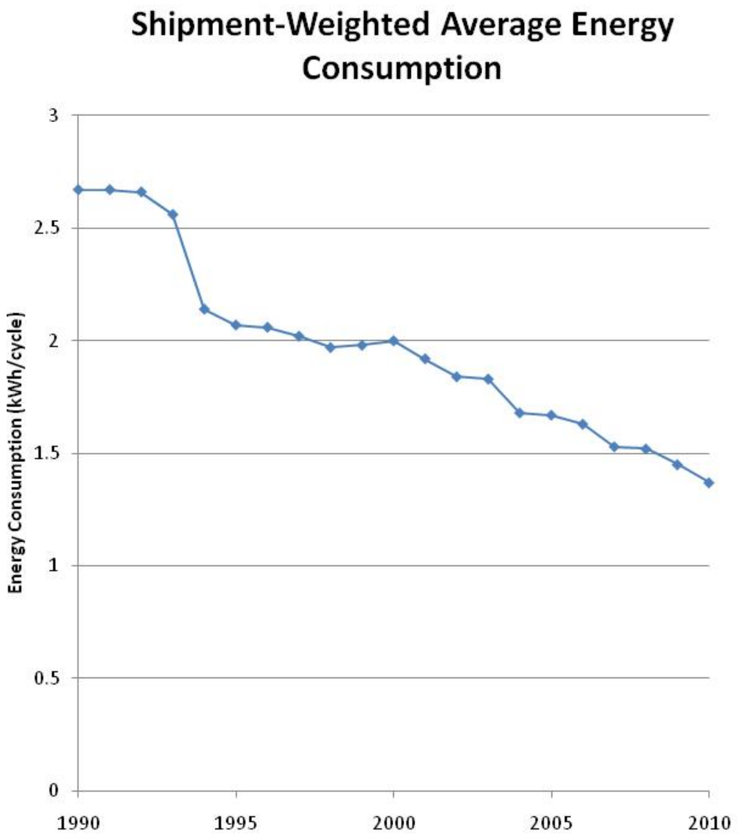
| Year | Imports | | Exports | |
|---|---|---|---|---|
| | Units *(1000)* | % of Total Shipments | Units *(1000)* | % of Total Shipments |
| 2013 | 1,383 | | 598 | |
| 2012 | 867 | 15.2% | 615 | 10.8% |
| 2011 | 804 | 14.5% | 610 | 11.0% |
| 2010 | 1,132 | 19.8% | 640 | 11.2% |
| 2009 | 923 | 17.1% | 595 | 11.0% |
| 2008 | 698 | 11.6% | 653 | 10.9% |
| 2007 | 736 | 10.5% | 630 | 9.0% |
| 2006 | 409 | 5.6% | 534 | 7.4% |
| 2005 | 345 | 4.6% | 520 | 7.0% |
| 2004 | 279 | 3.9% | 502 | 7.1% |
| 2003 | 249 | 3.9% | 453 | 7.0% |
| 2002 | 241 | 3.9% | 458 | 7.4% |
| 2001 | 175 | 3.1% | 413 | 7.3% |
| 2000 | 253 | 4.4% | 408 | 7.0% |
| 1999 | 216 | 3.8% | 412 | 7.2% |
| 1998 | 135 | 2.6% | 352 | 6.8% |
| 1997 | 236 | 4.9% | 322 | 6.7% |
| 1996 | 498 | 10.8% | 262 | 5.7% |



## 3.10 HISTORICAL EFFICIENCIES

The average efficiency of new residential dishwashers has increased greatly since 1990. Table 3.10.1 shows the shipment-weighted average energy consumption per cycle. Over the period from 1990 to 2010, the average energy consumption per cycle decreased by over 48 percent.

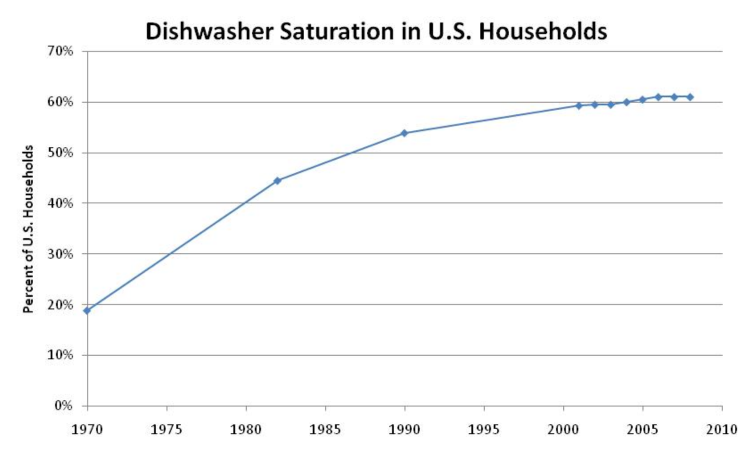
**Table 3.10.1 Annual Shipment-Weighted Per-Cycle Residential Dishwasher Energy Consumption**[32, 33]

<table>
<tr><th>Year</th><th>Energy Consumption <i>(kWh/cycle)</i></th><th>% Change vs. 1990</th><td rowspan="22">
</td></tr>
<tr><td>2010[a]</td><td>1.37</td><td>-48.7%</td></tr>
<tr><td>2009</td><td>1.45</td><td>-45.7%</td></tr>
<tr><td>2008</td><td>1.52</td><td>-43.1%</td></tr>
<tr><td>2007</td><td>1.53</td><td>-39.0%</td></tr>
<tr><td>2006</td><td>1.63</td><td>-37.5%</td></tr>
<tr><td>2005</td><td>1.67</td><td>-37.1%</td></tr>
<tr><td>2004</td><td>1.68</td><td>-37.1%</td></tr>
<tr><td>2003</td><td>1.83</td><td>-31.5%</td></tr>
<tr><td>2002</td><td>1.84</td><td>-31.1%</td></tr>
<tr><td>2001</td><td>1.92</td><td>-28.1%</td></tr>
<tr><td>2000</td><td>2.00</td><td>-25.1%</td></tr>
<tr><td>1999</td><td>1.98</td><td>-25.8%</td></tr>
<tr><td>1998</td><td>1.97</td><td>-26.2%</td></tr>
<tr><td>1997</td><td>2.02</td><td>-24.3%</td></tr>
<tr><td>1996</td><td>2.06</td><td>-22.8%</td></tr>
<tr><td>1995</td><td>2.07</td><td>-22.5%</td></tr>
<tr><td>1994[b]</td><td>2.14</td><td>-19.9%</td></tr>
<tr><td>1993</td><td>2.56</td><td>-4.1%</td></tr>
<tr><td>1992</td><td>2.66</td><td>-0.4%</td></tr>
<tr><td>1991</td><td>2.67</td><td>0.0%</td></tr>
<tr><td>1990</td><td>2.67</td><td>-</td></tr>
<tr><td colspan="4">a) DOE energy conservation standards for annual energy use took effect on January 1, 2010.<br>b) DOE energy conservation standards for EF took effect on May 14, 1994.</td></tr>
</table>

## 3.11 MARKET SATURATION

AHAM's *2005 Fact Book* and the January 2010 *Appliance Market Research Report* present the market saturation for residential dishwashers. The market saturation of residential dishwashers has more than tripled since 1970. However, from 2001 through 2008 the market saturation only increased by 1.7 percent. For the 3 years from 2006 through 2008, the market saturation remained constant at 61 percent. Table 3.11.1 presents the percentage of U.S. households with residential dishwashers.

**Table 3.11.1 Percentage of U.S. Households with Residential Dishwashers**[34, 35]

| Year | % of U.S. Households |  |
|---|---|---|
| 2008 | 61.0 | |
| 2007 | 61.0 | |
| 2006 | 61.0 | |
| 2005 | 60.5 | |
| 2004 | 60.0 | |
| 2003 | 59.5 | |
| 2002 | 59.5 | |
| 2001 | 59.3 | |
| 1990 | 53.9 | |
| 1982 | 44.5 | |
| 1970 | 18.9 | |

## 3.12 INDUSTRY COST STRUCTURE

DOE used information gathered in support of the May 2012 direct final rule, updated with more recent data when available, as the starting point in developing the industry cost structure. In that rulemaking, DOE developed the household appliance industry cost structure from publicly available information from the *ASM* and Economic Census, (Table 3.12.1 and Table 3.12.3) and the U.S. Securities and Exchange Commission (SEC) 10-K reports filed by publicly owned manufacturers (summarized in Table 3.12.5). Table 3.12.1 presents the major appliance manufacturing industry (NAICS code 33522) employment levels and earnings from 1997 through 2011. The statistics illustrate a steady decline in the number of production and non-production workers in the industry since 2000.

DOE converted cost data to constant 2013 dollars using the GDPIPD published by the U.S. Bureau of Economic Analysis. Table 3.12.1 shows that as industry employment levels decline, the industry payroll in constant 2013 dollars also decreases. The percent decrease in total industry employees tracks closely with the percent decrease in payroll for all employees.

**Table 3.12.1 Major Appliance Manufacturing Industry Employment and Earnings**[36]

| Year | Production Workers | All Employees | Payroll for All Employees *(2013 $ Mil)* |
|---|---|---|---|
| 2011 | 30,240 | 34,804 | 1,478.2 |
| 2010 | 31,924 | 36,475 | 1,603.0 |
| 2009 | 32,875 | 37,905 | 1,525.7 |
| 2008 | 39,163 | 44,717 | 1,822.1 |
| 2007 | 45,370 | 52,045 | 2,038.7 |
| 2006 | 49,360 | 56,174 | 2,298.0 |
| 2005 | 54,083 | 62,877 | 2,427.9 |
| 2004 | 57,660 | 68,213 | 2,701.5 |
| 2003 | 58,289 | 68,593 | 2,738.0 |
| 2002 | 59,234 | 70,013 | 2,867.8 |
| 2001 | 60,669 | 70,938 | 2,951.1 |
| 2000 | 64,417 | 75,055 | 3,163.0 |
| 1999 | 64,066 | 73,884 | 3,106.4 |
| 1998 | 62,822 | 73,113 | 3,036.7 |
| 1997 | 59,697 | 69,727 | 2,838.4 |

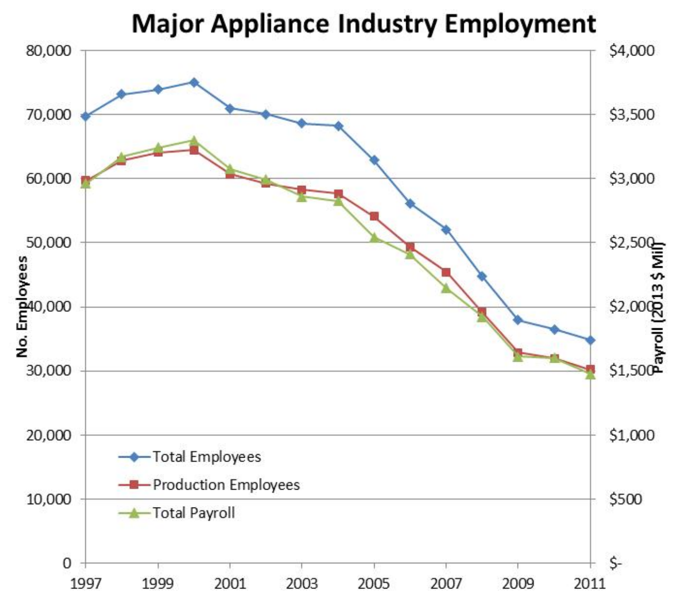


Table 3.12.2 presents the employments levels and payroll for the "Other Major Home Appliances" portion of the major appliance industry. As shown in Table 3.9.5, dishwashers represent slightly less than half of the total shipments value for the Other Major Home Appliance industry. Statistics for both employment levels and payroll show a slight decrease from 1997 to 2011. The decrease is of a much smaller magnitude than for the major appliance industry overall.

**Table 3.12.2 Other Major Home Appliance Industry Employment and Earnings**[37]

| Year | Production Workers | All Employees | Payroll for All Employees *(2013 $ Mil)* |
|---|---|---|---|
| 2011 | 7,513 | 9,305 | 409.3 |
| 2010 | 7,525 | 9,272 | 416.6 |
| 2009 | 7,651 | 9,516 | 408.7 |
| 2008 | 9,103 | 11,113 | 471.7 |
| 2007 | 9,792 | 11,516 | 490.5 |
| 2006 | 10,281 | 11,974 | 520.7 |
| 2005 | 10,179 | 12,360 | 535.7 |
| 2004 | 10,304 | 12,672 | 549.2 |
| 2003 | 10,519 | 12,819 | 549.9 |
| 2002 | 10,118 | 12,671 | 579.3 |
| 2001 | 10,392 | 12,770 | 576.6 |
| 2000 | 11,775 | 14,088 | 592.5 |
| 1999 | 11,081 | 13,166 | 577.1 |
| 1998 | 11,195 | 13,215 | 544.8 |
| 1997 | 10,881 | 12,848 | 535.8 |

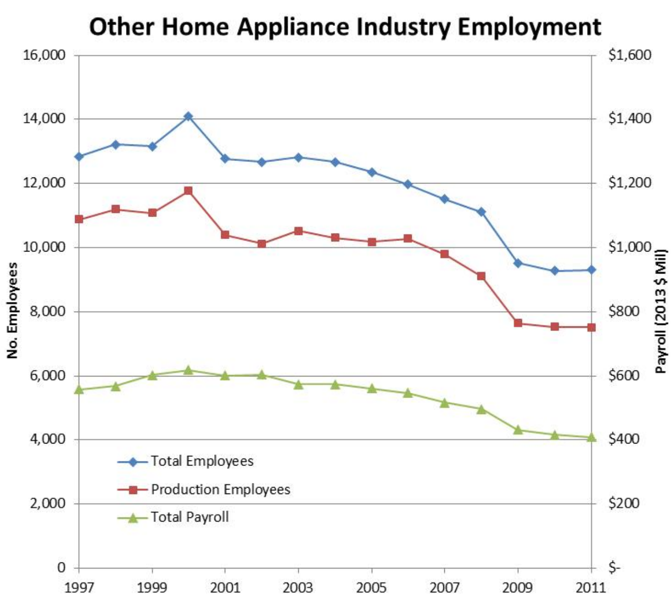


Table 3.12.3 presents the costs of materials and industry payroll as a percentage of value of shipments from 1997 to 2010 for the major appliance industry. The cost of materials as a percentage of value of shipments has slowly risen over the 14-year period, with small fluctuations. DOE notes that fluctuations in raw material costs are common from year to year. The cost of payroll for both production and non-production workers as a percentage of value of shipments has declined since 2000, with a sharp decrease in 2009.

**Table 3.12.3 Major Appliance Manufacturing Industry Materials and Wages Cost[38]**

| | **Cost as a Percentage of Value of Shipments** *(%)* | | |
|---|---|---|---|
| **Year** | **Materials** | **Payroll for Production Workers** | **Payroll for All Other Employees** |
| 2010 | 45.1% | 6.2% | 1.9% |
| 2009 | 44.7% | 6.4% | 1.9% |
| 2008 | 59.4% | 7.8% | 2.2% |
| 2007 | 58.4% | 8.0% | 2.0% |
| 2006 | 58.7% | 8.5% | 2.1% |
| 2005 | 57.4% | 8.3% | 2.3% |
| 2004 | 58.3% | 9.3% | 2.7% |
| 2003 | 56.8% | 9.5% | 2.9% |
| 2002 | 57.0% | 10.2% | 3.3% |
| 2001 | 58.5% | 10.7% | 3.3% |
| 2000 | 57.3% | 10.8% | 3.4% |
| 1999 | 55.7% | 10.7% | 3.2% |
| 1998 | 55.6% | 10.8% | 3.2% |
| 1997 | 53.4% | 10.9% | 3.1% |

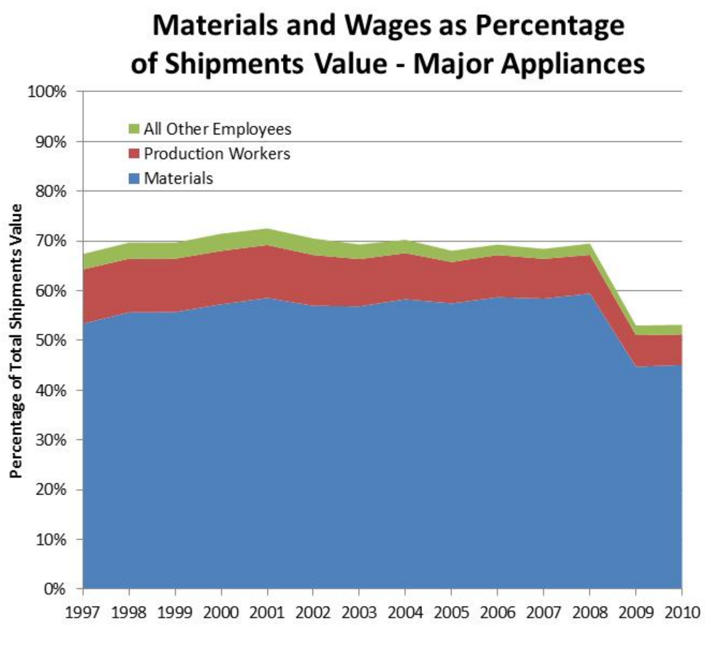
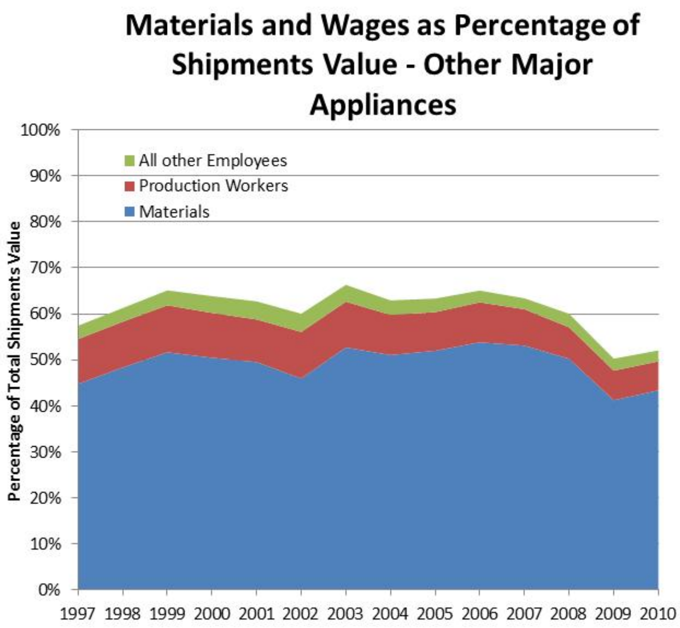


Table 3.12.4 shows the cost of materials and industry payroll as a percentage of value of shipments for the other major appliance industry from 1997 to 2010. Material prices and the cost of payroll as a percentage of value of shipments have remained relatively constant over the 14-year period, with fluctuations from year-to-year. DOE notes that, overall, wages and cost of materials combined represent a smaller percentage of the total shipments value for the other major appliance industry than for the major appliance industry as a whole.

## Table 3.12.4 Other Major Appliance Industry Materials and Wages Cost[39]

| | Cost as a Percentage of Value of Shipments *(%)* | | |
|---|---|---|---|
| **Year** | **Materials** | **Payroll for Production Workers** | **Payroll for All Other Employees** |
| 2010 | 43.4% | 6.3% | 2.4% |
| 2009 | 41.2% | 6.4% | 2.6% |
| 2008 | 50.2% | 6.9% | 2.9% |
| 2007 | 53.1% | 7.9% | 2.4% |
| 2006 | 53.8%[a] | 8.7% | 2.5% |
| 2005 | 52.0% | 8.4% | 3.0% |
| 2004 | 51.0% | 8.7% | 3.1% |
| 2003 | 52.7% | 10.0% | 3.7% |
| 2002 | 45.9% | 10.1% | 4.0% |
| 2001 | 49.5% | 9.3% | 3.9% |
| 2000 | 50.4% | 9.8% | 3.6% |
| 1999 | 51.6% | 10.2% | 3.3% |
| 1998 | 48.3% | 10.0% | 3.0% |
| 1997 | 44.7% | 9.8% | 2.9% |



a) Cost of Materials data not available for 2006; the average value from 2005 and 2007 was used as an estimate.

Table 3.12.5 presents the industry cost structure derived from publicly available sources of financial data including SEC 10-K reports for U.S.-based home appliance manufacturers whose range of products includes residential dishwashers. DOE averaged the financial data from 2003–2010 for each manufacturer and weighted this by their respective market share to obtain an industry average. Each financial statement entry is presented as a percentage of total revenues.

## Table 3.12.5 Industry Cost Structure, Average 2003–2010

| **Financial Statement Entry** | **Percent of Revenues** |
|---|---|
| Cost of sales | 80.6% |
| Earnings before interest and taxes | 5.7% |
| Selling, general and administrative | 13.3% |
| Capital expenditure | 3.2% |
| Research and development | 2.3% |
| Depreciation | 3.1% |
| Net plant, property and equipment | 16.7% |
| Working capital | 7.0% |

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

## 3.13 INVENTORY LEVELS AND CAPACITY UTILIZATION RATES

Table 3.13.1 and Table 3.13.2 show the year-end inventory for the major appliance manufacturing and other major appliance manufacturing industries, according to the *ASM*. Both in dollars and as a percentage of value of shipments, the end-of-year inventory for the major appliance industry steadily declined between 1997 and 2005. Inventories of major appliance manufacturers increased as a percentage of the total value of shipments beginning in 2006, corresponding to the slowdown of the U.S. economy during that period. The other major appliance inventories do not show these same trends; the value of the end-of-year inventories remained relatively steady over the 14-year period, as did the inventory as a percentage of total shipment values, with fluctuations from year-to-year.

**Table 3.13.1 Major Appliance Manufacturing Industry Inventory Levels**[40]

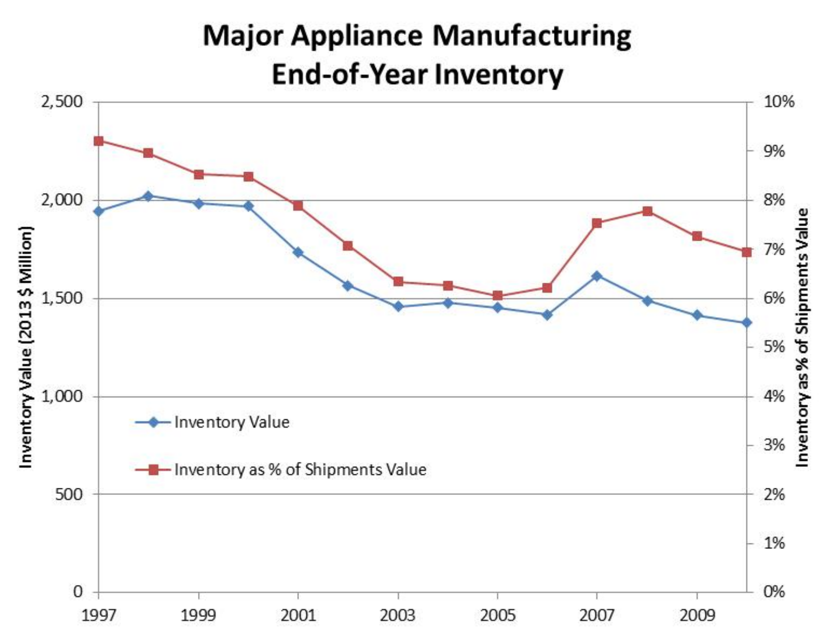
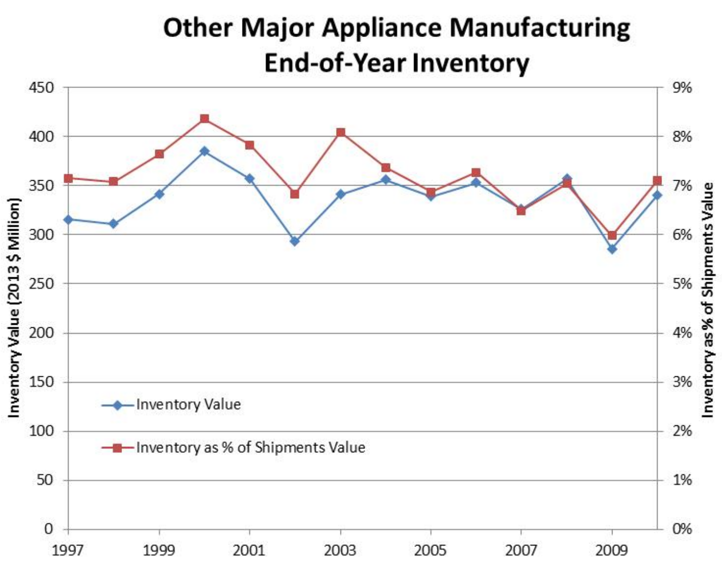
| **Year** | **End-of-Year Inventory** *(2013 $ Mil)* | **EOY Inventory as % of Shipments Value** |  |
|---|---|---|---|
| 2010 | 1,376.3 | 6.9% | |
| 2009 | 1,413.4 | 7.3% | |
| 2008 | 1,489.2 | 7.8% | |
| 2007 | 1,616.6 | 7.5% | |
| 2006 | 1,417.1 | 6.2% | |
| 2005 | 1,453.3 | 6.1% | |
| 2004 | 1,478.1 | 6.3% | |
| 2003 | 1,458.3 | 6.3% | |
| 2002 | 1,565.5 | 7.1% | |
| 2001 | 1,734.2 | 7.9% | |
| 2000 | 1,971.4 | 8.5% | |
| 1999 | 1,984.5 | 8.5% | |
| 1998 | 2,023.2 | 9.0% | |
| 1997 | 1,946.5 | 9.2% | |

**Table 3.13.2 Other Major Appliance Manufacturing Industry Inventory Levels**[41]

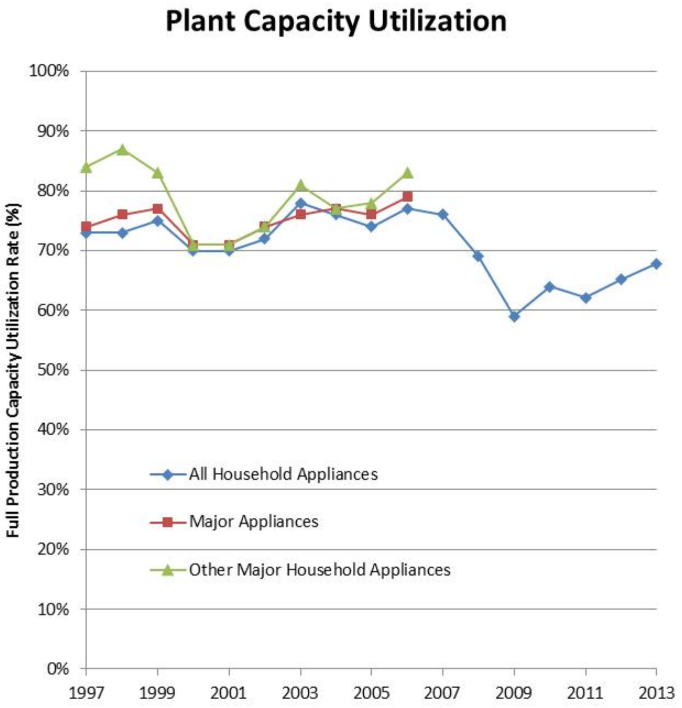
| **Year** | **End-of-Year Inventory** *(2013 $ Mil)* | **EOY Inventory as % of Shipments Value** |  |
|---|---|---|---|
| 2010 | 340.9 | 7.1% | |
| 2009 | 285.7 | 6.0% | |
| 2008 | 357.1 | 7.0% | |
| 2007 | 326.0 | 6.5% | |
| 2006 | 353.1 | 7.3% | |
| 2005 | 339.4 | 6.9% | |
| 2004 | 356.2 | 7.4% | |
| 2003 | 340.9 | 8.1% | |
| 2002 | 293.2 | 6.8% | |
| 2001 | 356.9 | 7.8% | |
| 2000 | 385.3 | 8.4% | |
| 1999 | 341.8 | 7.6% | |
| 1998 | 311.1 | 7.1% | |
| 1997 | 315.7 | 7.2% | |

DOE obtained full production capacity utilization rates from the U.S. Census Bureau's *Survey of Plant Capacity* from 1997–2006. After 2006, the Census Bureau discontinued this survey, and began a new *Quarterly Survey of Plant Capacity Utilization*. However, this survey does not break down the utilization data beyond the "all household appliances" industry. Table 3.13.3 presents utilization rates for various sectors of the household appliance industry.

Full production capacity is defined as the maximum level of production an establishment could attain under normal operating conditions. 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 level. The full production capacity utilization rate for all household appliances shows fairly steady utilization between 70 and 78 percent from 1997 through 2007, with a significant decrease to less than 60 percent from 2007 through 2009. However, from 2010 through 2013, the utilization rate rebounded slightly from its low in 2009. Data for major appliance and "other major household appliance" manufacturers tracks closely with the overall household appliance data from 1997 through 2006.

**Table 3.13.3 Full Production Capacity Utilization Rates**[42, 43]

| | **Plant Capacity Utilization Rates** *(%)* | | |
|---|---|---|---|
| **Year** | **All Household Appliances** | **Major Appliances**[a] | **Other Major Home Appliances**[a] |
| 2013 | 68% | N/A | N/A |
| 2012 | 65% | N/A | N/A |
| 2011 | 62% | N/A | N/A |
| 2010 | 64% | N/A | N/A |
| 2009 | 59% | N/A | N/A |
| 2008 | 69% | N/A | N/A |
| 2007 | 76% | N/A | N/A |
| 2006 | 77% | 79% | 83% |
| 2005 | 74% | 76% | 78% |
| 2004 | 76% | 77% | 77% |
| 2003 | 78% | 76% | 81% |
| 2002 | 72% | 74% | 74% |
| 2001 | 70% | 71% | 71% |
| 2000 | 70% | 71% | 71% |
| 1999 | 75% | 77% | 83% |
| 1998 | 73% | 76% | 87% |
| 1997 | 73% | 74% | 84% |



a) Data unavailable after 2006.

## 3.14 TECHNOLOGY ASSESSMENT

This section provides a technology assessment for residential dishwashers. Contained in this technology assessment are details about product characteristics and operation (section 3.14.1), an examination of possible technological improvements (section 3.14.2), and a characterization of the product efficiencies commercially available (section 3.14.3).

### 3.14.1 Residential Dishwasher Operations and Components

Residential dishwashers are a product designed to clean dishes, utensils, and cookware by using a solution of detergent and heated water. Dishwashers spray this solution from rotating spray arms onto the dishes in order to clean and sterilize them. Dishwashers use electricity to power an electric motor for the pump system that circulates the wash solution, a heating element that heats the wash solution and may assist in drying the dishes, and an optional drain pump. In addition, dishwasher controls consume some electricity and some dishwashers contain a drying fan that circulates air through the dishwasher to aid dish drying. Although almost all dishwashers are capable of heating water with their internal heating element, dishwashers in the United States are typically connected to the hot water line to supply hot water. Water is automatically fed to the dishwasher through an electrically-operated water valve connected to the hot water supply.

The dishes, utensils, and cookware are washed, rinsed and dried within a tub that is inside the dishwasher cabinet.

Residential dishwashers are traditionally front-loading appliances. The door on the front of the cabinet cantilevers down, and the washer racks slide out on rails for loading and unloading. When the dishwasher is loaded and the washer racks are slid into the dishwasher cabinet, the cabinet door is closed, sealing the tub, and a door switch indicates that the door latch has sealed the cabinet door. The dishwasher controls, which may be electromechanical or electronic, can then begin the wash cycle.

The wash cycle begins when the water fill valve fills the dishwasher tub until the control timer indicates a complete fill, or the dishwasher float switch indicates that the tub is full, or a water meter indicates a sufficient amount of water has entered the tub. The main pump, which provides pressurized fluid to the dishwasher spray arm or arms, is attached to the sump of the tub, where water accumulates. The pump, which uses a rotating impeller to pressurize the fluid and deliver it to the spray arms, is connected directly to the electric motor, or connected by a belt or other form of transmission. The heating element can be part of the sump or installed above it within the tub. The heating element ensures the water is heated to an adequate temperature for cleaning. The detergent is released from an electrically controlled detergent container which is filled with detergent prior to initiating the dishwashing cycle.

Residential dishwashers can be further segregated, depending on whether they feature one or two pumps. On a one-pump model, the main pump not only pressurizes the wash and rinse system, but it can also be used to drain the wash fluid, either by reversing the pump direction (forcing the fluid out the drain), or by using a diverting valve located on the pump output line. Dishwashers with two pumps use one pump optimized for cleaning and rinsing procedures and a second pump optimized for draining. After each drain cycle (until the cleaning cycle ends), the tub is refilled with water for rinse or wash operations. Dishwashers may drain and refill the tub multiple times during the dishwashing cycle as the washing and rinsing water becomes soiled. In some dishwashers this process is controlled by a timer, while other dishwashers use sensors and electronic controls to determine when to change the water, the amount of water for each fill, water temperatures in each cycle, and other variables.

The heating element may be activated to heat the dishwasher cabinet and speed up drying once the dishwasher completes the rinse and drain cycles. Dishwashers with an additional drying fan and air heater utilize these devices during the drying phase of the wash cycle.

Some dishwashers use separate drawers for each washing rack, instead of one large tub with two or more racks running on extensible rails. These multi-drawer dishwashers are essentially two small dishwashers stacked on top of each other. This two-drawer system allows users to run the dishwasher with smaller loads without wasting the water or energy a full-size dishwasher would use on a half-empty load, although some full-size dishwashers allow single-rack cleaning as well.

### 3.14.2 Residential Dishwasher Technology Options

For residential dishwashers, DOE will consider technologies identified in the following three sources: (1) DOE's May 2012 direct final rule establishing energy conservation standards for residential dishwashers (77 FR 31918 (May 30, 2012)); (2) information provided by trade publications; and (3) design data identified in manufacturer product offerings. The technology options identified for residential dishwashers are listed in Table 3.14.1.

**Table 3.14.1 Technology Options for Residential Dishwashers**

| |
|---|
| 1. Condensation drying |
| 2. Control strategies |
| 3. Fan/jet drying |
| 4. Flow-through heating |
| 5. Improved fill control |
| 6. Improved food filter |
| 7. Improved motor efficiency |
| 8. Improved spray-arm geometry |
| 9. Increased insulation |
| 10. Low-standby-loss electronic controls |
| 11. Microprocessor controls and fuzzy logic, including adaptive or soil-sensing controls |
| 12. Modified sump geometry, with and without dual pumps |
| 13. Reduced inlet-water temperature |
| 14. Supercritical carbon dioxide washing |
| 15. Ultrasonic washing |
| 16. Variable washing pressures and flow rates |

#### *Condensation drying*

This technology reduces the amount of energy required to dry the dishes at the end of the wash cycle. Instead of using an exposed electric heating element to dry the dishes, hot rinse water is used to heat the dishes to a high temperature. Subsequently, room air is admitted into the dishwasher. Simple convection then pulls cooler, less moist air into the dishwasher from the bottom of the cabinet and discharges warm, moist air out of the top of the cabinet. Some designs do not allow outside air into the dishwasher and pull cool air over the exterior cabinet surface instead. As the warm, moist air inside the dishwasher encounters the cavity walls (via natural convection), the water condenses on the wall surface and runs into the sump. Most European installations connect the dishwasher to the cold water line. A reservoir of cold water can thus be maintained on the outside of the stainless tub, providing a chilled surface on which the moisture can condense. U.S. condensing systems may be less effective because the condensing surface is not as cool.

#### *Control strategies*

Effective dishwashing requires water, heat, mechanical action (spraying of water), time, and detergent. Manufacturers may adjust the controls of a dishwasher to limit the amount of water used, or the set-point temperature of the wash or rinse water. This improves efficiency by decreasing the amount of energy associated with water heating. To help compensate for the negative impact on cleaning performance associated with decreasing water use and water temperature, manufacturers will typically increase the cycle time. This allows more time for the smaller volume of water to be circulated within the cabinet, helping to maintain wash performance.

### *Fan/jet drying*

To reduce drying times, some residential dishwasher designs use a fan to circulate air and to accelerate the drying process outlined in the condenser drying section above. Fans may be installed in the dishwasher door or in the cabinet itself, with the condensing water being diverted back into the sump. Convection fan systems are found on some of the higher efficiency dishwashers currently available on the U.S. market.

### *Flow-through heating*

As discussed in section 3.14.1, residential dishwashers use either an exposed tubular or a flow-through supplemental water heating element to bring water inside the dishwasher up to operating temperature. Water is heated before being pumped and distributed to the spray arms. Typically, dishwashers with exposed tubular heating elements require more standing water than dishwashers with flow-through heaters. Flow-through heaters consist of a metallic flow tube around which an electrical tubular resistance heater is wrapped. The flow-through heater usually connects the sump to the main pump and hence forms an integral part of the water circuit. The volume of water required to fill a flow-through element is typically much lower than the volume required to at least partially submerge a tubular supplemental heating element. The potential water and energy savings depend upon the configuration of the sump and type of supplemental water heating element.

### *Improved fill control*

Modifying the fill control to admit a lower volume of water can reduce hot water consumption and energy use. In models that use electro-mechanical controls, this could be accomplished by reducing the safety factor employed by manufacturers to ensure proper fill volumes. Safety factors, which result in overfill for some consumers, are applied to the volume of the sump region and also to the timer-activated water fill to ensure enough water for proper pump action and cleaning. The use of more accurate electronic timers would maintain a tighter tolerance on the fill time period.

Residential dishwashers with electromechanical controls also employ an overfill factor to account for varying water pressures. Water flow rates through valves vary with water pressure, so the use of mechanical timer controls could cause a variation in the quantity of hot water delivered. Therefore, an additional overfill factor of 10 or 15 percent is traditionally used to compensate for the range of water pressures existing in the United States. The use of pressure-activated water volume sensors could be used to control water fill rather than a mechanical timer to reduce overfills.

Residential dishwashers may alternatively use a float switch mounted in the sump to terminate the filling process. The float switch is an electro-mechanical switch activated by the rising water level in the sump. Once the sump has been filled to the appropriate level, the float triggers the switch, terminating the fill. Because the float switch directly measures the water level, it can enable a high degree of fill control. However, simple float switches can only measure one fill level, which may be inadequate for washers with very high efficiency targets.

The most sophisticated water fill control option is to incorporate a water meter into the dishwasher. Such a device allows the controller to measure exactly how much water has been added and allows the washer to tailor its water input precisely to the needs of each individual wash or rinse cycle. By metering the water precisely, this approach gives the dishwasher controller greater flexibility than a timed fill or float switch. However, unlike a timed fill or a float switch, a water meter approach requires an electronic dishwasher controller that can make use of the pulses generated by the water meter.

### *Improved food filter*

Improved food filters help prevent the re-deposition of food particles, possibly leading to one less fill for rinsing. Residential dishwashers utilizing fine filters have less food re-deposited on dishes, because the food is filtered out before being re-circulated by the pump through the spray arms. Another benefit is that the water supply lines, nozzles, etc. can have small cross-sections without the risk of clogging due to entrained food particles. Thus, a fine food filter can enable a manufacturer to reduce the volume of the water needed to fill all parts of the water system.

Typical filter designs have a self-cleaning feature that backwashes the filter automatically and therefore minimizes manual filter cleaning. Although less water is required overall for dishware rinsing, the washing of the filter requires water use. The task can be changed to an intermittent event via the inclusion of a pressure transducer, which can sense how clogged the filter is and thus signal a rinse requirement to an electronic controller. The filter is cleaned whenever the need arises, allowing the designer to implement lower-volume sump designs. Another implementation approach could monitor the pump motor directly to detect excessive slip, resistance, or other parameter to infer a clogged filter condition.

### *Improved motor efficiency*

An electric motor runs the main water pump and, if separate, the drain pump as well. Dishwashers have typically used split-phase or shaded-pole motors because of their low torque requirement and constant starting current condition. A capacitor-type motor, such as a permanent split capacitor (PSC) motor, is more efficient than a split-phase or shaded-pole motor. It uses a capacitor in both the starting and running modes. The capacitor-type motor increases the power factor, and, therefore, reduces heating losses in the stator. An electric motor efficiency of 65 percent should be possible using a capacitor-type motor.

A 30-percent improvement in motor efficiency produces approximately a 2.5-percent overall reduction in dishwasher energy consumption. Dishwashers with permanent magnet motors could reduce the electrical consumption of the pump motor by a further 10–20 percent from the levels attainable with PSC motors.

### ***Improved spray-arm geometry***

Spray arms, which are typically located at the center and the bottom of a dishwasher cavity, are designed to rotate and spray pressurized water on the dishwasher contents. If the spray arms are designed to more effectively remove food particles, the dishwasher will use less hot water and energy.

### ***Increased insulation***

Some dishwashers feature some insulation to reduce noise levels. Generally, these dishwashers use bitumen attached to the wash tub to dampen noised caused by vibrations in the tub during operation. However, the added thermal mass of the bitumen insulation typically results in higher energy consumption. Other dishwashers use a cotton liner to decrease heat losses from the tub. The cotton insulates the wash tub with a lower thermal mass than bitumen. The marginal benefit for this type of additional insulation is typically very small.

### ***Low-standby-loss electronic controls***

Electronic controls may consume power even when the dishwasher 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 dishwasher, but will not impact the energy consumption of the dishwasher during operation. Low-standby-loss electronic controls can be implemented in a wide variety of ways.

### ***Microprocessor controls and fuzzy logic, including adaptive or soil-sensing controls***

Microprocessor controls and fuzzy logic, including adaptive or soil-sensing controls, are able to reduce the energy and water consumption of a dishwasher by allowing the machine to adapt to variable conditions inside the unit. Sensors located inside the dishwasher provide a stream of information, including turbidity, conductivity, temperature, and spray arm rotation, to the fuzzy logic controller which, in turn, controls the operation of the dishwasher by adjusting the amount of water used and/or the water temperature, based on inferred load and/or soil level. This is somewhat analogous to manually selecting light-, normal- or heavy-duty wash selection.

For example, some dishwasher designs have sensors that measure the amount of food soil in the water and algorithms that adjust water temperature, fill levels, and cycle time accordingly. This design feature may also track the amount of time between loads so the controller can adjust for dried-on food, as well as taking into account the number of times the door has been opened to determine load size. According to Honeywell, a key developer and supplier of soil-sensing packages, such a system can reduce energy consumption by 35 percent and water consumption by 45 percent.[44] Most manufacturers offer dishwashers using soil-sensing controls.

In 2003, the DOE test procedure was updated to more accurately measure energy efficiency for machines equipped with soil-sensing controls. For these machines, water and electrical energy consumption are measured under varying soil load conditions, and the results are averaged via a weighted formula that represents typical usage patterns.

### ***Modified sump geometry, with and without dual pumps***

The amount of water used for each cycle can be reduced by a change in the geometry of the sump and its integration with the main pump and a drain pump (if any). During the wash part of the cycle, approximately half of the water at any given time in the dishwasher is in the sump to ensure an air-free water supply to the pump. Current sump designs attempt to minimize water use while maintaining an adequate water supply to the pump. This technology option would optimize the sump to minimize the total amount of water needed per fill. Another factor in sump design is how quickly water can flow back to the sump after being sprayed on the dishes.

Many baseline dishwashers use one pump to deliver pressurized water, with detergent in solution, to the spray arms, and to drain the wash solution when the wash cycle is complete. This pump is powered by a single electric motor. By using two pumps and two electric motors, with one set optimized for washing and one set optimized for draining, the overall energy consumption due to water pumping may be decreased.

### ***Reduced inlet-water temperature***

This option uses cold temperature water for some of the rinse cycles. Dishwashers with adequate heating elements could tap only to the cold water supply line, allowing the dishwasher’s heating element to heat the water as required. For reduced-temperature rinse cycles, the water would be heated to a lower temperature than the temperature of water typically available from the hot water supply line (120 °F), reducing energy consumption. The dishwasher’s internal water heater may also be more efficient than the household water heater. However, a connection to the cold water line may require more time to complete the washing cycle because the dishwasher requires additional time to internally heat the water to operating temperatures.

Alternatively, a dishwasher could tap both the hot and cold water lines, and mix hot and cold water in order to reduce inlet water temperatures. Again, because U.S. dishwashers are conventionally connected to a hot water line only, this option would necessitate plumbing in a cold water line to the dishwasher in addition to the currently-used hot water line.

Another means to lower rinse water temperature is to lower the hot water temperature setting on the household water heater and use the dishwasher's heating element to raise the water to the needed temperature. But lowering the household water heater temperature below 120 °F may not satisfy other household hot water requirements.

### *Supercritical carbon dioxide washing*

At an Electrolux-sponsored design competition, students from the University of New South Wales designed a dishwasher with a cleaning process based upon supercritical carbon dioxide instead of the conventional detergent and water solution.[45] The supercritical carbon dioxide within the dishwasher behaves simultaneously as a liquid and a gas, completely filling the washing tub and covering the dishes, like a gas, but dissolving grease like a liquid. The supercritical carbon dioxide is used in a closed-loop process. After the wash cycle, contamination is removed from the carbon dioxide, which is stored for the next wash cycle.

### *Ultrasonic washing*

Ultrasonic washing uses high frequency sound generators to create cavitation bubbles within the wash water, in which the dishware is completely submerged. These bubbles implode upon contact with a surface, effecting a mechanical scrubbing action that removes soil from the dishware. This cleaning action is not dependent on water temperature, water flow rate, or detergents, making the process highly energy efficient, because a standing pool of room temperature water may be used. However, standing ultrasonic waves within the washing cavity and the force of cavitation implosion can damage fragile dishware. Also, consumers may not perceive ultrasonic dishwashers as properly sterilizing dishes at low temperatures, resulting in a perceived decrease in consumer utility, even though not all current dishwashers operate at high enough temperatures to effectively sterilize their contents.

Sharp introduced an ultrasonic and ionic dishwasher for the Japanese market in September 2002, which utilizes a different ultrasonic technique for soil removal.[46] The dishwasher tank is partially filled with water, and a superfine mist is created using an ultrasonic generating element to remove food stains from dishes. Hard water ion washing is then performed using table salt. A prepared salt-water mixture is put through an exchange system to make hard water containing an abundance of calcium ions (Ca2+) and magnesium ions (Mg2+). This water washes the dishes using a salting-in effect to remove protein-based stains, which would otherwise become hardened and difficult to remove when using conventional heated tap water. The ion exchange system then removes calcium and magnesium ions from the tap water to create soft water for rinsing. The combination of the ultrasonic waves and the salt-water mixture is designed to wash without the need for dishwasher detergent. Unlike the technology described above, Sharp's ultrasonic dishwasher does not rely on immersing the dishes in an ultrasonically excited fluid.

### *Variable washing pressure and flow rates*

Variable washing pressure and flow rates are being employed in some residential dishwasher models to reduce cycle times or to accommodate the various levels of soiling. For example, the user can choose an option to provide a 30-percent increase in washing pressure and, thus, more rapidly (and powerfully) clean dishes. The user interface usually presents this option as, for example, a “pots and pans” wash setting versus a “normal” setting. Higher energy consumption from the dishwasher pump is required to achieve the increase in washing pressure.

Conversely, reduced washing pressure requires less energy from the dishwasher pump to run the cleaning cycles, reducing the energy consumption of the dishwasher as long as the cycle time is not increased. Such a strategy may be employed for rinse cycles, during which clean water is used to remove detergent from the dishes. Because the rinse cycle does not need high washing pressure to remove food material from soiled dishes, a reduced water pressure is feasible without degrading the overall cleaning performance of the dishwasher.

Some dishwashers alternate the delivery of water to the top-rack spray arm and the bottom-rack spray arm. This diversion is accomplished by using a valve or other fluid control mechanism to route the water to one spray arm at a time. Once the active spray arm has completed its cycle, the water may be circulated through the other spray arm to complete a similar cycle. This reduces the amount of water required by the dishwasher, because the dishwasher only heats and circulates enough water for one spray arm. By reducing the amount of water required, and therefore the amount of water heating required, alternating water delivery to the top and bottom spray arms reduces the energy consumption of the dishwasher.

In order to implement this feature, the dishwasher must be capable of adequately filtering the wash water. Because a smaller quantity of water is used to remove the same quantity of dish soiling, the water will contain a higher concentration of soiling. If the dishwasher filtering system does not adequately filter the water, re-deposition of food soiling could increase as the soiled water is circulated.

In addition to reducing the energy consumption of dishwashers washing full loads, this technology option also lets manufacturers offer dishwashers with efficient “half-load” wash cycles in which water is only routed to one spray arm, which allow consumers to run the dishwasher when it is half-full without wasting the water and energy necessary to wash a full load.

### 3.14.3 Energy Efficiency

In preparation for the screening and engineering analyses, DOE gathered data on the energy efficiency of dishwashers available in the marketplace at the time of its analysis. Figure 3.14.1 displays the distribution of standard residential dishwasher basic models in DOE’s compliance certification database, as of May 18, 2014, as a function of estimated annual energy use, rounded down to 10 kWh/year intervals.[j]

---

[j] Available at *http://www.regulations.doe.gov/certification-data/*.

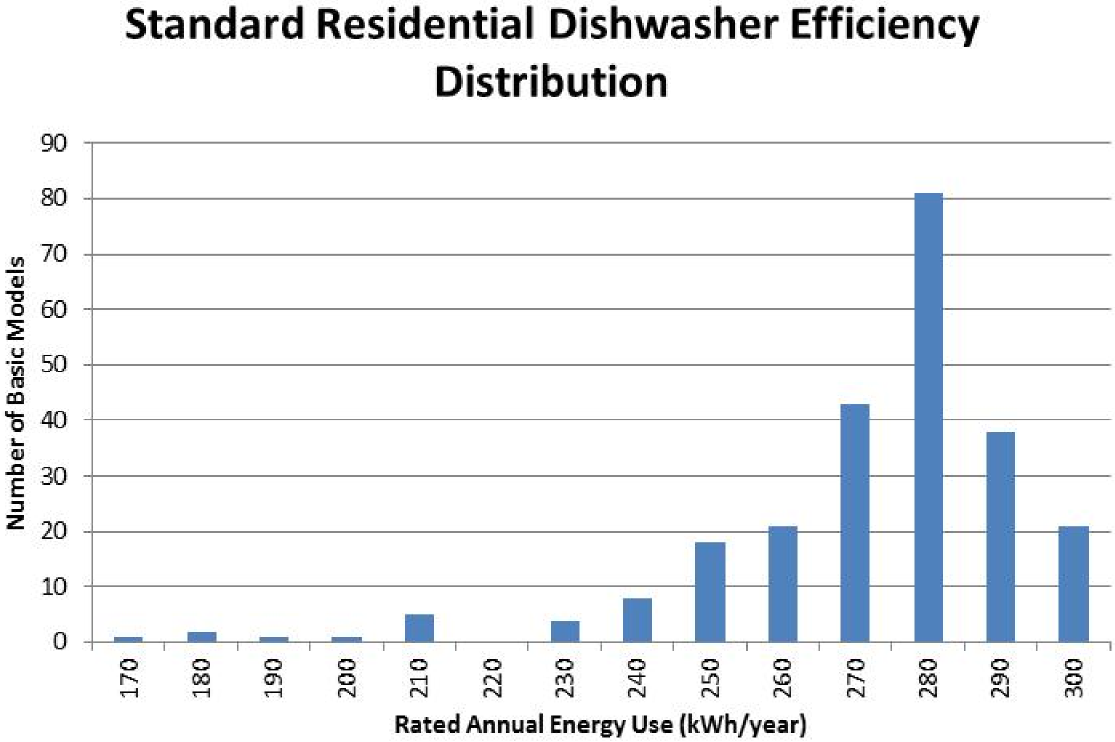


**Figure 3.14.1 Standard Residential Dishwashers in the DOE Compliance Certification Database[47]**

## REFERENCES

1 "U.S. Appliance Industry: Market Share, Life Expectancy & Replacement Market, and Saturation Levels". *Appliance Magazine Market Research Report*, January 2010.

2 *Ibid.*

3 Maytag. 2005. "Whirlpool Corporation and Maytag Corporation Sign Definitive Merger Agreement". *Maytag Press Release*, August 22, 2005.

4 P. Hussmann. 2006. "Justice to Extend Maytag-Whirlpool Merger Review". *Newton Daily News Online*, February 14, 2006.

5 W. Ryberg. 2006. "Harkin, Boswell want Maytag sale blocked". *Des Moines Register*, January 13, 2006.

6 *Ibid.*

7 U.S. Department of Justice (U.S. DOJ). 2006. *Department of Justice Antitrust Division Statement on the Closing of its Investigation of Whirlpool's Acquisition of Maytag*. March 29, 2006.

8 *Ibid.*

9 U.S. Small Business Administration (U.S. SBA), 2010. *Table of Small Business Size Standards Matched to North American Industry Classification System Codes*. Available online at *www.sba.gov/sites/default/files/Size_Standards_Table.pdf* (Accessed July 15, 2011).

10 Association of Home Appliance Manufacturers (AHAM) *Fact Book* 2005.

11 AHAM *Fact Book* 2003.

12 U.S. Census Bureau. "New Residential Construction." Available online at *www.census.gov/construction/nrc/* (Accessed July 15, 2014).

13 AHAM *Fact Book* 2005.

14 "U.S. Appliance Shipment Statistics Monthly: January 2011". *Appliance Magazine Market Research Report*, January 2011.

15 "2011 Full-Year Appliance Industry Shipment Statistics". *Appliance Magazine Market Research Report*, March 2012.

---

[16] "2012 Full-Year Appliance Industry Shipment Statistics & Year-In-Review". *Appliance Magazine Market Research Report*, March 2013.

[17] ENERGY STAR Annual Sales Data. 2000 to 2012. Available online at: *www.energystar.gov/index.cfm?c=partners.unit_shipment_data* (Accessed July 15, 2014).

[18] U.S. Census Bureau. 2006. "Table 2 - Statistics for Industry Groups and Industries: 2005 and Earlier Years." *2005 Annual Survey of Manufactures* (*ASM*), November 2006.

[19] U.S. Census Bureau. 2003. "Table 2 - Statistics for Industry Groups and Industries: 2001 and Earlier Years." *2001 Annual Survey of Manufactures* (*ASM*), January 2003.

[20] U.S. Census Bureau. 2010. "Sector 31: Annual Survey of Manufactures: General Statistics: Statistics for Industry Groups and Industries: 2008 and 2007." *2008 Annual Survey of Manufactures* (*ASM*), March 2010. Available online at: *http://www.census.gov/manufacturing/asm/historical_data/index.html* (Accessed July 15, 2014).

[21] U.S. Census Bureau. 2008. "Sector 31: Annual Survey of Manufactures: General Statistics: Statistics for Industry Groups and Industries: 2006 and 2005." *2006 Annual Survey of Manufactures* (*ASM*), November 2008. Available online at: *http://www.census.gov/manufacturing/asm/historical_data/index.html* (Accessed July 15, 2014).

[22] U.S. Census Bureau. 2011. *2010 Current Industrial Report – Major Household Appliances* (*CIR*), May 2011. Available online at: *www.census.gov/manufacturing/cir/historical_data/ma335f/ma335f10.xls* (Accessed July 15, 2014).

[23] U.S. Census Bureau. 2006. "Table 2 - Statistics for Industry Groups and Industries: 2005 and Earlier Years." *2005 Annual Survey of Manufactures* (*ASM*), November 2006.

[24] U.S. Census Bureau. 2003. "Table 2 - Statistics for Industry Groups and Industries: 2001 and Earlier Years." *2001 Annual Survey of Manufactures* (*ASM*), January 2003.

[25] U.S. Census Bureau. 2010. "Sector 31: Annual Survey of Manufactures: General Statistics: Statistics for Industry Groups and Industries: 2008 and 2007." *2008 Annual Survey of Manufactures* (*ASM*), March 2010. Available online at: *http://www.census.gov/manufacturing/asm/historical_data/index.html* (Accessed July 15, 2014).

[26] U.S. Census Bureau. 2008. "Sector 31: Annual Survey of Manufactures: General Statistics: Statistics for Industry Groups and Industries: 2006 and 2005." *2006 Annual*

---

*Survey of Manufactures* (*ASM*), November 2008. Available online at: *http://www.census.gov/manufacturing/asm/historical_data/index.html* (Accessed July 15, 2014).

[27] U.S. Census Bureau. 2011. *2010 Current Industrial Report – Major Household Appliances* (*CIR*), May 2011. Available online at: *www.census.gov/manufacturing/cir/historical_data/ma335f/ma335f10.xls* (Accessed July 15, 2014).

[28] U.S. Census Bureau. 2010. *2009 Current Industrial Report – Major Household Appliances* (*CIR*), May 2010. Available online at: *www.census.gov/manufacturing/cir/historical_data/ma335f/ma335f09.xls* (Accessed July 15, 2014).

[29] U.S. Census Bureau. 2009. *2008 Current Industrial Report – Major Household Appliances* (*CIR*), July 2009. Available online at: *www.census.gov/manufacturing/cir/historical_data/ma335f/ma335f08.xls* (Accessed July 15, 2014).

[30] U.S. Census Bureau. 2008. *2007 Current Industrial Report – Major Household Appliances* (*CIR*), April 2008. Available online at: *www.census.gov/manufacturing/cir/historical_data/ma335f/ma335f07.xls* (Accessed July 15, 2014).

[31] U.S. International Trade Commission. *USITC Interactive Tariff and Trade Data Web*. Available online at: *http://dataweb.usitc.gov/scripts/user_set.asp* (Accessed July 15, 2014).

[32] AHAM *Fact Book*. 2005.

[33] AHAM, DOE Docket No. EERE–2011–BT–STD–0060, Submission 03.

[34] AHAM *Fact Book*. 2005.

[35] “U.S. Appliance Industry: Market Share, Life Expectancy & Replacement Market, and Saturation Levels”. *Appliance Magazine Market Research Report*, January 2010.

[36] U.S. Census Bureau. 1997–2011. Statistics.

[37] *Ibid*.

[38] *Ibid*.

[39] *Ibid*.

---

[40] *Ibid.*

[41] *Ibid.*

[42] U.S. Census Bureau, *Survey of Plant Capacity*, 1997 to 2006.

[43] U.S. Census Bureau, *Quarterly Survey of Plant Capacity Utilization*, 2007 to 2013.

[44] "An Intelligent Wash Process Sensor." *Scientific Honeyweller,* Sensors Issue, 1996.

[45] *Appliance Magazine*, November 2005.

[46] *Appliance Magazine*, October 2002.

[47] DOE Compliance Certification Database. Available online at: *www.regulations.doe.gov/certification-data/* (Accessed July 15, 2014).

# CHAPTER 4. SCREENING ANALYSIS

## TABLE OF CONTENTS

## LIST OF TABLES

# CHAPTER 4. SCREENING ANALYSIS

## 4.1 INTRODUCTION

This chapter discusses the screening analysis conducted by the U.S. Department of Energy (DOE) of the design options identified in the market and technology assessment for residential dishwashers (chapter 3 of this notice of proposed rulemaking (NOPR) technical support document (TSD)). In the market and technology assessment, DOE presented an initial list of technology options that can be used to reduce energy and/or water consumption for residential dishwashers. The goal of the screening analysis is to identify any design options that will be eliminated from further consideration in the rulemaking analyses.

The candidate technology options are assessed based on DOE analysis as well as inputs gathered from interested parties including manufacturers, trade organizations, and energy efficiency advocates in support of the direct final rule published on May 30, 2012 (May 2012 direct final rule). Design options that are judged to be viable approaches for improving energy efficiency are retained as inputs to the subsequent engineering analysis (chapter 5 of this NOPR TSD). Design 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 design option is detailed in the following sections.

## 4.2 DISCUSSION OF DESIGN OPTIONS

For residential dishwashers, the screening criteria specified in section 4.1 were applied to the design options to either retain or eliminate each technology from the engineering analysis.

### 4.2.1 Screened-Out Design 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 design options that were screened out for this rulemaking, and the reasons why they were eliminated.

### *Reduced inlet-water temperature*

Reduced inlet-water temperature requires that residential dishwashers tap the cold water line for their water supply. Because most dishwashers in the United States tap the hot water line, this design option would require significant alteration of existing dishwasher installations in order to accommodate newly purchased units incorporating this design option. Therefore, DOE believes that it would not be practicable to install this technology on the scale necessary to serve the relevant market at the time of the effective date of an amended standard.

### *Supercritical carbon dioxide washing*

Supercritical carbon dioxide washing, which uses supercritical carbon dioxide instead of conventional detergent and water to wash dishes, is currently being researched. Thus, DOE believes that it would not be practicable to manufacture, install and service this technology on the scale necessary to serve the relevant market at the time of the effective date of an amended standard. Furthermore, because this technology is in the research stage, it is not yet possible to assess whether it would have any adverse impacts on equipment utility to consumers or equipment availability, or any adverse impacts on consumers' health or safety.

***Ultrasonic washing***

A residential dishwasher using ultrasonic waves to generate a cleaning mist was produced for the Japanese market in 2002; however, this model is no longer available on the market. Available information indicates that the use of a mist with ion generation instead of water with detergent would decrease cleaning performance, impacting consumer utility.

Ultrasonic dishwashing based upon soiled-dish immersion in a fluid that is then excited by ultrasonic waves has not been demonstrated. In an immersion-based ultrasonic dishwasher, standing ultrasonic waves within the washing cavity and the force of bubble cavitation implosion can damage fragile dishware. Because no manufacturers currently produce ultrasonic dishwashers, it is impossible to assess whether this design option would have any impacts on consumers' health or safety, or product availability.

Based on this information, DOE has screened out both identified product types that incorporate the ultrasonic washing technology option.

### 4.2.2 Remaining Design Options

For residential dishwashers, DOE will consider the design options shown in Table 4.2.1 for further analysis. DOE has retained each of these design options because they either are available, or have previously been available, in commercially available equipment and also meet the criteria listed in section 4.2.1 relating to product utility, availability, and impacts on health and safety. Each of these technologies will be evaluated further in the subsequent engineering analysis.

**Table 4.2.1 Retained Design Options for Residential Dishwashers**

| |
|---|
| 1. Condensation drying |
| 2. Control strategies |
| 3. Fan/jet drying |
| 4. Flow-through heating |
| 5. Improved fill control |
| 6. Improved food filter |
| 7. Improved motor efficiency |
| 8. Improved spray-arm geometry |
| 9. Increased insulation |
| 10. Low-standby-loss electronic controls |
| 11. Microprocessor controls and fuzzy logic, including adaptive or soil-sensing controls |
| 12. Modified sump geometry, with and without dual pumps |
| 13. Variable washing pressures and flow rates |

# CHAPTER 5. ENGINEERING ANALYSIS

## TABLE OF CONTENTS

## LIST OF TABLES

## LIST OF FIGURES

# 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 and water consumption and costs of residential dishwashers 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 notice of proposed rulemaking (NOPR) technical support document (TSD)) and technology options from the screening analysis (chapter 4). Additional inputs include cost and energy efficiency data, which DOE determined through investigative testing and teardown analysis. The primary output of the engineering analysis is a relationship comparing increases in manufacturer production costs (MPCs) to decreases in energy and water consumption at each efficiency level, or 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 curves served as the input to the energy use analysis (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 decreasing energy and water consumption at each efficiency level, without regard to the particular design options used to achieve such decreases; 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.

DOE used a hybrid approach of all three methods in developing cost estimates at each efficiency level for residential dishwashers, focusing on the design-option and reverse-engineering approaches. This approach involved physically disassembling commercially available products, reviewing publicly available cost and performance information, and modeling equipment cost. From this information, DOE estimated the MPC for a range of products currently available on the market. DOE then considered the incremental steps manufacturers may take to achieve lower energy and water consumption. In its modeling, DOE started with the baseline MPC and added the expected design options at each higher efficiency level to estimate incremental MPCs. By doing this, the engineering analysis did not factor in additional higher-cost features with no impact on efficiency that are included in some models. However, at efficiency levels where the product designs significantly deviated from the baseline product, DOE used the efficiency-level approach to determine a MPC estimate, while removing the costs associated with non-efficiency-related components or features. This TSD chapter further describes the process DOE followed to establish its cost-efficiency relationship for residential dishwashers.

## 5.2 PRODUCT CLASSES ANALYZED

DOE separated residential dishwashers into two product classes. In general, the criteria for separation into different classes are (1) type of energy used (natural gas or electricity), and (2) capacity or other performance-related features such as those that provide utility to the consumer, or others deemed appropriate by the Secretary that would justify the establishment of a separate energy conservation standard. (42 U.S.C. 6295 (q))

For residential dishwashers, the size of the unit impacts the energy consumed. Because standard residential dishwashers offer enhanced consumer utility over compact units (*i.e.*, the ability to wash more dishes), DOE has established the following product classes, which are based on the size of the dishwasher (as specified in American National Standards Institute (ANSI)/Association of Home Appliance Manufacturers (AHAM) Standard DW-1-2010, *Household Electric Dishwashers*):

- Compact, capacity less than eight place settings plus six serving pieces; and
- Standard, capacity equal to or greater than eight place settings plus six serving pieces.

For this engineering analysis, DOE analyzed products from both the standard and compact product classes.

## 5.3 EFFICIENCY LEVELS

For residential dishwashers, energy conservation standard levels are currently defined by two factors: annual energy use, in terms of kilowatt-hours per year (kWh/year), and per-cycle water consumption, in terms of gallons per cycle (gal/cycle). The annual energy use calculation accounts for machine electrical energy consumption, external water heating energy consumption, and standby-mode and off-mode energy consumption. Water consumption is a direct measurement of the water used during the energy test for non-soil-sensing dishwashers, and a weighted average of the water used for the three different test cycles (with heavy, medium, and light soil loads) for soil-sensing dishwashers.

### 5.3.1 Baseline Units

DOE selected baseline units to represent the basic characteristics of equipment for residential dishwashers. Typically, a baseline unit is a unit that just meets current energy conservation standards and provides basic consumer utility. DOE used the baseline units in the engineering analysis and the LCC and PBP analyses. To determine energy savings and changes in price, DOE compared each higher energy efficiency design option with the baseline units.

In a direct final rule published in the *Federal Register* on May 30, 2012 (May 2012 direct final rule), DOE established the following energy and water conservation standards for residential dishwashers manufactured on or after May 30, 2013 (77 FR 31918), which DOE has incorporated into this NOPR analysis as the baseline efficiency levels:

- Standard dishwashers – 307 kWh/year and 5.0 gal/cycle; and
- Compact dishwashers – 222 kWh/year and 3.5 gal/cycle.

### 5.3.2 Incremental Efficiency Levels

#### 5.3.2.1 Standard Product Class

DOE analyzed several efficiency levels for standard residential dishwashers, and obtained incremental cost data at each of these levels. Table 5.3.1 includes the analyzed efficiency levels and the reference source of each level for the standard product class.

**Table 5.3.1 Standard Residential Dishwasher Efficiency Levels**

| **Level** | **Efficiency Level Reference Source** | **Efficiency Level** | |
|---|---|---|---|
| | | **Annual Energy Use** *(kWh/year)* | **Water Consumption** *(gal/cycle)* |
| Baseline | DOE Standard | 307 | 5.00 |
| EL 1 | ENERGY STAR (current) | 295 | 4.25 |
| EL 2 | Gap Fill | 280 | 3.50 |
| EL 3 | Gap Fill | 234 | 3.10 |
| EL 4 | Maximum Available[a] | 180 | 2.22 |
| a) Source: DOE-certified dishwashers as of May 22, 2014 | | | |

DOE analyzed four efficiency levels beyond the baseline for standard residential dishwashers in this engineering analysis. Efficiency Level 1 corresponds to the existing

ENERGY STAR[a] criteria for standard residential dishwashers. Efficiency Level 2 corresponds to potential ENERGY STAR criteria identified during the process of setting the current ENERGY STAR criteria. This level was included in the Draft 2 V5.0 Dishwashers Specification, released on February 3, 2011.[b] Efficiency Level 3 is a gap-fill level, developed as described below. Efficiency Level 4 is the maximum available efficiency level, as defined by the maximum available technology that DOE identified on the market at the time of this analysis. DOE did not identify any working prototypes that were more efficient than this maximum available technology.[c]

To determine the appropriate energy and water consumption for Efficiency Level 3, DOE surveyed the products currently available on the market in the United States. DOE's Compliance Certification Database[d] contains standard residential dishwasher models with a range of rated annual energy consumption and per-cycle water consumption between the maximum available and baseline levels. However, after removing products certified using a cold-water connection, which DOE screened out as a technology option as discussed in chapter 4 of this NOPR TSD, DOE observed that very few products are available with rated annual energy consumption below 234 kWh/year and per-cycle water consumption below 3.1 gal/cycle. Figure 5.1 shows the distribution of standard residential dishwashers included in DOE's Compliance Certification Database, after removing models certified using a cold-water connection. DOE developed Efficiency Level 3 based on this distribution.

---

[a] Information on the ENERGY STAR program can be found at *www.energystar.gov*.

[b] The draft specification document is available at *https://www.energystar.gov/products/specs/sites/products/files/ES_Draft_2_V5.0_Dishwashers_Specification.pdf*. DOE notes that this level was removed from the Final V5.0 Dishwashers Specification, and subsequent specification versions 5.1 and 5.2; however, the energy and water consumption represent a technically feasible efficiency level beyond the current ENERGY STAR criteria.

[c] DOE notes that a standard residential dishwasher is available with rated annual energy consumption of 171 kWh/year and water consumption of 4.1 gal/cycle. These ratings are based on a cold-water connection, which DOE eliminated from consideration as a technology option in the screening analysis.

[d] DOE's Compliance Certification Database is accessible at http://www.regulations.doe.gov/certification-data/

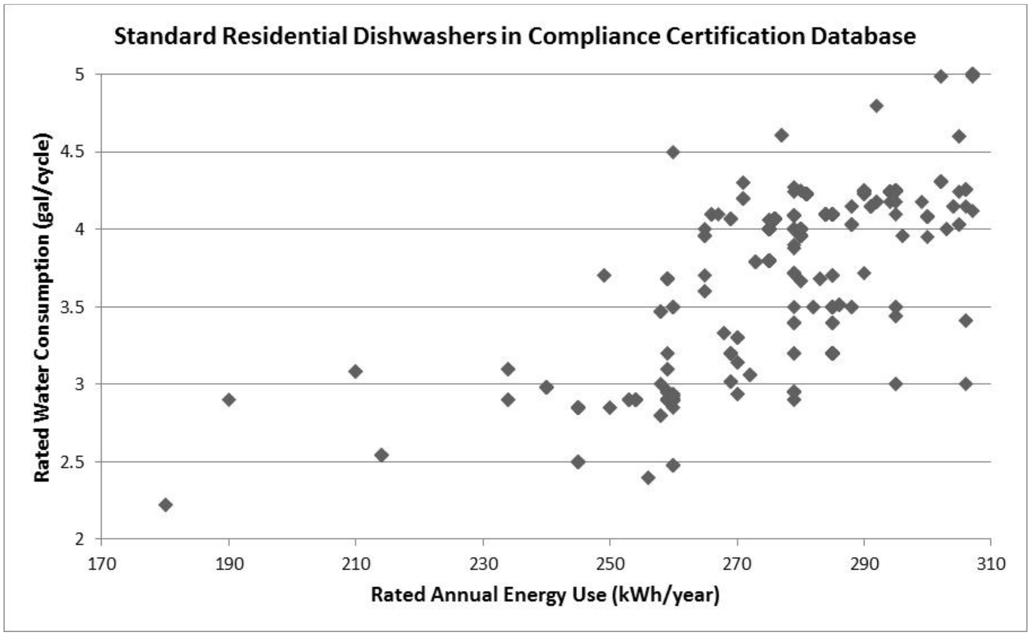


**Figure 5.1: Market Availability of Standard Residential Dishwashers**[e]

EPCA mandates that DOE analyze the maximum technologically feasible (max-tech) model, based on a minimum annual energy use and a minimum water consumption for residential dishwashers. The two variables are related to a certain extent (via external and internal water heating energy consumption) and DOE evaluates the relative importance of each metric in setting the energy conservation standards. It is not certain that a residential dishwasher with the lowest possible annual energy use will also achieve the lowest possible water consumption. However, for residential dishwashers available on the market at the time of this analysis, the units achieving the lowest annual energy use also achieve the lowest water consumption, and therefore represent the max-tech level.

#### 5.3.2.2 Compact Product Class

Table 5.3.2 below shows the three efficiency levels DOE analyzed for the compact product class.

---

[e] Units certified using a cold-water connection removed. Database accessed on May 22, 2014.

**Table 5.3.2 Compact Residential Dishwasher Efficiency Levels**

| Level | Efficiency Level Description | Annual Energy Use *(kWh/year)* | Water Consumption *(gal/cycle)* |
|---|---|---|---|
| Baseline | DOE Standard | 222 | 3.50 |
| EL 1 | Proposed ENERGY STAR Criteria | 203 | 3.10 |
| EL 2 | Maximum Available[a] | 141 | 2.00 |
| a) Source: DOE-certified dishwashers as of May 22, 2014 | | | |

Based on basic model numbers listed in DOE's Compliance Certification Database, DOE expects that fewer than 10 individual compact basic models are currently available on the market. The majority of models included in the Compliance Certification Database are also rated either at the baseline or max-tech efficiency level. In the ENERGY STAR Draft 2 Version 6.0 Residential Dishwasher Specification[f], however, the Environmental Protection Agency proposed eligibility criteria for compact residential dishwashers consistent with Efficiency Level 1. As part of its proposal, ENERGY STAR discussed with manufacturers feasible energy and water improvements for compact products. ENERGY STAR's supporting analysis included the expected design options that manufacturers would use to reach this intermediate efficiency level. Accordingly, DOE considered the proposed compact ENERGY STAR criteria as an efficiency level in this analysis. Efficiency Level 2 is the maximum available efficiency level, defined by the maximum available technology that DOE could identify on the market at the time of its analysis. DOE did not identify any working prototypes that were more efficient than the maximum available technology, and thus this level is the max-tech for the compact product class.

## 5.4 METHODOLOGY OVERVIEW

DOE relied on multiple sources of information for this engineering analysis. These sources include a review of TSDs from previous rulemakings, internal product testing, and product teardowns.

### 5.4.1 Review of Previous Technical Support Documents and Models

DOE reviewed previous rulemaking TSDs to assess their applicability to the current standard setting process for residential dishwashers. These previous rulemaking TSDs served as a source for design options and energy consumption analysis, in addition to other sources. The most recent TSD for residential dishwashers was created in support of the May 2012 direct final rule.

---

[f] Information on the ENERGY STAR specification is available at: *https://www.energystar.gov/products/specs/residential_dishwasher_specification_version_6_0_pd*.

### 5.4.2 Product Testing

Much of the analysis in this chapter relies on data from publicly available sources such as the DOE Compliance Certification Database. However, DOE also conducted its own limited performance testing according to the ENERGY STAR Test Method for Determining Dishwasher Cleaning Performance (Cleaning Performance Test Method)[g] for the following purposes:

- To develop a better understanding of the design options and product features currently available on the market; and
- To determine a relationship between energy and water consumption and cleaning performance.

### 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 component using a process commonly called a physical teardown. A supplementary method, called a catalog teardown, uses published manufacturer catalogs and supplementary component data to estimate the major physical differences between a product that has been physically disassembled and another similar product. DOE performed physical teardown analysis on both standard and compact residential dishwashers. 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.

---

[g] The ENERGY STAR Cleaning Performance Test Method is available at *https://www.energystar.gov/products/specs/sites/products/files/ENERGY%20STAR%20Final%20Test%20Method%20for%20Determining%20Residential%20Dishwasher%20Cleaning%20Perfor%20%20%20.pdf*

#### 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, and purchased parts that 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[h] (AMM). Past price quotes are indexed using applicable Bureau of Labor Statistics producer price index tables as well as AMM monthly data.

#### 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 5.2 shows the three major steps in generating the manufacturing cost.

**Figure 5.2 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

---

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

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 5.4.1.

**Table 5.4.1 Major Manufacturing Processes**

| Fabrication | Finishing | Assembly/Joining | Quality Control |
|---|---|---|---|
| Fixturing<br>Stamping/Pressing<br>Brake Forming<br>Cutting and Shearing<br>Insulating<br>Turret Punch<br>Tube Forming<br>Enameling | Washing<br>Powder Coating<br>De-burring<br>Polishing<br>Refrigerant Charging | Adhesive Bonding<br>Spot Welding<br>Seam Welding<br>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. Previous site visits allowed DOE to confirm its cost model assumptions through direct observation of manufacturing plants, as well as through previous manufacturer interviews, reviews of current Bureau of Labor Statistics data, *etc*.

## 5.5 ANALYSIS AND RESULTS

### 5.5.1 Product Testing

DOE conducted investigative testing in support of this rulemaking and considered testing conducted in support of developing the ENERGY STAR Cleaning Performance Test Method to consider how energy and water consumption affect cleaning performance.

Figure 5.3 through Figure 5.8 show the aggregated results from DOE's investigative testing and testing conducted in support of the ENERGY STAR Cleaning Performance Test Method. The results are divided by soil load type (heavy, medium, and light), and compare the cleaning performance to the measured per-cycle energy consumption, in kilowatt-hours per cycle (kWh/cycle), or per-cycle water consumption of the test unit.[i]

---

[i] Cleaning performance in these tables is presented as the 100-point per-cycle cleaning performance score. DOE notes that the final version of the ENERGY STAR Cleaning Performance Test Method includes the calculation of a 100-point per-cycle cleaning index, which is based on grading the items in the test load according to the instructions in ANSI/AHAM Standard DW-1-2010. Prior to finalizing the ENERGY STAR Cleaning Performance Test Method, earlier draft versions of the test method included calculations for a 100-point per-cycle cleaning performance score based on grading items in the test load according to the method outlined in International Electrotechnical Commission (IEC) Standard 60436, *Electric dishwashers for household use – Methods for measuring the performance* Edition 3.1, 2009-11 (IEC Standard 60436). Because the early draft versions of the test method relied on IEC Standard 60436 grading, certain rounds of testing did not include grading according to ANSI/AHAM Standard DW-1-2010. To present the most complete set of data, the tables below present results based in the IEC Standard 60436 grading and corresponding 100-point per-cycle cleaning performance score. DOE notes that the per-cycle cleaning performance score and per-cycle cleaning index typically reflect the same relative cleaning performance trends shifted to a slightly different scale according to the different grading procedures.

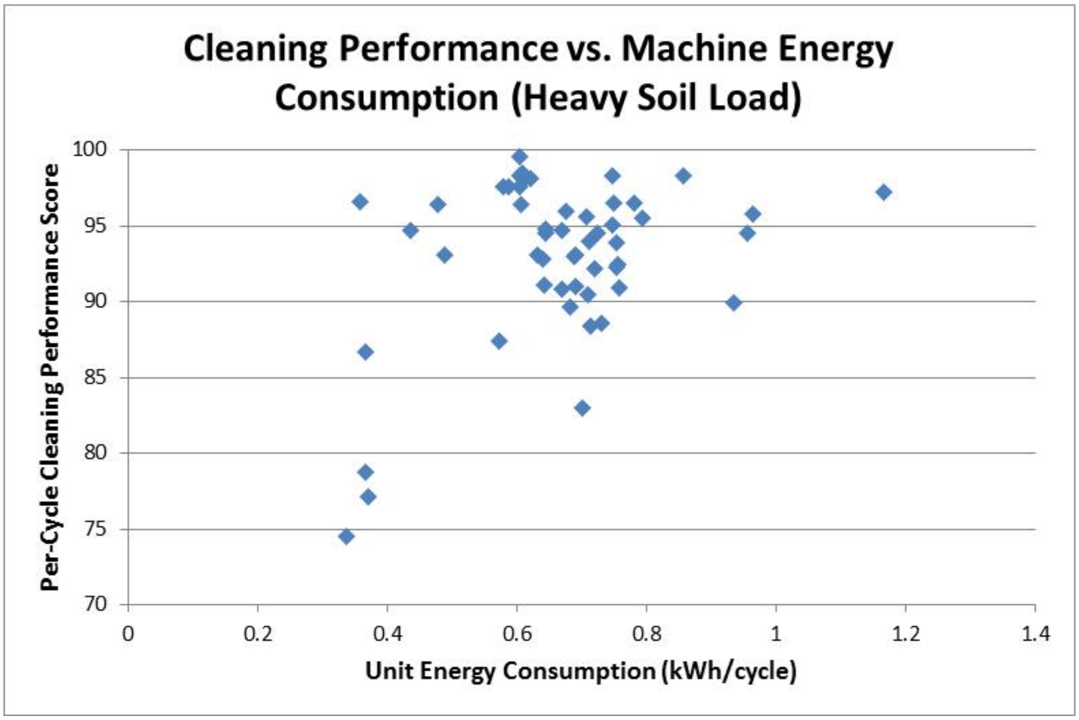


Figure 5.3 Heavy Soil Load Cleaning Performance vs. Machine Energy Consumption

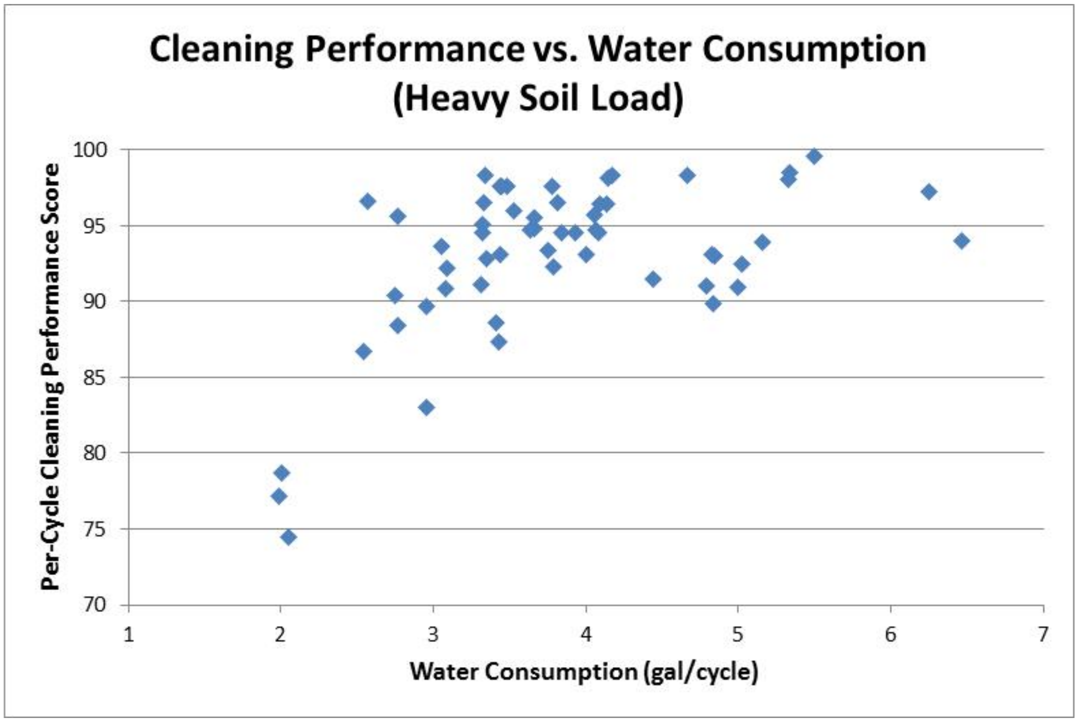


Figure 5.4 Heavy Soil Load Cleaning Performance vs. Water Consumption

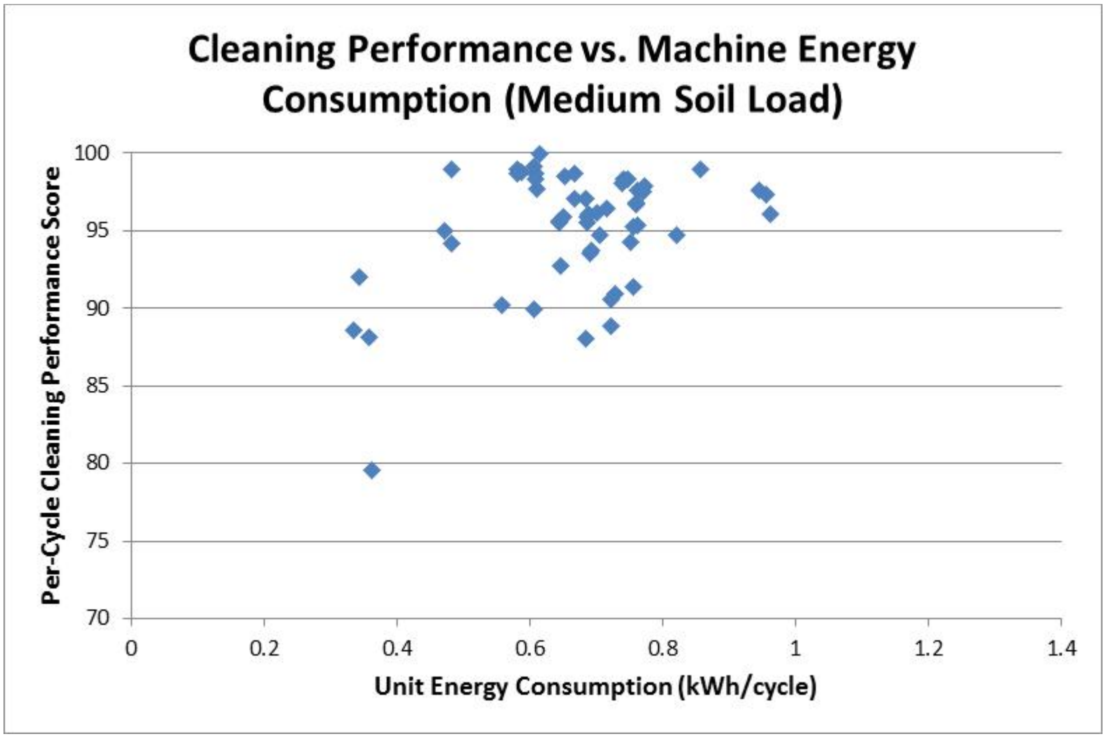


Figure 5.5 Medium Soil Load Cleaning Performance vs. Machine Energy Consumption

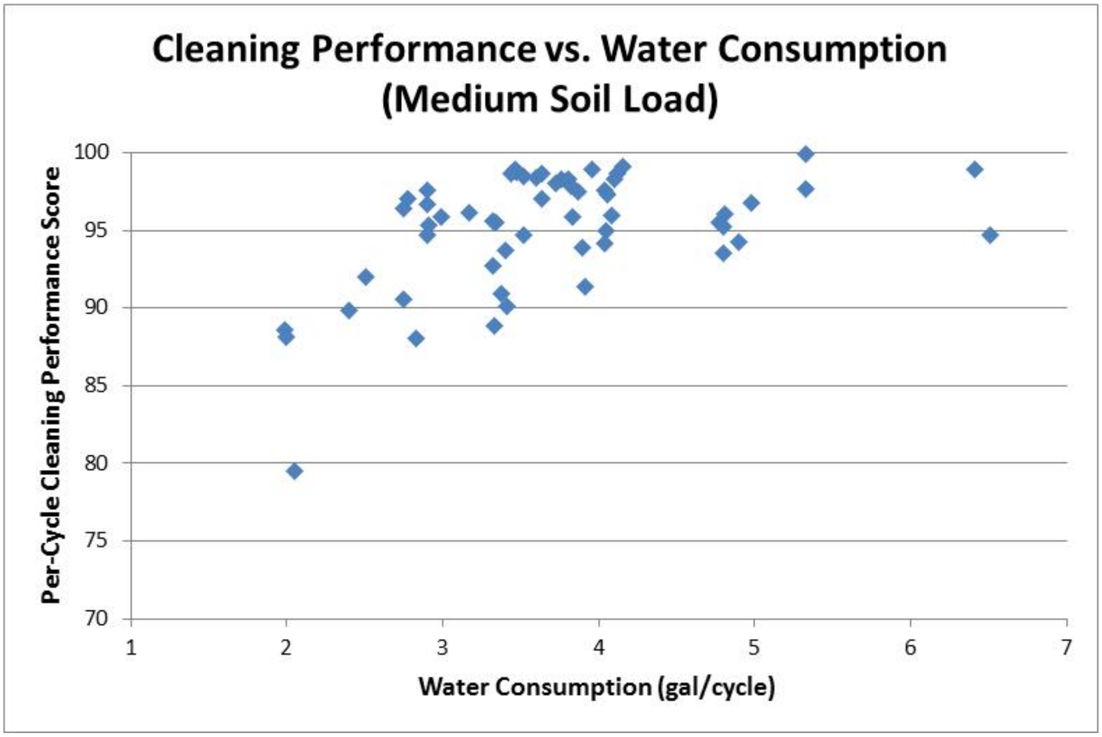


Figure 5.6 Medium Soil Load Cleaning Performance vs. Water Consumption

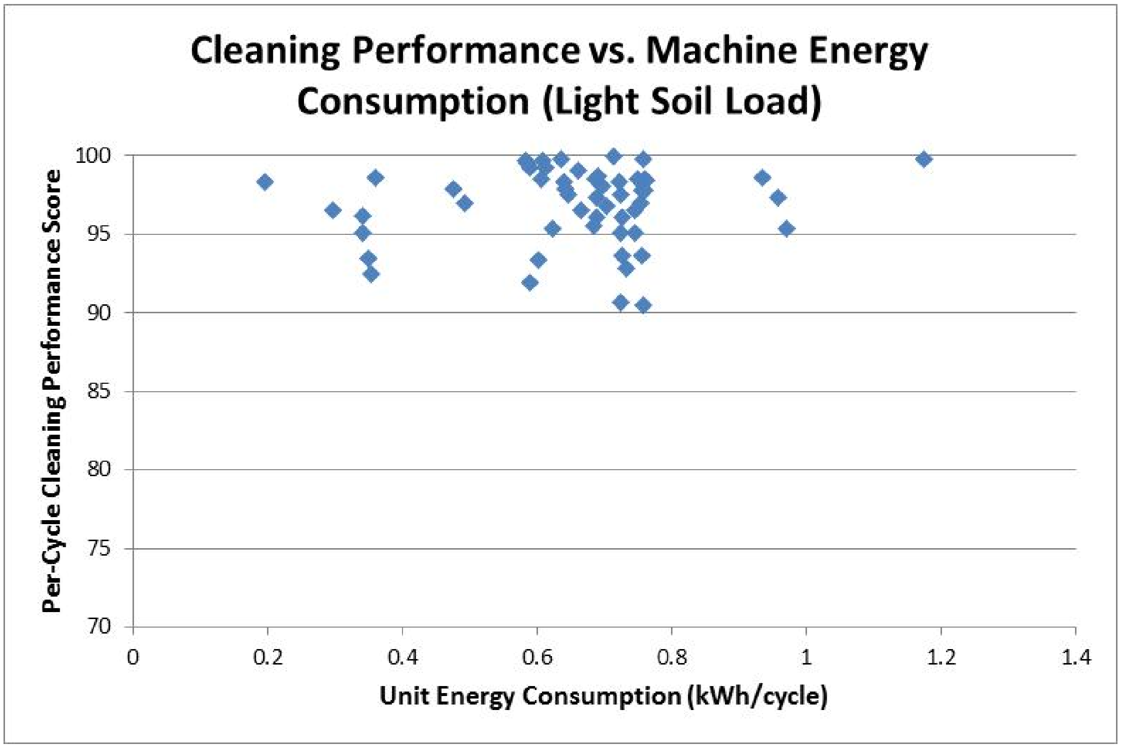


Figure 5.7 Light Soil Load Cleaning Performance vs. Machine Energy Consumption

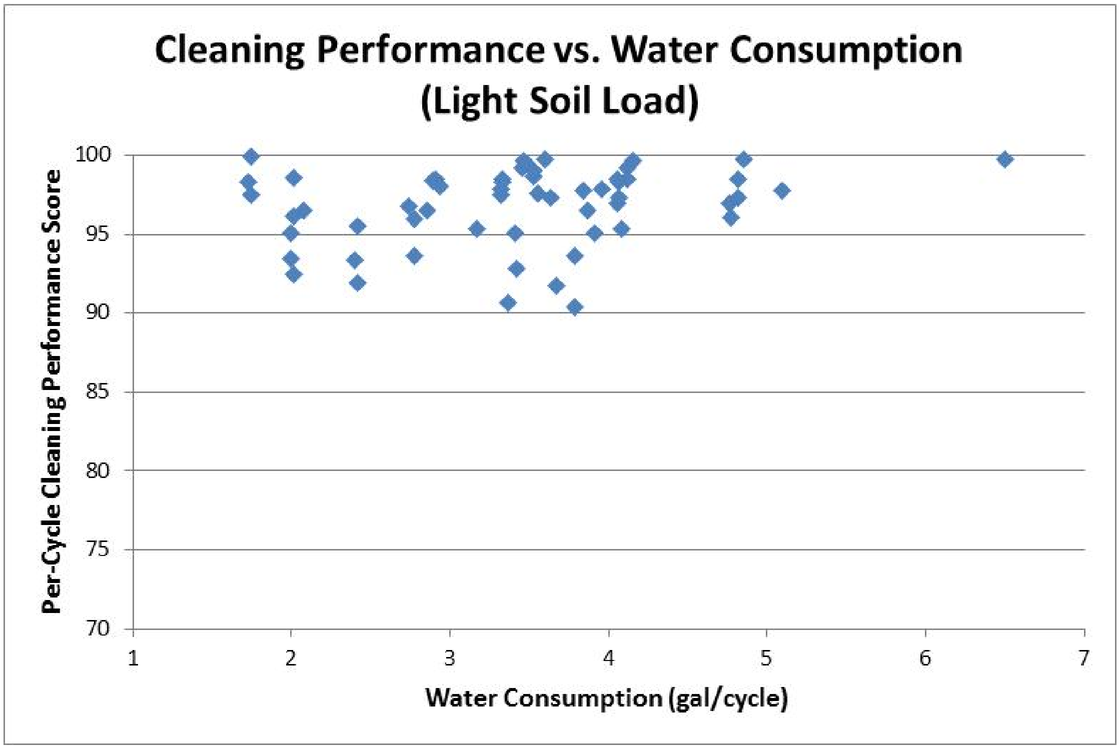


Figure 5.8 Light Soil Load Cleaning Performance vs. Water Consumption

The heavy and medium soil load test results in Figure 5.3 through Figure 5.6 show that cleaning performance typically decreases at lower energy and water consumptions. DOE observed that the decrease in cleaning performance is most apparent for units with measured water consumption less than approximately 3 gal/cycle and measured machine energy consumption less than 0.4 kWh/cycle.

The test results for the light soil load do not show a similar relationship between cleaning performance and energy and water consumption. However, DOE notes that the quantity of soil used for the light soil load is significantly less than for both the heavy and medium soil loads (one-eighth and one-quarter of the respective soil quantities). Additionally, only one of the eight place settings, not including flatware or serving pieces, is soiled for the light soil load test.

Based on this testing, products with rated annual energy consumption of at least 234 kWh/year and rated per-cycle water consumption of at least 3.1 gal/cycle (the levels corresponding to Efficiency Level 3) were determined to typically maintain adequate cleaning performance. As a result, DOE does not expect Efficiency Level 3 to negatively impact consumer utility.

### 5.5.2 Product Teardowns

DOE conducted residential dishwasher teardowns to identify design features and corresponding manufacturing costs that are associated with successively higher efficiency levels. To choose appropriate models for the teardown analysis, DOE conducted a market survey of residential dishwasher models and their associated features. The products selected were based on the proposed efficiency levels and the range of product efficiencies and features available on the market.

DOE supplemented these teardowns with information gathered from teardowns from the May 2012 direct final rule, because DOE determined that many of the models selected for that rulemaking that meet the current energy conservation standards are either still available on the market or are functionally equivalent to the models currently available on the market.

#### 5.5.2.1 Baseline Construction: Standard Residential Dishwasher

The baseline standard residential dishwasher is equipped with electromechanical controls that allow the user to select specific cycle settings. These include a switch for selecting the power dry option and a rotary dial to initiate and set the cycle duration.

The wash tub is made of plastic using an injection molding process, with no added insulation. Inside the tub are upper and lower racks for loading the dishware. The baseline dishwasher has only one spray arm at the base of the tub, with a spray tower that extends up into the tub when water circulates. A tubular resistance heater, a coarse plastic filter, and an overflow float switch are also incorporated at the base of the tub.

The water system includes a single-speed motor that drives a pump to circulate water within the tub and to drain water out of the unit, with the function switched by means of a solenoid valve in the water lines. Because the baseline unit has only a coarse plastic filter, the motor also drives a disposal to break down food particles prior to entering the water lines. The baseline unit uses timed fills to control the volume of water entering the unit, with no flow meter or fill-level pressure switch.

In addition to these design features, which are similar to those observed for the baseline in the May 2012 direct final rule, manufacturers also adjusted the control schemes (*i.e.*, fill volumes and maximum water temperatures during the cycle) to achieve the lower energy and water consumption associated with the current baseline.

### 5.5.2.2 **Baseline Construction: Compact Dishwasher**

The baseline compact residential dishwasher is a countertop unit with electronic controls. The unit includes a flow meter and pressure switch for fill control, and a temperature sensor to control the heater operation.

The tub on the baseline unit is made of stainless steel with bitumen insulation around it to improve the unit’s noise performance. The tub only includes one dish rack and one spray arm because multiple racks cannot fit into the more compact volume. It uses a flow-through water heater integrated into the sump as opposed to a tubular in-tub heating element, which leaves more volume in the tub for loading dishes.

The baseline compact dishwasher includes a coarse stainless steel filter and a finer stainless steel mesh filter to catch smaller food particles. No disposal is necessary because large food particles do not pass through these filters into the water system.

### 5.5.2.3 **Construction at Higher Efficiency Levels**

Based on the design options retained from the screening analysis (see chapter 4 of the NOPR TSD), the teardown analysis, and information from the May 2012 direct final rule, DOE estimated the manufacturing costs associated with various design features necessary to achieve higher efficiencies.

The following are the design changes DOE believes manufacturers would typically use to meet each efficiency level considered in this engineering analysis. These configurations were subsequently modeled to obtain incremental manufacturing cost estimates.

#### ***Standard Residential Dishwashers***

#### **Efficiency Level 1**

DOE research suggests that Efficiency Level (EL) 1 is typically achieved in standard residential dishwashers through the following incremental changes to the baseline unit described in section 5.5.2.1:

1. Electronic Controls

Through its observations and discussions with manufacturers, DOE believes that in moving from the baseline level to EL 1, manufacturers would likely replace electromechanical controls with electronic controls. This would allow for more sophisticated control during the cycle, which could result in more precise timing and feedback control, eliminating excess energy and water consumption. DOE expects the electronic controls at EL 1 would use a switch-mode power supply, with corresponding low standby-mode and off-mode energy consumption.

2. Multiple Spray Arms

At EL 1, the single spray arm and spray tower of the baseline unit are likely replaced by two separate spray arms, one dedicated to each rack of dishes. This helps reduce water consumption by more accurately directing the water to the dishes. Less water is needed while still ensuring that the dishes are washed effectively.

3. Improved Water Filters

The coarse water filter in the baseline dishwasher allows food to pass through to the disposal. After the food is broken down, pieces still make their way through the water system, so the lines and spray arms must allow the food particles to pass through to prevent clogs. At EL 1, manufacturers would likely add finer plastic food filters. By trapping smaller food particles and eliminating the food disposer, the typical unit at EL 1 can use smaller tube diameters and thinner spray arms without clogging, decreasing the total volume of the water system.

4. Separate Drain Pump

The baseline unit uses a single pump to circulate water within the dishwasher and to drain water out of the unit. At EL 1, manufacturers would likely include a separate pump and motor dedicated to draining water from the unit. Circulating water within the unit requires a stronger motor than for draining the water, so the EL 1 unit avoids the excess energy consumption associated with using the circulating motor to pump water out of the unit.

5. 3-Phase Variable-Speed Motor

The EL 1 dishwasher would likely feature a variable-speed motor to drive the circulation pump. This motor, along with the more sophisticated electronic controls, allows the dishwasher to adjust the flow rate at which the water is pumped throughout the water system at different times during the cycle. Using the most energy-intensive pump operation only when needed eliminates excess energy consumption for portions of the wash cycle requiring less aggressive circulation.

6. Tub Insulation

The baseline unit features a plastic tub with no additional insulation. At EL 1, DOE expects manufacturers would add a layer of thermal insulation around the plastic tub. The insulation improves efficiency by minimizing heat lost from the tub during the heated portions of the wash cycle, thereby reducing the total amount of heat needed from the internal heater to maintain the higher water temperatures.

#### Efficiency Level 2

DOE expects that manufacturers would likely implement the design options used for EL 1 and incorporate additional features to reach EL 2:

1. Soil Sensing

A dishwasher meeting EL 2 likely incorporates more advanced controls, including a turbidity sensor. The turbidity sensor monitors the clarity of the water passing through the sump, and adjusts the wash cycle accordingly. As a result, the dishwasher can adjust its cycle to use less water and energy for less-soiled dish loads.

2. Hydraulic System Optimization

At EL 2, manufacturers would likely further decrease the capacity of the water system by optimizing the water lines and spray arms. This includes decreasing the volume of both the fill lines and spray arms; however, the sump area would likely remain unchanged from EL 1.

3. Control Strategies

As manufacturers decrease energy and water consumption, they increase certain other wash cycle parameters to maintain washing performance. At EL 2, manufacturers would likely increase the duration of the cycle to compensate for decreased water use. Running the dishwasher for a longer period of time has a minor machine electrical energy consumption penalty associated with the increased duration for pumping water and operating the controls, but it is outweighed by the corresponding decrease in water-heating energy consumption.

#### Efficiency Level 3

A dishwasher at EL 3 is likely to further improve on the design options at EL 2. The major incremental changes associated with the decreased energy and water consumption at this efficiency level are:

1. In-Pump Heater

At EL 3, manufacturers would likely replace the in-tub tubular heating element with a design that incorporates the heating element into the circulation pump. This design change eliminates the water volume necessary to immerse the tubular heaters expected on the baseline through EL 2 units.

2. Condensation Drying

Without the typical tubular in-tub water heater from the previous levels, manufacturers would likely eliminate the heated drying option. Heated drying typically uses the exposed in-tub resistance heater to warm the air in the tub and evaporate the water off the dishes. Condensation drying uses a higher temperature final rinse to raise the temperature of the dishes, evaporating water remaining on them, which then condenses on the cooler tub walls. The condensation drying strategy uses less energy compared to the heated drying method.

3. Improved Filters

At EL 3, manufacturers would likely further improve the water filtering system. For EL 1 and EL 2, DOE expects manufacturers would use plastic water filters. The fine filter at EL 3 would likely switch to a woven stainless steel cloth, which is capable of trapping even smaller food particles. This further decreases the potential for clogging in the water lines of EL 3 unit and thus allows the water line diameters and volume of the water system to be reduced as well.

4. Hydraulic System Optimization

Along with the improved water filters described above, manufacturers would likely further decrease the total volume of the water system via smaller supply lines and spray arms, as well as a redesigned sump with a smaller internal volume.

5. Water Diverter Assembly

DOE believes manufacturers would likely incorporate a water diverter valve at EL 3. The diverter directs the flow of water from the circulating pump to either the top or bottom spray arm depending on its position. This allows the dishes in both the top and bottom racks to receive the same spray volume, while maintaining a smaller volume of water in the sump and water lines. This technology may also correspond to a further increase in cycle duration as both racks are not washed simultaneously.

6. Temperature Sensor

Baseline through EL 2 dishwashers typically include temperature switches to control operation of the water heater. At EL 3, manufacturers would likely change to a temperature sensor to allow for closed-loop control, rather than timed heating with a maximum cutoff point determined by the switch. Better temperature control results in less energy use associated with internal water heating.

7. Flow Meter

At EL 3, manufacturers would likely switch from timed fill control to fill controlled by a water flow meter. A flow meter with an electronic controller allows a dishwasher to dose water very precisely, even at varying supply pressures. This reduces the excess energy and water consumption associated with over-filling the dishwasher, and helps prevent poor wash performance caused by under-filling.

**Efficiency Level 4**

A dishwasher at EL 4 is likely to employ the same design features as one at EL 3. The major incremental change associated with the decreased energy and water consumption at this level is:

1. Control Strategies

To further decrease energy consumption at EL 4, DOE believes manufacturers would decrease wash and/or rinse temperatures and total fill volumes. This decreases the amount of energy consumed for water heating (both internal and external), but has the potential to negatively impact wash performance.

### *Compact Residential Dishwashers*

Starting with the baseline compact residential dishwasher described in section 5.5.2.2, DOE expects that manufacturers may incorporate the following incremental changes to reach the higher efficiency levels.

#### Efficiency Level 1

As discussed in section 5.3.2.2, ENERGY STAR's analysis for the Draft 2 Version 6.0 Residential Dishwasher Specification included a set of design options manufacturers would likely incorporate to reach the energy and water consumption associated with EL 1 for compact residential dishwashers. These features, which DOE also expects manufacturers to use to reach EL 1, are listed below:

1. Permanent Magnet Motor

DOE expects manufacturers would switch to a permanent magnet motor to reach EL 2. With this type of motor, the pump impeller is attached directly to the rotor, so no drive system is required. Additionally, manufacturers would likely use this motor both for circulating water during the wash or rinse cycles and for pumping water out of the unit, depending on which direction the rotor spins.

2. Reduced Sump Volume

DOE expects manufacturers would decrease the sump volume to the extent that it would only house the pump impeller. Because there is only one pump impeller housing with the permanent magnet motor described above, the volume of water required to fill the sump is much less than for the sump configuration on the baseline units.

3. Improved Controls

Manufacturers would likely update the controls at EL 1 compared to the baseline unit, including adjusting the power supply to reduce standby and off mode energy consumption and incorporating new controls for the updated pump motor. Manufacturers may also use control strategies at EL 1 to optimize the wash cycle, reducing the overall per-cycle water consumption and the associated internal and external water-heating energy consumption.

4. Tub Insulation

At EL 1, DOE expects manufacturers would add a layer of thermal insulation around the tub of the baseline unit. The insulation improves efficiency by minimizing heat lost from the tub during the high-temperature portions of the wash cycle, thereby reducing the energy required for the internal heater to maintain necessary water temperatures.

#### Efficiency Level 2

The max-tech dishwasher available on the market is a dish drawer instead of a countertop unit. The configuration of dish drawers makes them significantly more expensive to manufacture compared to a countertop unit. However, DOE believes the design features used in the max-tech drawer unit could also be incorporated into a countertop platform. The additional features DOE expects manufacturers to use to move from EL1 to EL 2 are:

1. Improved Filters

At EL 2, manufacturers would likely improve the water filtering system by switching to finer stainless steel filters. This further decreases the potential for clogging in the water lines of EL 2 unit and thus allows the water line diameters and volume of the water system to be reduced as well.

2. Hydraulic System Optimization

Along with the improved water filters described above, manufacturers would likely further decrease the total volume of the water system at EL 2 via smaller supply lines and spray arms.

3. Heater Incorporated into Base of Tub

DOE observed that the max-tech compact residential dishwasher incorporates the internal water heater into the base of the tub. This requires a lower volume of water sitting in the bottom of the tub than a tubular in-tub water heater. Although the baseline and EL 1 units include a flow-through water heater in the sump, moving the heater to the base of the tub allows for a further reduction in the sump volume, while requiring only a small fill volume of water in the tub to cover the heater.

### 5.5.3 Cost-Efficiency Curves

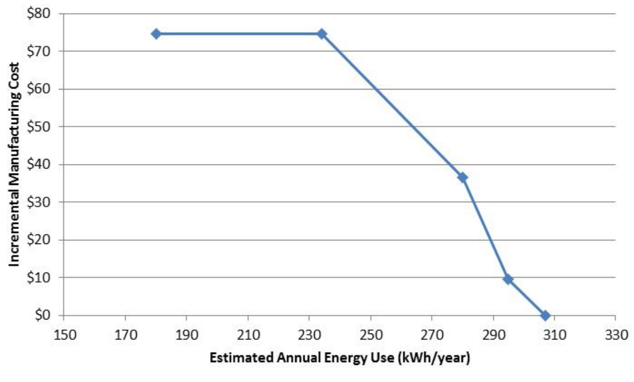
Based on product teardowns and cost modeling, DOE developed the following cost-efficiency relationships for standard and compact residential dishwashers. The corresponding cost-efficiency curves are shown in the sections below.

#### 5.5.3.1 Standard Residential Dishwashers

For standard residential dishwashers, DOE developed incremental manufacturing costs by tearing down units, observing the design options included for each unit, and creating a cost model at each efficiency level based on the expected combination of design options discussed in section 5.5.2.3.

DOE started with the baseline unit cost model and added the expected changes associated with improving efficiency at each higher efficiency level. By doing this, DOE excluded the costs of any non-efficiency related components from the more efficient units. The more efficient units are generally sold at a higher price point, and sometimes include features that increase manufacturing cost, but are not necessarily efficiency-related. One example of such a feature is the typical use of stainless steel wash tubs in more expensive units. Table 5.5.1 shows the incremental manufacturing costs from DOE’s reverse-engineering analysis for standard residential dishwashers.

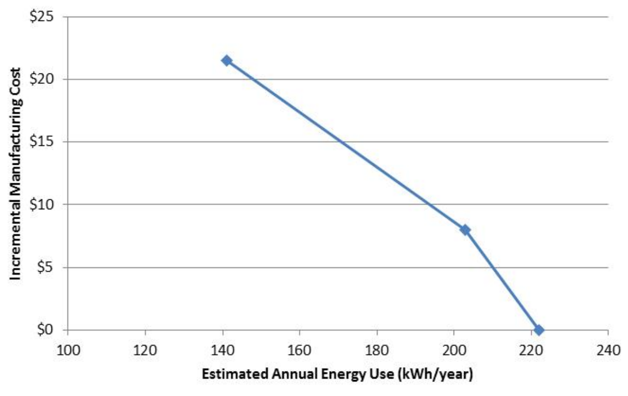
**Table 5.5.1 Standard Residential Dishwasher Incremental Manufacturing Costs**

| **Efficiency Level** | **Annual Energy Use** *(kWh/year)* | **Water Consumption** *(gal/cycle)* | **Incremental Costs** *($2013)* |  |
|---|---|---|---|---|
| Baseline | 307 | 5.00 | - | |
| EL 1 | 295 | 4.25 | $ 9.52 | |
| EL 2 | 280 | 3.50 | $ 36.53 | |
| EL 3 | 234 | 3.10 | $ 74.72 | |
| EL 4 | 180 | 2.22 | $ 74.72 | |

### 5.5.3.2 Compact Residential Dishwashers

Similar to the cost estimates for the standard product class, DOE started with the baseline unit cost model for compact residential dishwashers and added in the expected changes associated with improving efficiency at the higher efficiency levels as discussed in section 5.5.2.3. Table 5.5.2 shows the incremental manufacturing costs for compact residential dishwashers as a result of DOE's reverse-engineering analysis.

**Table 5.5.2 Compact Residential Dishwasher Incremental Manufacturing Costs**

| **Efficiency Level** | **Annual Energy Use** *(kWh/year)* | **Water Consumption** *(gal/cycle)* | **Incremental Costs** *($2013)* |  |
|---|---|---|---|---|
| Baseline | 222 | 3.50 | $ - | |
| EL 1 | 203 | 3.10 | $ 8.01 | |
| EL 2 | 141 | 2.00 | $ 21.50 | |

# CHAPTER 6. MARKUPS FOR EQUIPMENT PRICE DETERMINATION

## TABLE OF CONTENTS

## LIST OF TABLES

# CHAPTER 6. MARKUPS FOR EQUIPMENT PRICE DETERMINATION

## 6.1 INTRODUCTION

To carry out its analyses, the U.S. Department of Energy (DOE) needed to determine the cost to the consumer of baseline products and the cost of more-efficient units. As discussed in chapter 8, DOE developed retail prices for baseline products using proprietary retail price data collected by The NPD Group. For products with higher-than-baseline efficiency, DOE estimated the consumer prices by applying appropriate markups to the incremental manufacturing costs estimated in the engineering analysis.

### 6.1.1 Distribution Channels

The appropriate markups for determining consumer product prices depend on the type of distribution channels through which products move from manufacturers to consumers. At each point in the distribution channel, companies mark up the price of the product to cover their business costs and profit margin.

Data from the Association of Home Appliance Manufacturers (AHAM) (1) indicate that an overwhelming majority of residential appliances are sold through retail outlets. Because DOE is not aware of any other distribution channel that plays a significant role for residential dishwashers, DOE assumed that all of the dishwashers are purchased by consumers from retail outlets. DOE did not include a separate distribution channel for dishwashers products included as part of a new home, as it did not have information on the extent to which these products are pre-installed by builders in new homes.

### 6.1.2 Markup Calculation Procedure

As just discussed, at each point in the distribution channel, companies mark up the price of the product to cover their business costs and profit margin. In financial statements, gross margin is the difference between the company revenue and the company cost of sales or cost of goods sold (*CGS*). The gross margin includes the expenses of companies in the distribution channel—including overhead costs (sales, general, and administration); research and development (R&D) and interest expenses; depreciation, and taxes—and company profits. To cover costs and to contribute positively to company cash flow, the price of products 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 the products of interest.

## 6.2 MANUFACTURER MARKUPS

DOE uses manufacturer markups to transform a manufacturer's production costs into a manufacturer sales price. Using the *CGS* and gross margin (GM), DOE calculated the manufacturer markup ($MU_{MFG}$) with the following equation:

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

Where:

$MU_{MFG}$ = manufacturer markup,
$CGS_{MFG}$ = 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 whose product offerings include residential dishwashers. DOE determined the weighted-average manufacturer markup to be 1.24 and used the 1.24 markup for both standard and compact dishwashers.

## 6.3 RETAILER MARKUP

### 6.3.1 Approach for Retailer Markups

DOE based the retailer markups for dishwashers on financial data for electronics and appliance stores from the 2007 U.S. Census *Annual Retail Trade Survey* (ARTS), which is the most recent survey that includes industry-wide detailed operating expenses for that economic sector.[3] DOE organized the financial data into statements that break down cost components incurred by firms within the economic sector. DOE assumes that the income statements faithfully represent the various average costs incurred by firms selling home appliances. Although electronics and appliance stores handle multiple commodity lines, the data provide the best available indication of expenses for selling dishwashers.

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 new energy conservation standards). DOE used the following equation to calculate an average baseline markup ($MU_{BASE}$) for retailers.

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

Where:

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

Incremental markups are coefficients that relate the change in the MSP of higher efficiency models to the change in retailer sales price. DOE considers higher efficiency models to be products sold under market conditions having new efficiency standards. The incremental markup reflects the retailer's increase in a product's CGS because of new or amended standards.

There is a lack of empirical data regarding appliance retailer markup practices in response to a product's cost increase (due to increased efficiency or other factors). DOE understands that real-world markup practices vary depending on the market conditions that retailers face and on the magnitude of the change in CGS. Pricing in retail stores also may involve rules of thumb that are difficult to quantify and to incorporate into DOE's analysis.

Given the uncertainty about actual markup practices in appliance retailing, DOE's approach reflects the following key concepts.

1. Changes in the efficiency of goods sold are not expected to increase economic profits. Thus, DOE calculates markups/gross margins to allow cost recovery for retail companies in the distribution channel (including changes in the cost of capital) without changes in company profits.
2. Efficiency improvements affect some distribution costs but not others. DOE sets markups and retail prices to cover the distribution costs expected to change with efficiency, but not the distribution costs that are not expected to change with efficiency.

The approach to incremental markups is described in more detail in Dale and Fujita.[4] To estimate incremental retailer markups, DOE divides retailers' operating expenses into two categories: (1) those that do not change when CGS increases because of amended efficiency standards ("invariant"), and (2) those that increase proportionately with CGS ("variant"). DOE defines invariant costs as including labor and occupancy expenses, because those costs likely will not increase as a result of a rise in CGS. All other expenses, as well as net profit, are assumed to vary in proportion to CGS. Although it is possible that some other expenses may not scale with CGS, DOE takes a conservative position that includes other expenses as variant costs. (Note that, under DOE's approach, a high fixed cost component yields a low incremental markup.)

DOE used the following equation to calculate the incremental markup ($MU_{INCR}$) for retailers.

$$MU_{INCR} = \frac{CGS_{RTL} + VC_{RTL}}{CGS_{RTL}}$$

Where:

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

In developing incremental markups, DOE envisions that retailers cover costs without changing profits. Although retailers may be able to reap higher profits for a time, DOE's approach assumes that competition in the appliance retail market, combined with relatively inelastic demand (*i.e.*, the demand is not expected to decrease significantly in response to a relatively small increase in price), will tend to pressure retail margins back down.

To measure the degree of competition in appliance retailing, DOE estimated the four-firm concentration ratio (FFCR) of major appliance sales in three retail channels: electronics and appliance stores, building materials and supplies dealers, and general merchandise stores. The FFCR represents the market share of the four largest firms in a given sector. Generally, an FFCR of less than 40 percent indicates that the sector is not concentrated; an FFCR of more than 70 percent indicates that a sector is highly concentrated.[a, b]

The FFCR of appliance sales within each retail channel is equal to the sector FFCR times the percent of total sales within each channel accounted for by major appliances. As shown in Table 6.3.1, appliance sales in electronics and appliance stores, household appliance stores, building materials and supplies dealers, and general merchandise stores have a FFCR less than the 40-percent threshold. The electronics and appliance stores sector includes a subsector titled "household appliance stores." Because that subsector includes numerous stores, it has a FFCR of 21.3 percent.

---

[a] University of Maryland University College: http://info.umuc.edu/mba/public/AMBA607/IndustryStructure.html.

[b] Quick MBA: http://www.quickmba.com/econ/micro/indcon.shtml.

**Table 6.3.1 Four-Firm Concentration Ratio for Major Appliance Sales in Three Retail Channels**

| Sector | FFCR (% of Sector Sales) | Percent of Sales Accounted for by Major Appliances (%) | FFCR (% of Major Appliance Sales) |
|---|---|---|---|
| Electronics and appliance stores | 46.3 | 42.1 | 19.5 |
| *Subsector: household appliance stores* | 21.3 | 37.1 | 7.9 |
| Building materials and supplies dealers | 45.9 | 17.0 | 7.8 |
| General merchandise stores | 73.2 | 31.6 | 23.1 |

Source: U.S. Economic Census. *Establishment and Firm Size* (*Including Legal Form of Organization*). 2007.
*Note: It is assumed that major appliance sales are uniformly distributed within all firms in each sector.

### 6.3.2 Derivation of Retailer Markups

The 2007 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 2011 ARTS publishes a separate document containing historical sales and gross margin from 1993 to 2011 for household appliance stores. DOE took the GM as a percent of sales reported for 2007 and combined that percent with 2007 ARTS data 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 | 110.673 |
| Cost of goods sold (CGS) | 81.234 |
| Gross margin (GM) | 29.439 |
| Baseline markup = (CGS+GM)/CGS | 1.36 |

Source: U.S. Census, *2007 Annual Retail Trade Survey*.

Table 6.3.3 shows the breakdown of operating expenses for electronics and appliance stores based on the 2007 ARTS data. The incremental markup is calculated as 1.11.

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

| **Business Item** | **Amount ($1,000,000)** |
|---|---|
| Sales | 110,673 |
| *Cost of goods sold (CGS)* | *81,234* |
| *Gross margin (GM)* | *29,439* |
| **Labor & Occupancy Expenses (invariant)** | |
| Annual payroll | 11,714 |
| Employer costs for fringe benefit | 1,829 |
| Contract labor costs, including temporary help | 154 |
| Purchased utilities, total | 623 |
| Cost of purchased repair and maintenance services | 369 |
| Cost of purchased professional and technical services | 1,164 |
| Purchased communication services | 396 |
| Lease and rental payments | 3,576 |
| Taxes and license fees (mostly income taxes) | 619 |
| Subtotal: | 20,444 |
| **Other Operating Expenses & Profit (variant)** | |
| Expensed equipment | 114 |
| Cost of purchased packaging and containers | 68 |
| Other materials and supplies not for resale | 502 |
| Cost of purchased transportation, shipping, and warehousing services | 606 |
| Cost of purchased advertising and promotional services | 2,625 |
| Cost of purchased software | 159 |
| Cost of data processing and other purchased computer services, except communications + commissions paid | 368 |
| Depreciation and amortization charges | 1,525 |
| Other operating expenses | 2,070 |
| *Net profit before tax (operating profit)* | *958* |
| Subtotal: | 8,995 |
| Incremental markup = (CGS + Total Other Operating Expenses and Profit)/CGS | 1.11 |

Source: U.S. Census. *2007 Annual Retail Trade Survey* (for sales), and *2011 Annual Retail Trade Survey* (for GM and CGS).

## 6.4 SALES TAXES

The sales tax represents state and local sales taxes that are applied to the consumer product price. 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. (2) DOE derived population-weighted average tax values for each Census division and large state, as shown in Table 6.4.1.

**Table 6.4.1 Average Sales Tax Rates by Census Division and Large State**

| Census Division/State | Population (2013) | Tax Rate (2014) % |
|---|---|---|
| New England | 14,618,806 | 5.69 |
| Middle Atlantic | 21,673,140 | 6.63 |
| East North Central | 46,662,180 | 6.91 |
| West North Central | 20,885,710 | 7.09 |
| South Atlantic | 42,230,787 | 6.07 |
| East South Central | 18,716,202 | 8.02 |
| West South Central | 11,435,411 | 8.65 |
| Mountain | 22,881,245 | 6.44 |
| Pacific | 13,040,657 | 5.30 |
| New York | 19,651,127 | 8.40 |
| California | 38,332,521 | 8.45 |
| Texas | 26,448,193 | 7.90 |
| Florida | 19,552,860 | 6.65 |
| Population-Weighted Average | | 7.11 |

## 6.5 SUMMARY OF MARKUPS

Table 6.5.1 summarizes the markups at each stage in the distribution channel and provides the average sales tax to arrive at overall markups.

**Table 6.5.1 Summary of Markups**

| | Standard | | Compact | |
|---|---|---|---|---|
| **Markup** | **Baseline** | **Incremental** | **Baseline** | **Incremental** |
| Manufacturer | 1.24 | | 1.24 | |
| Retailer | 1.36 | 1.11 | 1.36 | 1.11 |
| Sales Tax | 1.071 | | 1.071 | |
| **Overall** | 1.81 | 1.47 | 1.81 | 1.47 |

## REFERENCES

1. Association of Home Appliance Manufacturers. *AHAM 2003 Fact Book*. 2003. Washington, DC. p. 25.

2. Securities and Exchange Commission, SEC 10-K Reports, Various dates, 2004-2009, (Last accessed July 10, 2012.) <http://www.sec.gov/edgar/searchedgar/webusers.htm>.

3. U.S. Census Bureau, *2007 Annual Retail Trade Survey, Electronics and Appliance Stores.* 2007: Washington, DC. http://www.census.gov/retail/arts/historic_releases.html

4. Dale, L., D. Millstein, K. Coughlin, R. Van Buskirk, G. Rosenquist, A. Lekov, and S. Bhuyan. *An Analysis of Price Determination and Markups in the Air-Conditioning and Heating Equipment Industry*. January 2004. Lawrence Berkeley National Laboratory: Berkeley, CA. Report No. LBNL-52791.

5. Sales Tax Clearinghouse, Inc. State sales tax rates along with combined average city and county rates. (Last accessed January 20, 2014.) <http://thestc.com/STrates.stm>

6. U.S. Department of Energy–Energy Information Administration. Residential Energy Consumption Survey, 2005. Public Use Data Files. Washington, DC. (Last accessed July 10, 2012.) < http://www.eia.gov/emeu/recs/recspubuse05/pubuse05.html>

# CHAPTER 7. ENERGY AND WATER USE ANALYSIS

## TABLE OF CONTENTS

## LIST OF TABLES

## LIST OF FIGURES

# CHAPTER 7. ENERGY AND WATER USE ANALYSIS

## 7.1 INTRODUCTION

To carry out the life-cycle cost (LCC) and payback period (PBP) calculations described in chapter 8 of this TSD, the U.S. Department of Energy (DOE) had to determine the savings in operating costs that consumers would derive from more efficient products. DOE used data on consumer energy and water use, along with energy and water prices, to develop consumer savings related to operating costs for energy and water. (Maintenance and repair costs are the other contributors to operating costs.) This chapter describes how DOE determined the annual energy and water consumption of residential dishwashers.

## 7.2 PER-CYCLE ENERGY AND WATER CONSUMPTION BY EFFICIENCY LEVEL

A dishwasher consumes energy for three processes per cycle: heating the water, operating the machine, and drying the dishes. The energy used to operate the machine powers the motor (to pump water and dispose of food) and the heating element, which boosts the supplied water's temperature to the required washing temperature. The DOE test procedure provides the following equations to calculate the total per-cycle energy consumption of dishwashers.

$$DW_{CYCLE} = WH + M + D$$

$$DW_{CYCLE} = V \times T \times \frac{K}{e} + M + D$$

Where:

$DW_{CYCLE}$ = per-cycle dishwasher energy consumption;
$V$ = volume of water used in gallons per cycle;
$T$ = 70 ºF nominal increase in water temperature (assuming a nominal inlet water temperature of 120 ºF);
$K$ = specific heat of water in kWh per gallon per degree Fahrenheit (0.0024), or Btus per gallon per degree Fahrenheit (8.2);
$e$ = efficiency of electric water heater (100 percent) or gas water heater (75 percent);
$WH = V \bullet T \bullet K/e$ = per-cycle energy consumption for heating water;
$M$ = per-cycle energy consumption to operate machine; and
$D$ = per-cycle energy consumption for drying.

Heating water represents the largest component of dishwasher energy consumption. The energy used for heating water depends directly on the volume of water used.

To determine values for per-cycle energy use, DOE used data from its engineering analysis (chapter 5). As discussed in the engineering analysis, DOE examined specific efficiency levels for standard and for compact dishwashers. Table 7.2.1 and Table 7.2.2 provide the annual energy use, per-cycle water use, and standby power consumption that correspond to each efficiency level for standard and compact dishwashers, respectively.

**Table 7.2.1 Standard Dishwashers: Annual Energy Use, Per-Cycle Water Use, and Standby Power Use by Efficiency Level**

| Efficiency Level | Annual Energy Use (kWh/yr) | Water Use (gal/cycle) | Standby Power (Watts) |
|---|---|---|---|
| Baseline | 307 | 5.00 | 0.0 |
| 1 | 295 | 4.25 | 0.5 |
| 2 | 280 | 3.50 | 0.5 |
| 3 | 234 | 3.10 | 0.5 |
| 4 | 180 | 2.22 | 0.5 |

**Table 7.2.2 Compact Dishwashers: Annual Energy Use, Per-Cycle Water Use, and Standby Power Use by Efficiency Level**

| Efficiency Level | Annual Energy Use (kWh/yr) | Water Use (gal/cycle) | Standby Power (Watts) |
|---|---|---|---|
| Baseline | 222 | 3.50 | 2.3 |
| 1 | 203 | 3.10 | 1.7 |
| 2 | 141 | 2.00 | 0.5 |

Given the data in Table 7.2.1 and Table 7.2.2, DOE used equations and assumptions in the DOE test procedure to estimate per-cycle energy use. DOE developed per-cycle dishwasher energy use by first subtracting standby power energy use from total annual dishwasher energy use. The result is the annual energy use dedicated to dishwashing only. The per-cycle dishwasher energy use is simply the annual dishwasher energy use divided by the average cycles per year.[1] Arthur D. Little (ADL) conducted a comprehensive analysis of dishwasher use in 2001 that revealed that dishwashers are used, on average, 215 cycles per year.[2]

The following equation for total annual energy use from the DOE test procedure demonstrates how per-cycle dishwasher energy use is determined.

$$DW_{ANNUAL} = DW_{CYCLE} \times N + S_m \times \frac{H - \left(N \times L\right)}{1000}$$

Where:

$DW_{ANNUAL}$ = total annual dishwasher energy consumption,
$DW_{CYCLE}$ = per-cycle dishwasher energy consumption,
$N$ = representative dishwasher use of 215 cycles per year,
$S_m$ = average standby power in Watts,
$H$ = total number of usage hours per year, or 8,766, and
$L$ = average duration of dishwasher cycle.

Because both the total annual dishwasher energy use and the standby power consumption are known, the per-cycle dishwasher energy consumption is found by:

$$DW_{CYCLE} = \frac{DW_{ANNUAL} - S_m \times \dfrac{H - (N \times L)}{1{,}000}}{N}$$

Per-cycle dishwasher energy use falls into two general categories: (1) water heating; and (2) machine (motor energy for pumping water and an electrical heating element for dish drying). DOE determined the per-cycle water-heating energy consumption by assuming the use of an electric water heater and multiplying the per-cycle water consumption by an assumed temperature rise of 70 °F (21 °C) and a specific heat of 0.0024 kWh/gal-°F (4.186 joule/gram-°C). DOE determined the per-cycle machine and drying energy by subtracting the per-cycle water-heating energy consumption from the per-cycle dishwasher energy consumption. Table 7.2.3 and Table 7.2.4 show overall energy use and each component's energy use by efficiency level for standard and compact dishwashers, respectively.

**Table 7.2.3 Standard Dishwashers: Per-Cycle Energy and Water Use by Efficiency Level**

| Level | Energy Use (kWh/yr) | Water Use (gal/cyc) | Standby Power (W) | Per-Cycle Energy Use Component | | |
|---|---|---|---|---|---|---|
| | | | | Total* (kWh/cyc) | Water Heating** (kWh/cyc) | Machine + Drying (kWh/cyc) |
| Baseline | 307 | 5.00 | 0.0 | 1.43 | 0.82 | 0.60 |
| 1 | 295 | 4.25 | 0.5 | 1.35 | 0.70 | 0.65 |
| 2 | 280 | 3.50 | 0.5 | 1.28 | 0.58 | 0.71 |
| 3 | 234 | 3.10 | 0.5 | 1.07 | 0.51 | 0.56 |
| 4 | 180 | 2.22 | 0.5 | 0.82 | 0.37 | 0.45 |

* Annual standby energy use is based on an assumed dishwasher cycle of one hour and 215 cycles per year. Standby hours = 8,766 hours minus 215 * 1 hour = 8,551 hours.

** Based on the use of an electric water heater at 100% efficiency.

**Table 7.2.4 Compact Dishwashers: Per-Cycle Energy and Water Use by Efficiency Level**

| Level | Energy Use (kWh/yr) | Water Use (gal/cyc) | Standby Power (W) | Per-Cycle Energy Use Component | | |
|---|---|---|---|---|---|---|
| | | | | Total* (kWh/cyc) | Water Heating** (kWh/cyc) | Machine + Drying (kWh/cyc) |
| Baseline | 222 | 3.50 | 2.3 | 0.94 | 0.58 | 0.36 |
| 1 | 203 | 3.10 | 1.7 | 0.88 | 0.51 | 0.37 |
| 2 | 141 | 2.00 | 0.5 | 0.64 | 0.33 | 0.31 |

* Annual standby energy use is based on an assumed dishwasher cycle of one hour and 215 cycles per year. Standby hours = 8,766 hours minus 215 * 1 hour = 8,551 hours.

** Based on the use of an electric water heater at 100% efficiency.

## 7.3 AVERAGE ANNUAL ENERGY AND WATER CONSUMPTION BY EFFICIENCY LEVEL

DOE determined the average annual energy and water consumption of residential dishwashers by multiplying the per-cycle energy and water consumption by the number of cycles per year.

In 2012, DOE revised its test procedure for dishwashers to more accurately establish their energy and water use. As noted previously, ADL conducted a comprehensive analysis of dishwasher use in 2001. ADL's survey of 26,000 households revealed that dishwashers are used, on average, 215 cycles per year. The 2009 Residential Energy Consumption Survey (RECS)[3] provides data on the annual energy use for households that have dishwashers. Of the almost 12,100 households in the 2009 RECS, 7,382 had dishwashers. In the 2009 RECS households that had dishwashers, dishwashers were used 171 cycles per year on average. Because the ADL survey is much larger and more comprehensive than is the RECS, DOE chose 215 cycles per year as the most representative value for average dishwasher use.

DOE calculated the annual energy consumption of dishwashers from the per-cycle values reported in Table 7.2.3 and Table 7.2.4, multiplying those values by average annual cycles as shown in the following equations.

$$DW_{WH-ANN} = WH \times N$$

$$DW_{MACH-ANN} = M \times N$$

$$DW_{DRY-ANN} = D \times N$$

Where:

$DW_{WH\text{-}ANN}$ = total annual dishwasher energy consumption for incremental water heating,
$DW_{MACH\text{-}ANN}$ = total annual dishwasher machine energy consumption,
$DW_{DRY\text{-}ANN}$ = total annual dishwasher energy consumption for drying, and
$N$ = representative dishwasher use of 215 cycles per year.

DOE calculated annual water consumption for dishwashers using the following equation.

$$DW_{WATER-ANN} = DW_{WATER-CYC} \times N$$

Where:

$DW_{WATER\text{-}ANN}$ = total annual dishwasher water consumption, and
$DW_{WATER\text{-}CYC}$ = total per-cycle dishwasher water consumption.

The annual energy and water consumption data shown in Table 7.3.1 for standard dishwashers and in Table 7.3.2 for compact dishwashers reflect an annual use of 215 cycles. The annual water-heating energy consumption reflects the use of an electric, gas, or oil water heater.

**Table 7.3.1 Standard Dishwashers: Annual Energy and Water Use by Efficiency Level**

| **Efficiency Level** | **Annual Energy Use** | | | | | | **Annual Water Use (gal/yr)** |
|---|---|---|---|---|---|---|---|
| | **Total (kWh/yr)** | **Water Heating*** | | | **Machine + Drying + (kWh/yr)** | **Standby Power (kWh/yr)** | |
| | | **Electric (kWh/yr)** | **Gas (MMBtu/yr)** | **Oil (MMBtu/yr)** | | | |
| Baseline | 307 | 177 | 0.74 | 0.76 | 130 | 0.0 | 1,075 |
| 1 | 295 | 150 | 0.63 | 0.64 | 140 | 4.3 | 914 |
| 2 | 280 | 124 | 0.52 | 0.53 | 152 | 4.3 | 753 |
| 3 | 234 | 110 | 0.46 | 0.47 | 120 | 4.3 | 667 |
| 4 | 180 | 79 | 0.33 | 0.34 | 97 | 4.3 | 477 |

* Water-heating energy use is based on water heater efficiencies of 98% for electric, 80% for gas, and 78% for oil.

**Table 7.3.2 Compact Dishwashers: Annual Energy and Water Use by Efficiency Level**

| Efficiency Level | Annual Energy Use | | | | | | Annual Water Use (gal/yr) |
|---|---|---|---|---|---|---|---|
| | Total (kWh/yr) | Water Heating* | | | Machine + Drying + (kWh/yr) | Standby Power (kWh/yr) | |
| | | Electric (kWh/yr) | Gas (MMBtu/yr) | Oil (MMBtu/yr) | | | |
| Baseline | 222 | 124 | 0.52 | 0.53 | 78 | 19.7 | 753 |
| 1 | 203 | 110 | 0.46 | 0.47 | 79 | 14.5 | 667 |
| 2 | 141 | 71 | 0.30 | 0.30 | 66 | 4.3 | 430 |

* Water-heating energy use is based on water heater efficiencies of 98% for electric, 80% for gas, and 78% for oil.

## 7.4 VARIABILITY OF DISHWASHER USE

For each of the 7,382 households (out of a total of 12,083) that the 2009 RECS reported as having a dishwasher, RECS provides data on the number of dishwasher cycles in the following bins: (1) less than once per week, (2) once per week, (3) 2 to 3 times per week, (4) 4 to 6 times per week, and (5) at least once per day. For calculating dishwasher energy use for this TSD, DOE converted the RECS data to annual values and created a triangular or uniform distribution for each bin. Table 7.4.1 shows the percent of households in each bin and the distribution DOE used. DOE randomly assigned a specific numerical value from within the appropriate bin to each household in the RECS dishwasher sample. The average number of cycles per year derived from the RECS 2009 data is 171.

**Table 7.4.1 RECS 2009 Dishwasher Usage Data**

| Bin | RECS Households Having a Dishwasher | | Distribution Used |
|---|---|---|---|
| | Percent* (%) | Number | |
| Less than once per week | 17 | 1,285 | Triangular, 1 to 52 |
| Once per week | 14 | 1,054 | Uniform, 26 to 78 |
| 2 to 3 times per week | 33 | 2,415 | Uniform, 78 to 182 |
| 4 to 6 times per week | 17 | 1,291 | Uniform, 182 to 338 |
| At least once per day | 18 | 1,337 | Triangular, 300/500/548 |

*Percentages represent weighted values.

For all RECS households, the frequency of dishwasher use ranged from 1 to more than 600 cycles per year. To determine the variability of dishwasher use, DOE normalized the household use values from RECS so that the average-use value equaled 215 cycles per year rather than the RECS weighted-average value of 171 cycles per year. DOE used the following equation to determine the usage for each RECS household having a dishwasher.

$$N_{DW} = N_{DW\_HH} \times \frac{N_{DOE\_AVG}}{N_{RECS\_AVG}}$$

Where:

$N_{DW}$ = modified dishwasher use for specific RECS household,
$N_{DW\_HH}$ = dishwasher use for specific RECS household as specified by RECS,
$N_{DOE\_AVG}$ = average dishwasher use of 215 cycles per year as established in the ADL study, and
$N_{RECS\_AVG}$ = average dishwasher use of 171 cycles per year as established by RECS.

Having identified the normalized dishwasher use for each RECS household, DOE determined the corresponding annual energy and water consumption. Figure 7.4.1 shows the probability distribution of the modified dishwasher use that DOE determined for each RECS household.

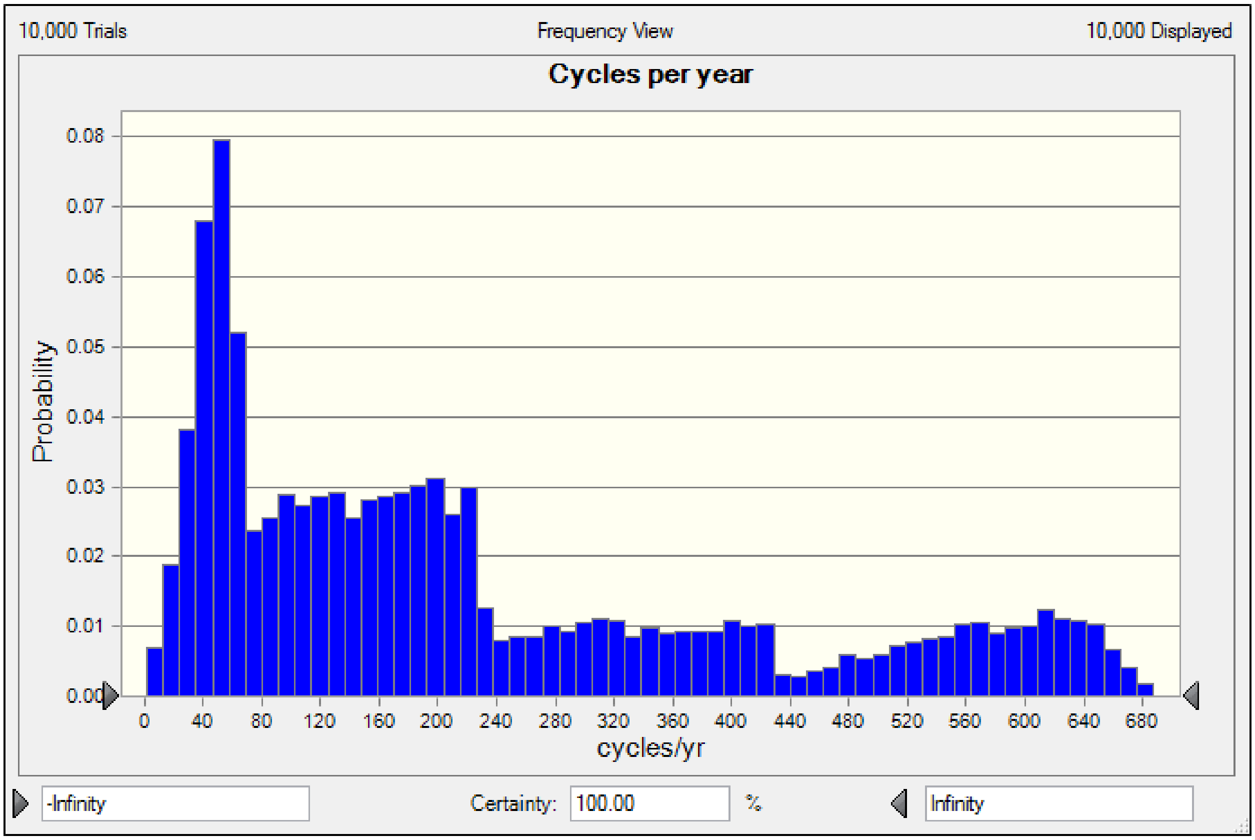


**Figure 7.4.1 Distribution of Annual Dishwasher Use (Cycles per Year) Based on 2009 RECS Usage Data**

## REFERENCES

---

1 U.S. Department of Energy–Office of Energy Efficiency and Renewable Energy. Energy Conservation Program for Consumer Products: Test Procedure for Dishwashers, Final Rule. *Federal Register*. August 29, 2003. Vol. 68, no. 168: pp. 51887–51903.

2 Arthur D. Little. *Review of Survey Data to Support Revisions to DOE's Dishwasher Test Procedure*. December 18, 2001. Prepared for the U.S. Department of Energy by Arthur D. Little, Cambridge, MA.

3 U.S. Department of Energy–Energy Information Administration. January 2013. *2009 RECS Survey Data*. (Last accessed June 16, 2014.) <http://www.eia.gov/consumption/residential/data/2009/index.cfm?view=characteristics>

# CHAPTER 8. LIFE-CYCLE COST AND PAYBACK PERIOD ANALYSIS

## TABLE OF CONTENTS

## LIST OF TABLES

## LIST OF FIGURES

# CHAPTER 8. LIFE-CYCLE COST AND PAYBACK PERIOD ANALYSIS

## 8.1 INTRODUCTION

This chapter describes the U.S. Department of Energy (DOE)'s methodology for analyzing the economic impacts of possible energy efficiency standards on individual consumers. Impacts include a change in operating expense (usually decreased) and a change in purchase price (usually increased). This chapter describes three metrics DOE used in the consumer analysis to determine the effect of standards on individual consumers:

- **Life-cycle cost** (LCC) is the total consumer expense over 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.

- **Payback period** (PBP) measures the amount of time it takes customers to recover the assumed higher purchase price of more energy-efficient products through lower operating costs.

- **Rebuttable payback period** is a special case of the PBP. Where LCC and PBP are estimated over a range of inputs that reflect real-world conditions, rebuttable payback period is based on laboratory conditions, specifically those representative of the DOE test procedure.

Inputs to the LCC and PBP are discussed in sections 8.2 and 8.3, respectively, of this chapter. Results of the LCC and PBP are presented in section 8.4. The rebuttable PBP is discussed in section 8.5. Key variables and calculations are presented for each metric. DOE performed the calculations discussed here using a series of Microsoft Excel spreadsheets, which are accessible on the Internet (http://www.eere.energy.gov/buildings/appliance_standards/). Details and instructions for using the spreadsheets are discussed in appendix 8-A.

### 8.1.1 General Approach for Life-Cycle Cost and Payback Period Analysis

Recognizing that several inputs to the analysis of consumer LCC and PBP are either variable or uncertain, DOE used Monte Carlo simulation and probability distributions to define inputs when appropriate. Appendix 8-B provides a detailed explanation of Monte Carlo simulation and the use of probability distributions. DOE developed LCC and PBP spreadsheet models that incorporate both Monte Carlo simulation and probability distributions by using Microsoft Excel spreadsheets combined with Crystal Ball (a commercially available add-in program).

In addition to using probability distributions to characterize several of the inputs to the analysis, DOE developed a sample of individual households that use dishwashers, which includes 7,382 household records. By developing household samples, DOE was able to perform the LCC and PBP calculations for each household to account for the variability in energy and water consumption and/or energy price associated with each household. As described in chapter 7, DOE used the DOE's Energy Information Administration (EIA)'s 2009 Residential Energy Consumption Survey (RECS) to develop household samples for standard and compact dishwashers.[1] The 2009 RECS is a national sample survey of housing units that collects statistical information on the consumption and expenditures for energy in housing units along with data on energy-related characteristics of the housing units and occupants. The 2009 RECS, which represents 12,083 housing units, was constructed by EIA to be a national representation of the household population in the United States.

DOE used RECS to establish the variability in annual energy use, energy pricing, annual water use, and water pricing. By using RECS, DOE was able to assign a unique annual energy use and/or energy price to each household in the sample. The large number of households considered in the analysis resulted in a large range of annual energy and water use and/or prices. (The actual ranges of energy consumption were presented and discussed in chapter 7.) The variability in annual energy and water use and pricing across all households contributes to the range of LCCs calculated for each standard level. As described section 8.2.2 of this chapter, DOE characterized the variability in energy and water prices through regional differences.

DOE displays the LCC results as distributions of impacts compared to the base case. Results are presented in section 8.5.2 of this chapter and are based on 10,000 samples per Monte Carlo simulation run.

The payback period is measured relative to the baseline product. The calculation uses average values for the inputs. It is calculated by dividing the change in installed cost by the change in first year operating cost for the baseline efficiency level and each increased efficiency level.

### 8.1.2 Overview of Life-Cycle Cost and Payback Period Inputs

The LCC is the total consumer expense over the life of the product, including purchase expense and operating expense (including energy and water expenditures). DOE discounts future operating expenses to the time of purchase and sums them over the lifetime of the product. The PBP is the change in purchase expense due to an increased efficiency standard divided by the change in first year operating cost that results from the standard. It represents the number of years it will take the customer to recover the increased purchase expense through decreased operating expenses.

DOE categorizes inputs to the LCC and PBP analysis as follows: (1) inputs for establishing the total installed cost, including the purchase price, and (2) inputs for calculating the operating cost.

The primary inputs for establishing the total installed cost are:

- *Baseline manufacturer cost* is the cost incurred by the manufacturer to produce products meeting existing minimum efficiency standards, or the baseline product.

- *Standard-level manufacturer cost increases* represent the change in manufacturer cost associated with producing products to meet a particular standard level.

- *Markups and sales tax* are costs associated with converting the manufacturer cost to a consumer product price. The markups and sale tax are described in detail in chapter 6, Markups for Equipment Price Determination.

- *Installation cost* is the cost to the consumer of installing the product after purchase, including costs for labor, overhead, and any miscellaneous materials and parts. Thus, the total installed cost equals the consumer product price plus the installation cost.

The primary inputs for calculating the operating cost are:

- *Product energy and water consumption* quantify the energy and water use associated with operating the product. Chapter 7, Energy and Water Use Analysis, details how DOE used various data sources to determine the product energy and water consumption of standard and compact dishwashers.

- *Product efficiency* dictates the energy and water consumption associated with a standard-level product (*i.e.*, a product having an efficiency greater than a baseline product). Chapter 7 details how energy and water consumption change with increasing product efficiency.

- *Energy and water prices* are the prices consumers pay for energy (*i.e.*, electricity, gas, or oil) and water. DOE determined current energy prices based on data from the DOE- EIA, *Natural Gas and Petroleum Monthly* (see section 8.2.2.2). DOE determined water prices based on data from the American Water Works Association (AWWA) and the Raftelis Financial Consultants (see section 8.2.2.2).[2]

- *Energy and water price trends* were developed from the following two sources. DOE used the reference case in EIA's *Annual Energy Outlook 2014* (*AEO2014*) to forecast future energy prices for the results presented in this chapter. DOE used the Bureau of Labor Statistics' consumer price index (CPI) data specific to water and sewage services to forecast future water prices.

- *Repair and maintenance costs* include costs associated with repairing or replacing components that have failed and costs associated with maintaining the operation of the product. Section 8.2.2.4 details DOE's method for estimating repair and maintenance costs.

- *Lifetime* is the age at which the product is retired from service. Section 8.2.3 describes the distribution DOE developed for product lifetimes.

- *Discount rate* is the rate at which DOE discounted future expenditures to establish their present value.

Figure 8.1.1 graphically depicts the relationships between the installed cost and operating cost inputs used to calculate the LCC and PBP. In the figure, the yellow boxes indicate the inputs, the green boxes indicate intermediate outputs, and the blue boxes indicate the final outputs (the LCC and PBP).

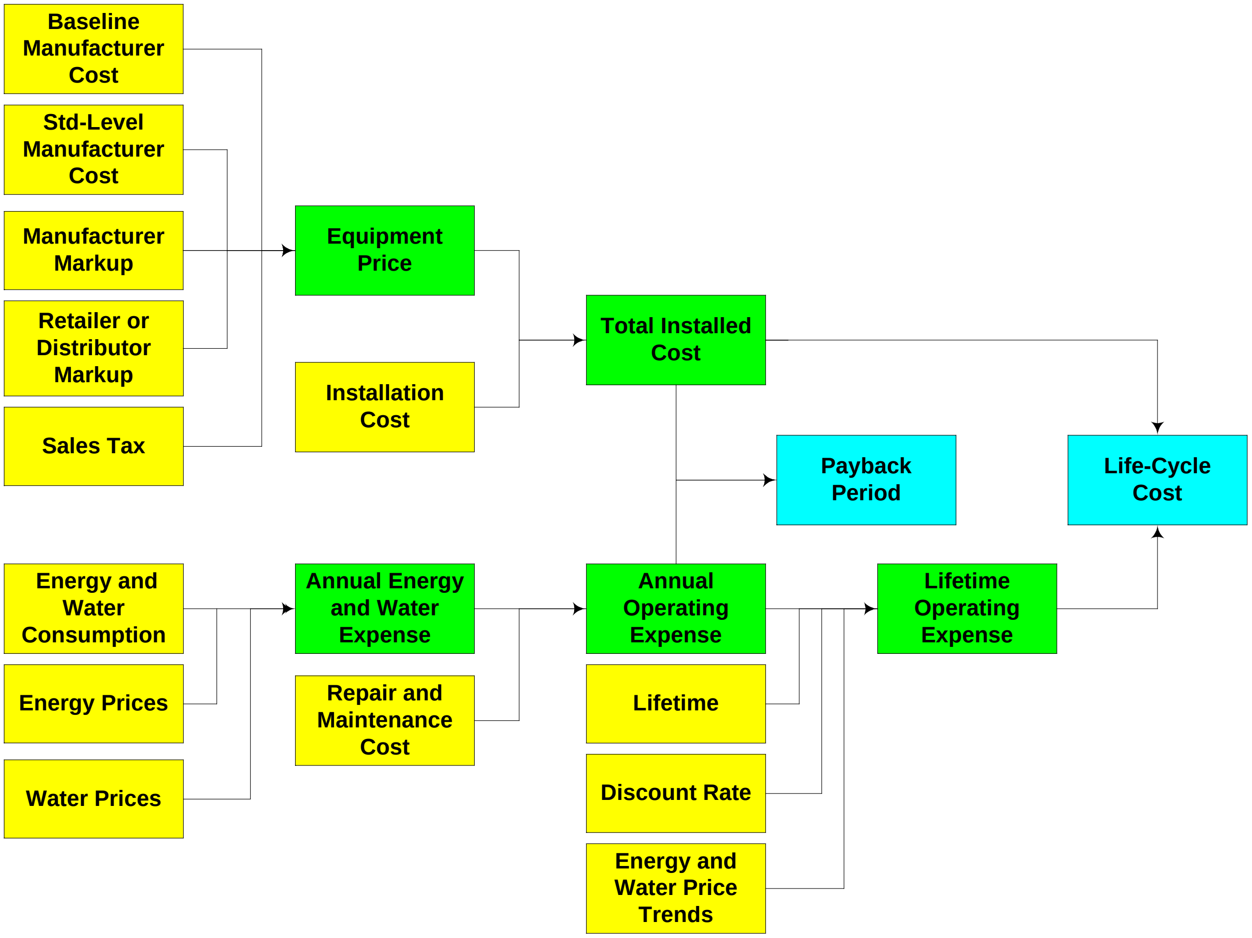


**Figure 8.1.1 Flow Diagram for the Determination of LCC and PBP**

## 8.2 INPUTS TO LIFE-CYCLE COST ANALYSIS

Life-cycle cost is the total customer expense over the life of an appliance, including purchase price and operating costs (including energy and water costs). 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 over the 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 2013$. The following sections discuss total installed cost, operating cost, lifetime, and discount rate.

### 8.2.1 Total Installed Cost Inputs

DOE defines the total installed cost using the following equation:

$$IC = EQP + INST$$

Where:

*EQP* = product price (*i.e.,* price the consumer pays for the product, including taxes), expressed in dollars, and
*INST* = installation cost (*i.e.,* the cost to the consumer to install the product, including labor and materials), also in dollars.

The product price is based on how the consumer purchases the product. As discussed in chapter 6, DOE defined markups and sales taxes for converting manufacturing costs into consumer product prices. The inputs for the total installed cost are:

- *Baseline manufacturer cost* is the cost incurred by the manufacturer to produce a product meeting existing minimum efficiency standards.
- *Standard-level manufacturer cost increases* are the changes in manufacturer cost associated with producing a product at a standard level.
- *Manufacturer and retailer markups and sales tax* convert the manufacturer cost to a consumer product price.

- *Installation cost* is the cost to the consumer of installing the product and represents all costs required to install the product other than the marked-up consumer product price. The installation cost includes labor, overhead, and any miscellaneous materials and parts.

Thus, the total installed cost equals the consumer product price plus the installation cost. DOE calculated the total installed cost for baseline products based on the following equation:

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

Where:

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

DOE calculated the total installed cost for standard-level products based on the following equation:

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

Where:

$IC_{STD}$ = standard-level total installed cost,
$EQP_{STD}$ = consumer product price for standard-level models,
$INST_{STD}$ = standard-level installation cost,
$EQP_{BASE}$ = consumer product price for baseline models,
$\Delta EQP_{STD}$ = change in product price for standard-level models,
$INST_{BASE}$ = baseline installation cost,
$\Delta INST_{STD}$ = change in installation cost for standard-level models,
$IC_{BASE}$ = baseline total installed cost,
$\Delta COST_{MFG}$ = change in manufacturer cost for standard-level models, and
$MU_{OVERALL\_INCR}$ = incremental overall markup (product of manufacturer markup, incremental retailer or distributor markup, and sales tax).

The remainder of this section provides information about each of the above input variables that DOE used to calculate the total installed cost for standard and compact residential dishwashers.

### 8.2.1.1 Forecasting Future Product Prices

Examination of historical price data for certain appliances and products that have been subject to energy conservation standards indicates that the assumption of constant real prices and costs may, in many cases, overestimate long-term trends in appliance and product prices. Economic literature and historical data suggest that the real costs of these products may in fact trend downward over time according to “learning” or “experience” curves. Desroches *et al.* (2013) summarizes the data and literature currently available that is relevant to price forecasts for selected appliances and equipment.[3]

For the default price trend for this final rule, DOE estimated an experience rate for residential dishwashers based on an analysis of long-term historical data. DOE derived a dishwasher price index from 1988 to 2013 using Producer Price Index (PPI) data for “other miscellaneous household appliances” from the Bureau of Labor Statistics’ (BLS).[a] DOE understands that “other miscellaneous household appliances” encompass much more than dishwashers; however, because no PPI data specific to dishwashers were available, DOE used PPI data for other miscellaneous household appliances as representative of dishwashers. An inflation-adjusted price index was calculated using the gross domestic product (GDP) price deflator for the same years. This proxy for historic price data was then regressed on the quantity of dishwashers produced, based on a corresponding series for total shipments of dishwashers.

To calculate an experience rate, a least-squares power-law fit was performed on the dishwasher price index versus cumulative shipments. DOE then derived a price factor index, with the price in 2013 equal to 1, to project prices in the year of compliance for amended energy conservation standards in the LCC and PBP analysis, and for the national impact analysis (NIA), for each subsequent year through 2048. The index value in each year is a function of the experience rate and the cumulative production through that year. To derive the latter, DOE used projected shipments from the base-case projections made for the NIA (see setion 10.4.2 of chapter 10). The average annual rate of price decline in the default case is 1.33 percent. DOE’s projection of product prices for dishwashers in the LCC and PBP analysis is described further in appendix 8-C.

### 8.2.1.2 Baseline Manufacturer Selling Price

DOE used data from the Association of Home Appliance Manufacturers (AHAM) to develop the baseline manufacturer selling prices for standard-sized and compact dishwashers.[4] Based on a manufacturer markup of 1.24 for all dishwashers (see section 6.2 of chapter 6), DOE

---

[a] PCU3352283352285: All other miscellaneous household appliances, including parts. Available at: http://www.bls.gov/ppi/

arrived at a baseline manufacturer selling price (MSP) of $203.72 for standard-sized dishwashers and $187.68 for compact dishwashers. Table 8.2.1 presents the baseline manufacturer costs along with the associated baseline annual energy use for the product classes of residential dishwashers.

**Table 8.2.1 Dishwashers: Baseline Manufacturer Selling Price**

| Product Class | Baseline Annual Energy Use (kWh/year) | Baseline Water Use (gallons/cycle) | Baseline Manufacturer Cost (2013$) |
|---|---|---|---|
| **Standard** | 307 | 5.0 | 203.72 |
| **Compact** | 222 | 3.5 | 187.68 |

### 8.2.1.3 Increases in Manufacturer Costs

DOE used cost data from a reverse engineering analysis to develop manufacturer cost increases associated with increases in standard levels for residential dishwashers. Refer to chapter 5, Engineering Analysis, for details. Table 8.2.2 and Table 8.2.3 present the standard-level manufacturer cost increases and associated annual energy use for the product classes.

**Table 8.2.2 Standard-Sized Dishwashers: Standard-Level Manufacturer Cost Increases**

| Efficiency Level | Annual Energy Use (kWh/year) | Water Use (gallons/cycle) | Standard-Level Manufacturer Cost Increases (2013$) |
|---|---|---|---|
| Baseline | 307 | 5.00 | -- |
| 1 | 295 | 4.25 | 9.52 |
| 2 | 280 | 3.50 | 36.53 |
| 3 | 234 | 3.10 | 74.72 |
| 4 | 180 | 2.22 | 74.72 |

**Table 8.2.3 Compact Dishwashers: Standard-Level Manufacturer Cost Increases**

| Efficiency Level | Annual Energy Use (kWh/year) | Water Use (gallons/cycle) | Standard-Level Manufacturer Cost Increases (2013$) |
|---|---|---|---|
| Baseline | 222 | 3.50 | -- |
| 1 | 203 | 3.10 | 8.01 |
| 2 | 141 | 2.00 | 21.50 |

### 8.2.1.4 Overall Markup

The overall markup is the value arrived at by multiplying the manufacturer and retailer markups and the sales tax together to arrive at a single markup value. Table 8.2.4 shows the overall baseline and incremental markups for dishwashers. Refer to chapter 6, Markups for Equipment Price Determination, for details.

**Table 8.2.4 Dishwashers: Overall Markups**

| Markup | Standard | | Compact | |
|---|---|---|---|---|
| | **Baseline** | **Incremental** | **Baseline** | **Incremental** |
| Manufacturer | 1.24 | | 1.24 | |
| Retailer | 1.36 | 1.11 | 1.36 | 1.11 |
| Sales Tax | 1.071 | | 1.071 | |
| **Overall** | 1.81 | 1.47 | 1.81 | 1.47 |

### 8.2.1.5 Installation Cost

DOE derived baseline installation costs for dishwashers from data in the *RS Means Residential Cost Data, 2013*,[5] which provides estimates on the labor required to install residential dishwashers. Table 8.2.5 summarizes the nationally representative average bare costs and overhead and profit costs of a four-or-more-cycle dishwasher. DOE determined that installation costs would not be impacted with increased standard levels.

**Table 8.2.5 Dishwashers: Baseline Installation Costs**

| Installation Type | Bare Costs (2013$) | | | Including Overhead & Profit (2013$) | | |
|---|---|---|---|---|---|---|
| | **Material** | **Labor** | **Total** | **Total** | **Material*** | **Labor**** |
| Average | 455 | 91.5 | 546.5 | 650 | 500.5 | 149.5 |
| **Average (2013$)** | | | | | | **149.5** |

* Material costs including overhead and profit (O&P) equal bare costs plus 10% profit.

** DOE derived labor costs including O&P by subtracting material with O&P from total with O&P.

Source: RS Means, *Residential Cost Data, 2013.*

### 8.2.1.6 Total Installed Cost

The total installed cost is the sum of the consumer product price and the installation cost. Section 8.2.1 covers the equations DOE used to calculate the total installed cost for baseline and standard-level products.

Table 8.2.6 and Table 8.2.7 present the consumer product price, installation cost, and total installed cost for standard-sized and compact dishwashers, respectively, at the baseline level and each standard level.

**Table 8.2.6 Standard-Sized Dishwashers: Consumer Product Prices, Installation Costs, and Total Installed Costs**

| Efficiency Level | Annual Energy Use (kWh/year) | Water Use (gallons/cycle) | Product Price (2013$) | Installation Cost (2013$) | Total Installed Cost (2013$) |
|---|---|---|---|---|---|
| Baseline | 307 | 5.00 | 333 | 150 | 483 |
| 1 | 295 | 4.25 | 346 | 150 | 495 |
| 2 | 280 | 3.50 | 382 | 150 | 531 |
| 3 | 234 | 3.10 | 433 | 150 | 582 |
| 4 | 180 | 2.22 | 433 | 150 | 582 |

**Table 8.2.7 Compact Dishwashers: Consumer Product Prices, Installation Costs, and Total Installed Costs**

| Efficiency Level | Annual Energy Use (kWh/year) | Water Use (gallons/cycle) | Product Price (2013$) | Installation Cost (2013$) | Total Installed Cost (2013$) |
|---|---|---|---|---|---|
| Baseline | 222 | 3.50 | 307 | 150 | 456 |
| 1 | 203 | 3.10 | 317 | 150 | 467 |
| 2 | 141 | 2.00 | 335 | 150 | 485 |

### 8.2.2 Operating Cost Inputs

DOE uses the following equation to define the operating cost of an appliance:

$$OC = EC + WC + RC + MC$$

Where:

$OC$ = operating cost,
$EC$ = energy cost associated with operating the product,
$WC$ = water cost associated with operating the product,
$RC$ = repair costs associated with component failure, and
$MC$ = service costs for maintaining product operation.

The inputs for calculating operating costs are also necessary to determine lifetime operating costs, which include the energy and water price trends, product lifetime, discount rate, and effective date of the standard.

- *Annual energy consumption* is the site energy use associated with operating the product.
- *Annual water consumption* is the site water use associated with operating the product. Both the annual energy and water consumption vary with the product efficiency. That is, the energy and water consumption associated with standard-level products (*i.e.*, products

having efficiencies greater than baseline product) are less than the consumptions associated with baseline products.

- *Energy and water prices* are the prices paid by consumers for energy (*i.e.*, electricity, gas, or oil) and water. Multiplying the annual energy and water consumption by the energy and water prices yields the annual energy cost and water cost, respectively.
- *Repair costs* are associated with repairing or replacing components that have failed.
- *Maintenance costs* are associated with maintaining the operation of the product.
- *Energy and water price trends* were used by DOE to forecast energy and water prices into the future and, along with the product lifetime and discount rate, to establish the lifetime energy and water costs.
- *Product lifetime* is the age at which the product is retired from service.
- The *discount rate* is the rate at which DOE discounted future expenditures to establish their present value.

DOE calculated the operating cost for baseline products based on the following equation:

$$\begin{aligned} OC_{BASE} &= EC_{BASE} + WC_{BASE} + RC_{BASE} + MC_{BASE} \\ &= AEC_{BASE} \times PRICE_{ENERGY} + AWC_{BASE} \times PRICE_{WATER} + RC_{BASE} + MC_{BASE} \end{aligned}$$

Where:

$OC_{BASE}$ = operating cost for the baseline product,
$EC_{BASE}$ = energy cost associated with operating the baseline product,
$WC_{BASE}$ = water cost associated with operating the baseline product,
$RC_{BASE}$ = repair cost associated with component failure for the baseline product,
$MC_{BASE}$ = service cost for maintaining baseline product operation,
$AEC_{BASE}$ = annual energy consumption for baseline product,
$PRICE_{ENERGY}$ = energy price,
$AWC_{BASE}$ = annual water consumption for baseline product, and
$PRICE_{WATER}$ = water price.

DOE calculated the operating cost for standard-level products based on the following equation:

$$\begin{aligned} OC_{STD} &= EC_{STD} + WC_{STD} + RC_{STD} + MC_{STD} \\ &= AEC_{STD} \times PRICE_{ENERGY} + AWC_{STD} \times PRICE_{WATER} + RC_{STD} + MC_{STD} \\ &= \left(AEC_{BASE} - \Delta AEC_{STD}\right) \times PRICE_{ENERGY} + \left(AWC_{BASE} - \Delta AWC_{STD}\right) \times PRICE_{WATER} \\ &\quad + \left(RC_{BASE} + \Delta RC_{STD}\right) + \left(MC_{BASE} + \Delta MC_{STD}\right) \end{aligned}$$

Where:

$OC_{STD}$ = operating cost for standard-level product,

$EC_{STD}$ = energy cost associated with operating standard-level product,
$WC_{STD}$ = water cost associated with operating standard-level product,
$RC_{STD}$ = repair cost associated with component failure for standard-level product,
$MC_{STD}$ = service cost for maintaining standard-level product operation,
$AEC_{STD}$ = annual energy consumption for standard-level product,
$PRICE_{ENERGY}$ = energy price,
$AWC_{STD}$ = annual water consumption for standard-level product,
$PRICE_{WATER}$ = water price,
$\Delta AEC_{STD}$ = change in annual energy consumption caused by standard-level product,
$\Delta AWC_{STD}$ = change in annual water consumption caused by standard-level product,
$\Delta RC_{STD}$ = change in repair cost caused by standard-level product, and
$\Delta MC_{STD}$ = change in maintenance cost caused by standard-level product.

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

#### 8.2.2.1 Annual Energy and Water Consumption

Chapter 7, Energy and Water Use Analysis, details how DOE determined the annual energy and water consumption for baseline and standard-level products.

As described in section 7.4 of chapter 7, DOE developed a sample of individual households that use one of the product classes of dishwashers. By developing household samples, DOE was able to perform the LCC and PBP calculations for each household to account for the variability in the usage and price of both energy and water associated with each household. DOE used EIA’s 2009 RECS to develop the household samples and, in turn, to establish the variability in both annual energy and water consumption and energy and water pricing. Refer to chapter 7 to review the variability of annual energy consumption for dishwashers.

The tables presented in this section are based on the energy and water use analysis described in chapter 7. Keep in mind that the annual energy and water consumption values in the tables are averages. DOE captured the variability in energy and water consumption in the LCC and PBP analysis.

Table 8.2.8 and Table 8.2.9 provide the average annual energy and water consumption by efficiency level for standard-sized and compact dishwashers, respectively. These tables are similar to those in section 7.3 of chapter 7 with the exception that, in Table 8.2.8 and Table 8.2.9, the electric, gas, and oil water-heating consumption takes into account the percentage of households in the United States that use electric, gas, and oil water heaters, respectively. In others words, the electric, gas, and oil water heating consumption is weighted by the share of households that use electric, gas, and oil water heaters. Based on data from the RECS, 41.4 percent of households use electric water heaters, 51.7 percent use gas, 3.7 percent use propane and liquid petroleum gas (LPG), and 3.2 percent use fuel oil.

**Table 8.2.8 Standard Dishwashers: Annual Energy and Water Use by Efficiency Level**

| Efficiency Level | Annual Energy Use (kWh/year) | Annual Energy Use Water Heating* | | | Annual Water Use (1,000 gal/year) |
|---|---|---|---|---|---|
| | | Electric (kWh/year) | Gas (MMBtu/year) | Oil (MMBtu/year) | |
| Baseline | 307 | 207 | 0.45 | 0.03 | 1.12 |
| 1 | 295 | 211 | 0.38 | 0.02 | 0.95 |
| 2 | 280 | 212 | 0.31 | 0.02 | 0.79 |
| 3 | 234 | 174 | 0.28 | 0.02 | 0.70 |
| 4 | 180 | 137 | 0.20 | 0.01 | 0.50 |

* Electric, gas, and oil water heating based on water heater efficiencies of 98% for electric, 80% for gas, 78% for oil.

**Table 8.2.9 Compact Dishwashers: Annual Energy and Water Use by Efficiency Level**

| Efficiency Level | Annual Energy Use (kWh/year) | Annual Energy Use Water Heating* | | | Annual Water Use (1,000 gal/year) |
|---|---|---|---|---|---|
| | | Electric (kWh/year) | Gas (MMBtu/year) | Oil (MMBtu/year) | |
| Baseline | 222 | 124 | 0.25 | 0.02 | 0.63 |
| 1 | 203 | 115 | 0.22 | 0.01 | 0.55 |
| 2 | 141 | 82 | 0.14 | 0.01 | 0.36 |

* Electric, gas, and oil water heating based on water heater efficiencies of 98% for electric, 80% for gas, 78% for oil.

#### 8.2.2.2 Energy and Water Prices

DOE used probability distributions to characterize the regional variability in energy and water prices. DOE developed the probability associated with each regional energy and water price based on the population weight of each region. DOE's method for deriving energy and water prices is described here.

***Electricity Prices***

DOE derived average energy prices from data that are published annually based on *EIA Form 861*.[6] Those data include, for every utility that serves final consumers, annual electricity sales in kilowatt-hours; revenues from electricity sales; and number of customers in the residential, commercial, and industrial sectors. DOE calculated prices for each of 27 geographic areas in accordance with *RECS 2009* geographic areas.

The calculation of average residential electricity price proceeded in two steps.

1. For each utility, DOE estimated an average residential price by dividing residential revenues by residential sales.
2. DOE calculated a regional average price, weighting each utility that serves residences in a region by the number of residential customers served in that region.

Table 8.2.10 shows the average prices for each geographic regions.

**Table 8.2.10 Average Residential Electricity Prices in 2012**

| | Geographic Area | 2013$/kWh |
|---|---|---|
| 1 | Connecticut, Maine, New Hampshire, Rhode Island, Vermont | 0.164 |
| 2 | Massachusetts | 0.152 |
| 3 | New York | 0.190 |
| 4 | New Jersey | 0.161 |
| 5 | Pennsylvania | 0.131 |
| 6 | Illinois | 0.116 |
| 7 | Indiana, Ohio | 0.115 |
| 8 | Michigan | 0.144 |
| 9 | Wisconsin | 0.134 |
| 10 | Iowa, Minnesota, North Dakota, South Dakota | 0.111 |
| 11 | Kansas, Nebraska | 0.109 |
| 12 | Missouri | 0.104 |
| 13 | Virginia | 0.112 |
| 14 | Delaware, District of Columbia, Maryland, West Virginia | 0.131 |
| 15 | Georgia | 0.114 |
| 16 | North Carolina, South Carolina | 0.114 |
| 17 | Florida | 0.116 |
| 18 | Alabama, Kentucky, Mississippi | 0.106 |
| 19 | Tennessee | 0.103 |
| 20 | Arkansas, Louisiana, Oklahoma | 0.092 |
| 21 | Texas | 0.112 |
| 22 | Colorado | 0.116 |
| 23 | Idaho, Montana, Utah, Wyoming | 0.099 |
| 24 | Arizona | 0.114 |
| 25 | Nevada, New Mexico | 0.119 |
| 26 | California | 0.156 |
| 27 | Alaska, Hawaii, Oregon, Washington | 0.119 |

Source: EIA Form 861 for 2012.

### ***Natural Gas Prices***

DOE obtained data for calculating regional prices of natural gas from the EIA publication, *Natural Gas Navigator*.[7] This publication presents monthly volumes of natural gas deliveries and average prices by state for residential, commercial, and industrial customers. The Department used the complete annual data for 2012 to calculate an average annual price for each geographic area. The calculation of average prices proceeded in two steps.

1. For each state, DOE calculated the annual residential price of natural gas using a simple average of data.
2. DOE then calculated a regional price, weighting each state in a region by its number of households. [8]

The method used to calculate natural gas prices differs from that used to calculate electricity prices, because the EIA does not provide consumer- or utility-level data on gas consumption and prices. The prices in Table 8.2.11 are in dollars per million Btu ($/MMBtu).

**Table 8.2.11 Average Residential Natural Gas Prices in 2012**

| | Geographic Area | 2013$/MMBtu |
|---|---|---|
| 1 | Connecticut, Maine, New Hampshire, Rhode Island, Vermont | 15.72 |
| 2 | Massachusetts | 13.40 |
| 3 | New York | 14.41 |
| 4 | New Jersey | 11.64 |
| 5 | Pennsylvania | 13.98 |
| 6 | Illinois | 10.07 |
| 7 | Indiana, Ohio | 12.30 |
| 8 | Michigan | 11.10 |
| 9 | Wisconsin | 10.05 |
| 10 | Iowa, Minnesota, North Dakota, South Dakota | 9.62 |
| 11 | Kansas, Nebraska | 11.88 |
| 12 | Missouri | 16.71 |
| 13 | Virginia | 14.83 |
| 14 | Delaware, District of Columbia, Maryland, West Virginia | 14.35 |
| 15 | Georgia | 19.98 |
| 16 | North Carolina, South Carolina | 15.71 |
| 17 | Florida | 19.11 |
| 18 | Alabama, Kentucky, Mississippi | 14.71 |
| 19 | Tennessee | 12.15 |
| 20 | Arkansas, Louisiana, Oklahoma | 13.72 |
| 21 | Texas | 12.66 |
| 22 | Colorado | 9.53 |
| 23 | Idaho, Montana, Utah, Wyoming | 8.90 |
| 24 | Arizona | 18.02 |
| 25 | Nevada, New Mexico | 10.83 |
| 26 | California | 9.33 |
| 27 | Alaska, Hawaii, Oregon, Washington | 16.09 |

Source: EIA Natural Gas Navigator for 2012.

### *Residential LPG Prices*

DOE collected 2012 average LPG prices from EIA's 2012 State Energy Consumption, Price, and Expenditures Estimates (SEDS).[9] SEDS includes annual LPG prices for residential, commercial, industrial, and transportation consumers by state. For areas with more than one state, DOE weighted each state's average price by its number of households. See Table 8.2.12.

**Table 8.2.12 Average Residential LPG Prices in 2012**

| | Geographic Area | 2013$/MMBtu |
|---|---|---|
| 1 | Connecticut, Maine, New Hampshire, Rhode Island, Vermont | 36.42 |
| 2 | Massachusetts | 38.60 |
| 3 | New York | 35.96 |
| 4 | New Jersey | 38.13 |
| 5 | Pennsylvania | 32.43 |
| 6 | Illinois | 23.36 |
| 7 | Indiana, Ohio | 27.38 |
| 8 | Michigan | 23.31 |
| 9 | Wisconsin | 21.10 |
| 10 | Iowa, Minnesota, North Dakota, South Dakota | 23.36 |
| 11 | Kansas, Nebraska | 23.30 |
| 12 | Missouri | 22.91 |
| 13 | Virginia | 27.06 |
| 14 | Delaware, District of Columbia, Maryland, West Virginia | 37.45 |
| 15 | Georgia | 28.84 |
| 16 | North Carolina, South Carolina | 31.25 |
| 17 | Florida | 43.04 |
| 18 | Alabama, Kentucky, Mississippi | 29.96 |
| 19 | Tennessee | 30.34 |
| 20 | Arkansas, Louisiana, Oklahoma | 27.86 |
| 21 | Texas | 31.21 |
| 22 | Colorado | 22.25 |
| 23 | Idaho, Montana, Utah, Wyoming | 22.61 |
| 24 | Arizona | 35.74 |
| 25 | Nevada, New Mexico | 33.06 |
| 26 | California | 34.34 |
| 27 | Alaska, Hawaii, Oregon, Washington | 33.48 |

Source: EIA SEDS 2012.

### *Residential Oil Prices*

DOE collected 2012 average fuel oil prices from EIA's SEDS. SEDS includes annual fuel oil prices for residential, commercial, industrial, and transportation consumers by state. For areas with more than one state, DOE weighted each state's average price by its number of households.

**Table 8.2.13 Average Monthly Residential Oil Prices in 2012**

| | Geographic Area | 2013$/MMBtu |
|---|---|---|
| 1 | Connecticut, Maine, New Hampshire, Rhode Island, Vermont | 28.92 |
| 2 | Massachusetts | 29.03 |
| 3 | New York | 28.85 |
| 4 | New Jersey | 30.18 |
| 5 | Pennsylvania | 29.99 |
| 6 | Illinois | 27.46 |
| 7 | Indiana, Ohio | 27.40 |
| 8 | Michigan | 27.40 |
| 9 | Wisconsin | 27.13 |
| 10 | Iowa, Minnesota, North Dakota, South Dakota | 27.45 |
| 11 | Kansas, Nebraska | 27.39 |
| 12 | Missouri | 26.94 |
| 13 | Virginia | 27.13 |
| 14 | Delaware, District of Columbia, Maryland, West Virginia | 29.17 |
| 15 | Georgia | 26.88 |
| 16 | North Carolina, South Carolina | 27.18 |
| 17 | Florida | 27.40 |
| 18 | Alabama, Kentucky, Mississippi | 25.96 |
| 19 | Tennessee | 27.65 |
| 20 | Arkansas, Louisiana, Oklahoma | 25.74 |
| 21 | Texas | 25.44 |
| 22 | Colorado | 25.88 |
| 23 | Idaho, Montana, Utah, Wyoming | 26.30 |
| 24 | Arizona | 29.79 |
| 25 | Nevada, New Mexico | 27.84 |
| 26 | California | 29.97 |
| 27 | Alaska, Hawaii, Oregon, Washington | 29.03 |

Source: EIA SEDS 2012.

### *Water Prices*

DOE obtained data on water prices for 2012 from the *Water and Wastewater Rate Survey* conducted by Raftelis Financial Consultants and the American Water Works Association.[10] The survey covers approximately 290 water utilities and 214 wastewater utilities, analyzing each industry (water and wastewater) separately. The water survey includes the cost to consumers of a given volume of water for each utility. The total consumer cost is divided into fixed and volumetric charges. DOE's calculation of water prices uses only volumetric charges, as only those charges would be affected by a change in water consumption. Including the fixed charge in the average would lead to a slightly higher water price.

For wastewater utilities, the data format is similar, except that the price represents the cost to treat a given volume of wastewater. A sample of 290 or 214 utilities is too small to calculate regional prices for all U.S. Census divisions and large states. (For comparison, data from EIA Form 861 cover more than 3,000 utilities.) Therefore, DOE calculated regional costs for wastewater service at the level of Census regions only (Northeast, South, Midwest, and West). The calculation of average prices per unit volume proceeds in the following three steps.

1. For each water or wastewater utility, DOE calculated the price per unit volume by dividing the total volumetric cost by the volume delivered.
2. DOE calculated a state-level average price by weighting each utility in a given state by the number of residential customers it serves.
3. DOE calculated a regional average by combining the state-level averages and weighting each by the state's population. This third step helps reduce any bias in the sample that may result from the relative under-sampling of large states.

Table 8.2.14 presents the results of the calculation of costs for water and wastewater service. The price units in the table are 2013 dollars per thousand gallons (/tg).

**Table 8.2.14 Average Water and Wastewater Prices per Unit Volume**

| Census Region | Water (2013$/tg) | Wastewater (2013$/tg) |
|---|---:|---:|
| Northeast | 4.67 | 6.39 |
| Midwest | 3.62 | 4.61 |
| South | 3.80 | 5.49 |
| West | 4.84 | 4.91 |
| **National Average** | 4.23 | 5.35 |

#### 8.2.2.3 Energy and Water Price Trends

DOE used EIA price forecasts to estimate the trends in natural gas, oil, and electricity prices. To arrive at prices in future years, it multiplied the average prices described in the preceding section by the forecast of annual average price changes in EIA's *AEO 2014*.[11] To estimate the trend after 2040, DOE followed past guidelines provided to the Federal Energy Management Program (FEMP) by EIA and used the average rate of change during 2030–2040.

The Department calculated LCC and PBP using three separate projections from *AEO 2014*: reference, low economic growth, and high economic growth. These three cases reflect the uncertainty of economic growth in the forecast period. The high and low growth cases show the projected effects of alternative growth assumptions on energy markets. Figure 8.2.1 shows the residential electricity price trend based on the three *AEO 2014* projections. For the LCC results presented in section 8.4, DOE used only the energy price forecasts from the AEO reference case.

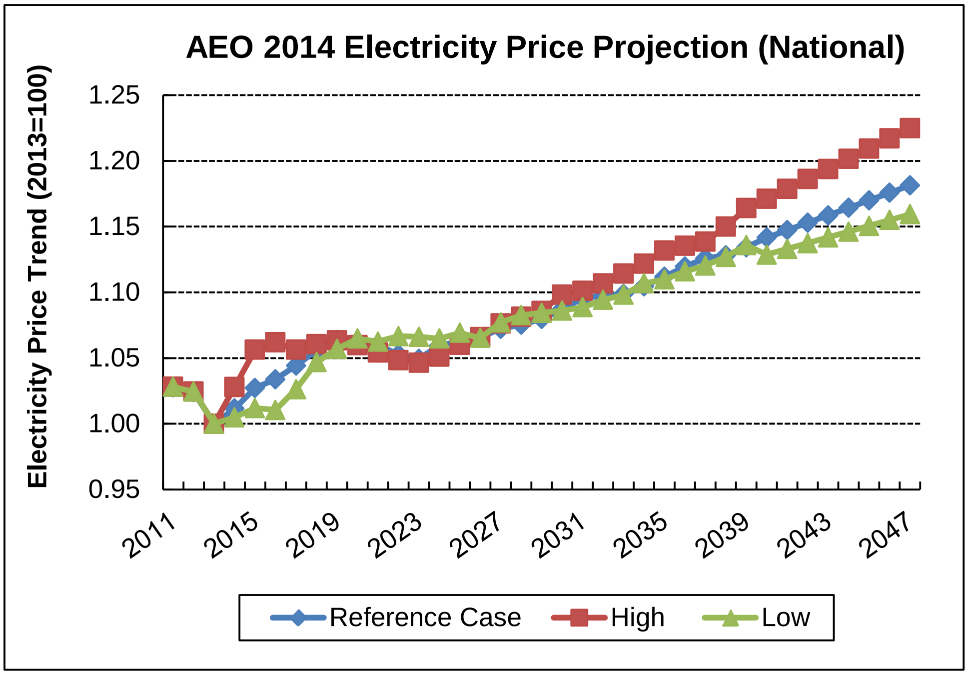


**Figure 8.2.1 Electricity Price Trends**

To estimate the future trend for water and wastewater prices, DOE used data on the historic trend in the national water price index (U.S. city average) from 1970 through 2012.[12] DOE extrapolated the future trend based on the linear growth from 1970 to 2012. DOE used the extrapolated trend to forecast prices through 2048. Figure 8.2.2 shows historical and projected trends in water and sewerage prices. DOE used the projected data to estimate water and wastewater prices for residential dishwashers.

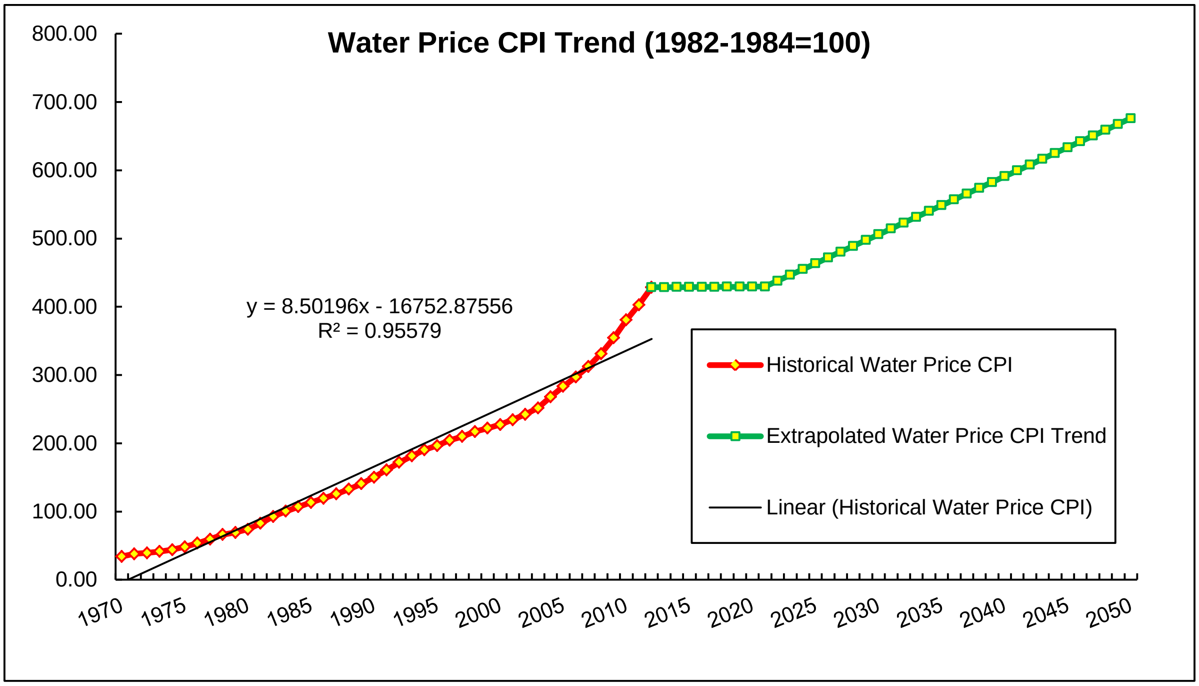


**Figure 8.2.2 Water Price Trend**

#### 8.2.2.4 Repair and Maintenance Costs

Typically, small incremental changes in product efficiency produce no, or only slight, changes in repair and maintenance costs over baseline products. However, products having significantly higher efficiencies, compared to baseline products, are more likely to incur higher repair and maintenance costs, because their increased complexity and higher part count typically increases the cumulative probability of failure. DOE requested that manufacturers and other stakeholders assist in developing appropriate repair and maintenance cost estimates, but it did not receive any input. Thus, DOE did not include any changes in repair and maintenance costs for products more efficient than baseline products.

### 8.2.3 Product Lifetimes

RECS records the presence of various appliances in each household and places the age of each appliance into bins comprising several years. Data from the U.S. Census's *American Housing Survey* (AHS),[13] which surveys all housing including vacant and second homes, enabled DOE to adjust the RECS data to reflect some appliance use outside of primary residences. By combining the results of both surveys with the known history of appliance shipments (collected from *Appliance* magazine or directly from manufacturer trade associations), DOE estimated the percentage of appliances of a given age still in operation. This survival function, which DOE assumed has the form of a cumulative Weibull distribution, provides an average and a median appliance lifetime. DOE calculated the average lifetime for both product classes at 15.4 years.

The Weibull distribution is a probability distribution commonly used to measure failure rates.[b] 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 particular fashion. The cumulative Weibull distribution takes the form:

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

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

Where:

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

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, $\beta$ commonly is greater than 1, reflecting an increasing failure rate as appliances age. Figure 8.2.3 shows the Weibull retirement function for dishwashers.

---

[b] 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/>.

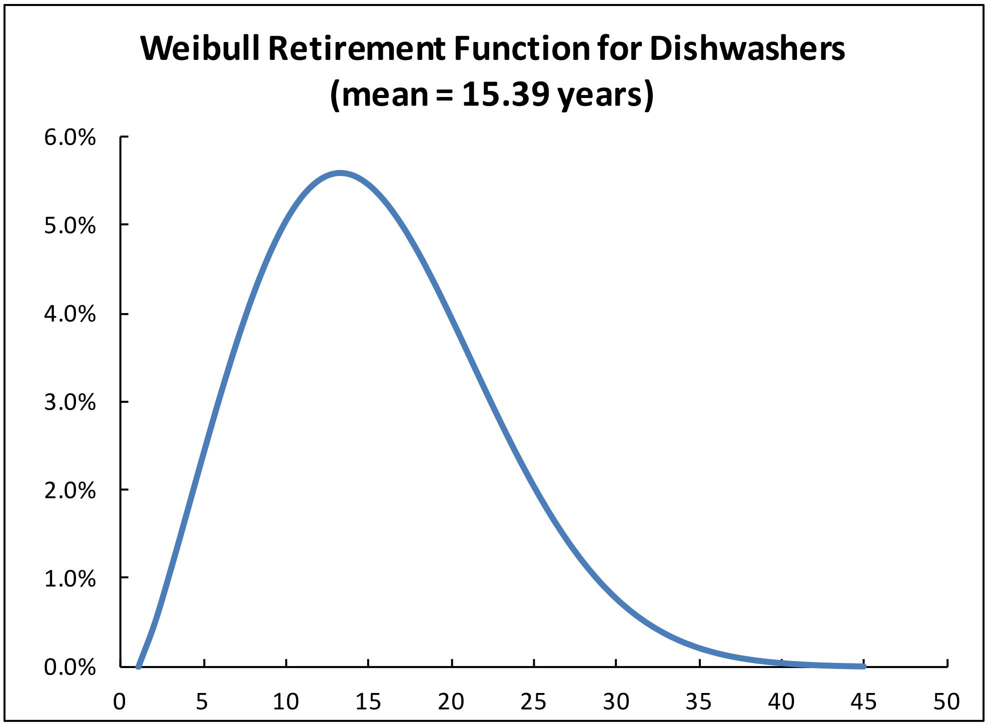


**Figure 8.2.3 Weibull Retirement Function for Dishwashers**

Appendix 8-D presents the Weibull distributions that DOE used in the LCC and PBP analysis.

### 8.2.4 Discount Rates

The discount rate is the rate at which future savings and expenditures are discounted to establish their present value. DOE uses publicly available data (the Federal Reserve Board's *Survey of Consumer Finances* (SCF)) to estimate a consumer's opportunity cost of funds related to appliance energy cost savings and maintenance costs. The discount rate value is applied in the LCC to future year energy cost savings and non-energy operations and maintenance costs in order to present the estimated net LCC and LCC savings. DOE notes that the discount rate used in the LCC analysis is distinct from an implicit discount rate, as 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 discount rate distributions for six income groups, divided based on income percentile as reported in the Federal Reserve Board's SCF.[14] This disaggregation reflects the fact that low and high income consumers tend to have substantially different shares of debt and asset types and tend to face different rates on debts and assets. Summaries of shares and rates presented in this chapter are averages across the entire population.

**Table 8.2.15 Definitions of 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. *Survey of Consumer Finances (SCF)* for 1995, 1998, 2001, 2004, 2007, and 2010.

### *Shares of 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.

The average share of total debt plus equity and the associated rate of each asset and debt type are used to calculate a weighted average discount rate for each SCF household (Table 8.2.16). The household-level discount rates are then aggregated to form discount rate distributions for each of the six income groups. Note that previously DOE performed aggregation of asset and debt types over households by summing the dollar value across all households and then calculating shares. Weighting by dollar value gave disproportionate influence to the asset and debt shares and rates 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 percentage shares of the various types of debt and equity using data from the Federal Reserve Board's SCF for 1995, 1998, 2001, 2004, 2007, and 2010.[c] DOE derived the household-weighted mean percentages of each source of financing throughout the 5 years surveyed. DOE posits that these long-term averages are most appropriate to use in its analysis.

---

[c] 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 15-year span covered by the six surveys included is sufficiently representative of recent debt and equity shares and interest rates.

**Table 8.2.16 Types of Household Debt and Equity by Percentage Shares (%)**

| 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, and 2010.

### *Rates for Types of Debt*

DOE estimated interest rates associated with each type of debt. The 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, and 2010, which associates an interest rate with each type of debt for each household in the survey.

In calculating effective interest rates for home equity loans and mortgages, DOE accounted for the fact that interest on both such loans is tax deductible (Table 8.2.17). This rate corresponds to the interest rate after deduction of mortgage interest for income tax purposes and after adjusting for inflation (using the Fisher formula).[d] For example, a 6-percent nominal mortgage rate has an effective nominal rate of 4.5 percent for a household at the 25-percent marginal tax rate. When adjusted for an inflation rate of 2 percent, the effective real rate becomes 2.45 percent.

---

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

**Table 8.2.17 Data Used to Calculate Real Effective Mortgage Rates**

| Year | Mortgage Interest Rates in Selected Years (*%)* | | | |
|---|---|---|---|---|
| | Average Nominal Interest Rate | Inflation Rate[15] | Applicable Marginal Tax Rate[16] | Average Real Effective Interest Rate |
| 1995 | 8.2 | 2.83 | 24.2 | 3.3 |
| 1998 | 7.9 | 1.56 | 25.0 | 4.3 |
| 2001 | 7.6 | 2.85 | 24.2 | 2.8 |
| 2004 | 6.2 | 2.66 | 20.9 | 2.2 |
| 2007 | 6.3 | 2.85 | 20.6 | 2.1 |
| 2010 | 5.7 | 1.64 | 20.0 | 2.9 |

Table 8.2.18 shows the household-weighted average effective real rates for different types of household debt. Because the interest rates for each type of household debt reflect economic conditions throughout numerous years and various phases of economic growth and recession, they are expected to be representative of rates in effect in 2019.

**Table 8.2.18 Average Real Effective Interest Rates for Household Debt**

| Type of Debt | Income Group | | | | | |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 |
| Mortgage | 6.6% | 6.2% | 6.1% | 5.2% | 5.0% | 4.0% |
| Home equity loan | 7.0% | 6.9% | 6.7% | 5.9% | 5.7% | 4.3% |
| Credit card | 15.2% | 15.0% | 14.5% | 14.2% | 14.0% | 14.5% |
| Other installment loan | 10.8% | 10.3% | 9.9% | 9.4% | 8.7% | 8.6% |
| Other residential loan | 9.8% | 10.2% | 8.9% | 8.2% | 7.7% | 7.4% |
| Other line of credit | 9.1% | 10.9% | 9.6% | 8.8% | 7.4% | 6.1% |

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

### *Rates for Types of Assets*

No similar rate data are available from the SCF for classes of assets, so DOE derived asset interest rates from various sources of national historical data (1983-2013). The interest rates associated with certificates of deposit,[17] savings bonds,[18] and bonds (AAA corporate bonds)[19] were collected from Federal Reserve Board time-series data. Rates on money market accounts came from Cost of Savings Index data.[20] Rates on savings accounts were estimated as one half of the rate for money market accounts, based on recent differentials between the return to each of these assets. The rates for stocks are the annual returns on the Standard and Poor's.[21] Rates for mutual funds are a weighted average of the stock rates (two-thirds weight) and the 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 8.2.19. Because the interest and return rates for each type of asset reflect economic conditions throughout numerous years, they are expected to be representative of rates that may be in effect in 2019. For each type, DOE developed a distribution of rates, as shown in appendix 8-F.

**Table 8.2.19 Average Nominal and Real Interest Rates for Household Equity**

| Type of Equity | Average Real Rate % |
|---|---|
| Savings accounts | 1.0 |
| Money market accounts | 1.9 |
| Certificates of deposit | 1.9 |
| Savings bonds | 3.4 |
| Bonds | 4.2 |
| Stocks | 9.4 |
| Mutual funds | 7.4 |

### *Discount Rate Calculation and Summary*

Using the asset and debt data discussed previously, DOE calculated discount rate distributions for each income group as follows. First, DOE calculated the discount rate for each consumer in each of the six versions of the SCF, using the following formula:

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

**Eq. 8.1**

Where:

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

The rate for each debt type is drawn from the SCF data for each household. The rate for each asset type is drawn from the distributions described previously.

Once the real discount rate was estimated for each consumer, DOE compiled the distribution of discount rates in each survey by income group by calculating the proportion of consumers with discount rates in bins of 1 percent increments, ranging from 0-1 percent to greater than 30 percent. Giving equal weight to each survey, DOE compiled the six-survey distribution of discount rates.

Table 8.2.20 presents the average real effective discount rate and its standard deviation for each of the six income groups. To account for variation among households, DOE sampled a rate for each RECS household from the distributions for the appropriate income group. (RECS provides household income data.) Appendix 8-F presents the full probability distributions for each income group that DOE used in the LCC and PBP analysis.

**Table 8.2.20 Average Real Effective Discount**

| Income Group | Discount Rate (%) |
|---|---|
| 1 | 4.85 |
| 2 | 5.12 |
| 3 | 4.75 |
| 4 | 4.04 |
| 5 | 3.80 |
| 6 | 3.57 |
| Overall Average | 4.49 |

### 8.2.5 Compliance Date

In the context of the Energy Policy and Conservation Act (EPCA), the compliance date is the future date when parties subject to the requirements of a new or amended standard must comply. The expected compliance date for any amended standard would be May 30, 2019. During which time, in no case may any amended standard apply to products manufactured within three years after publication of the final rule establishing such amended standard. (42 U.S.C. 6295(g)(10)(B)). Where appropriate, DOE calculated the LCC and PBP for dishwashers as if consumers would purchase new products in 2019, which is when an amended standard takes effect.

### 8.2.6 Product Assignment for the Base Case

To accurately estimate the percentage of consumers that would be affected by a particular standard level, DOE took into account the distribution of product efficiencies expected for the compliance year. In other words, rather than analyzing the impacts of a particular standard level assuming that all consumers are currently purchasing products at the baseline level, DOE conducted the analysis by taking into account the full breadth of product efficiencies that consumers purchase under the base case (*i.e.*, the case without new energy efficiency standards).

As noted in section 8.1.1, DOE's approach for conducting the LCC analysis for residential dishwashers relied on developing samples of households that use each product class. DOE used a Monte Carlo simulation technique to perform the LCC calculations for the households in the sample. Using the base-case distribution of product efficiencies, DOE assigned each household in the sample a unique product efficiency. Because it performed the LCC calculations on a household-by-household basis, DOE based the LCC for a particular trial standard level (TSL) on the efficiency of the product assigned to each given household. For example, if a household was assigned a product efficiency that is greater than or equal to the efficiency of the TSL under consideration, the LCC calculation would reveal that this household is not impacted by an increase in product efficiency that is equal to the standard level. The distributions of product efficiencies that DOE used for the LCC analysis for dishwashers are discussed next.

To assign a base-case energy efficiency distribution for 2019, DOE first considered the historical shipments-weighted base-case efficiency trend that was submitted by AHAM for the previous rulemaking for residential dishwashers.[22] Based on these historical data, DOE projected a future decline in annual energy use using an exponential function. This projection was not performed for compact dishwashers, because too few data were available. DOE then conducted an efficiency distribution anslysis for dishwashers based on DOE's Compliance Certification Database for Dishwashers.[23] Figure 8.2.4 presents the historical base-case efficiency trend and the base-case efficiency projected for 2019 for standard dishwashers. Table 8.2.21 presents the market shares of the efficiency levels in the base case in 2019 for standard-sized dishwashers.

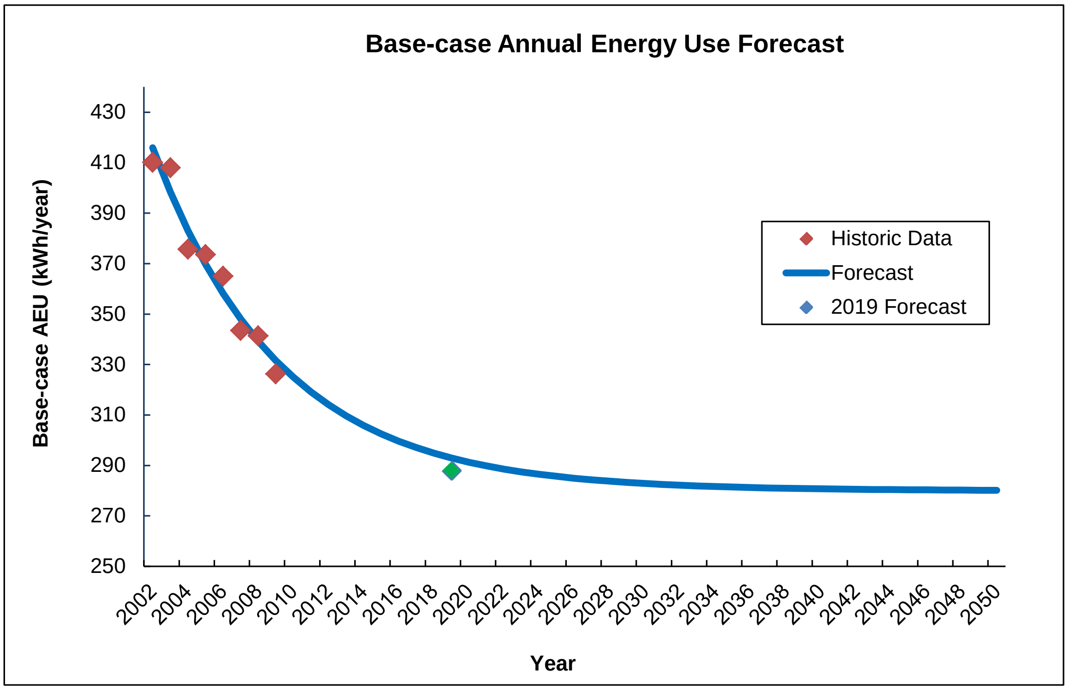


**Figure 8.2.4 Historic and Projected Base Case Trend in Dishwasher Average Energy Use**

**Table 8.2.21 Standard-Sized Dishwashers: Base-Case Efficiency Market Share for 2019**

| Efficiency Level | Annual Energy Use (kWh/year) | Water Use (gal/cycle) | Market Share (%) |
|---|---|---|---|
| Baseline | 307 | 5.00 | 12.1 |
| 1 | 295 | 4.25 | 43.9 |
| 2 | 280 | 3.50 | 40.3 |
| 3 | 234 | 3.10 | 3.2 |
| 4 | 180 | 2.22 | 0.4 |

Table 8.2.22 presents the market shares of the efficiency levels in the base case in 2019 for compact dishwashers.

**Table 8.2.22 Compact Dishwashers: Base-Case Efficiency Market Shares for 2019**

| Efficiency Level | Annual Energy Use (kWh/year) | Water Use (gal/cycle) | Market Share (%) |
|---|---|---|---|
| Baseline | 222 | 3.50 | 48.1 |
| 1 | 203 | 3.10 | 14.8 |
| 2 | 141 | 2.00 | 37.0 |

## 8.3 INPUTS TO PAYBACK PERIOD ANALYSIS

As discussed previously, PBP is the amount of time it takes the consumer to recover, through lower operating costs, the assumed higher purchase price of a more energy-efficient product. Numerically, the PBP is the ratio of the increase in purchase price (*i.e.*, from a less efficient design) to the decrease in first year operating costs. This type of calculation is known as a “simple” payback period, because it ignores changes in operating expense over time or the time value of money. That is, the calculation is done at an effective discount rate of zero percent.

The equation for PBP is:

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

Where:

$\Delta IC$ = difference in the total installed cost between the standard level unit and the baseline unit, and
$\Delta OC$ = difference in first year operating expenses.

Payback periods are expressed in years. A payback period greater than the life of the product means that the increased total installed cost is not recovered in reduced operating costs.

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 expenditures for each standard level. The inputs to the total installed cost are the product price and the installation cost. The inputs to the operating costs are the first-year costs of energy and water. The PBP uses the same inputs as the LCC analysis, as described in section 8.2, except that PBP does not require energy and water price trends or discount rates. The required energy and water prices are only for the year in which a new standard will take effect—in this case, 2019. The energy and water prices DOE used in the PBP calculation were the prices projected for that year.

## 8.4 RESULTS OF LIFE-CYCLE COST AND PAYBACK PERIOD ANALYSES

This section presents the LCC and PBP results for residential dishwashers. As discussed in section 8.1.1, DOE's approach to conducting the analysis relied on developing samples of households that use each product class. DOE also used probability distributions to characterize the uncertainty of many of the inputs. DOE applied a Monte Carlo simulation to calculate the LCC for the households in the sample. For each set of sample households using each product class, DOE calculated the average LCC and LCC savings. The payback period uses average values rather than distributions. It 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 increased efficiency level for each of the standard levels.

LCC calculations were performed 10,000 times on the sample of households established for each product class. Each LCC calculation was performed on a single household, which was selected from the sample based on its weight (*i.e.*, how representative a particular household is of other households in the distribution). Each LCC calculation also sampled from the probability distributions that DOE developed to characterize many of the inputs to the analysis.

DOE calculated LCC savings relative to the base-case product it assigned to the households. As discussed in section 8.2.6, DOE assigned some households a base-case product that is more efficient than some of the standard levels. For that reason, the average LCC impacts are not equal to the difference between the LCC of a specific standard level and the LCC of the baseline product. The calculation of average LCC savings includes households with zero LCC savings (no impact from a standard). DOE considered a household to receive no impact at a given efficiency level if DOE assigned it a base-case product having an efficiency equal to or greater than the efficiency level in question.

### 8.4.1 Standard Sized Dishwashers

Table 8.4.1 and Table 8.4.2 show the LCC and PBP results by TSL for standard-sized dishwashers. The average operating cost is the discounted sum.

**Table 8.4.1 Summary of LCC and PBP Results by Efficiency Level for Standard-Sized Dishwashers**

| TSL | Efficiency Level | Average Costs 2013$ | | | | Simple Payback years |
|---|---|---|---|---|---|---|
| | | Installed Cost | First Year's Operating Cost | Lifetime Operating Cost | LCC | |
| - | 0 | 483 | 45 | 518 | -- | -- |
| 1 | 1 | 495 | 43 | 492 | 987 | 6.1 |
| - | 2 | 531 | 40 | 462 | 993 | 10.8 |
| 2 | 3 | 582 | 34 | 387 | 970 | 9.0 |
| 3 | 4 | 582 | 26 | 296 | 879 | 5.3 |

Note: The average LCC, LCC savings, and simple payback for each TSL are calculated assuming that all consumers use products with that EL. This allows the results for each TSL to be compared under the same conditions.

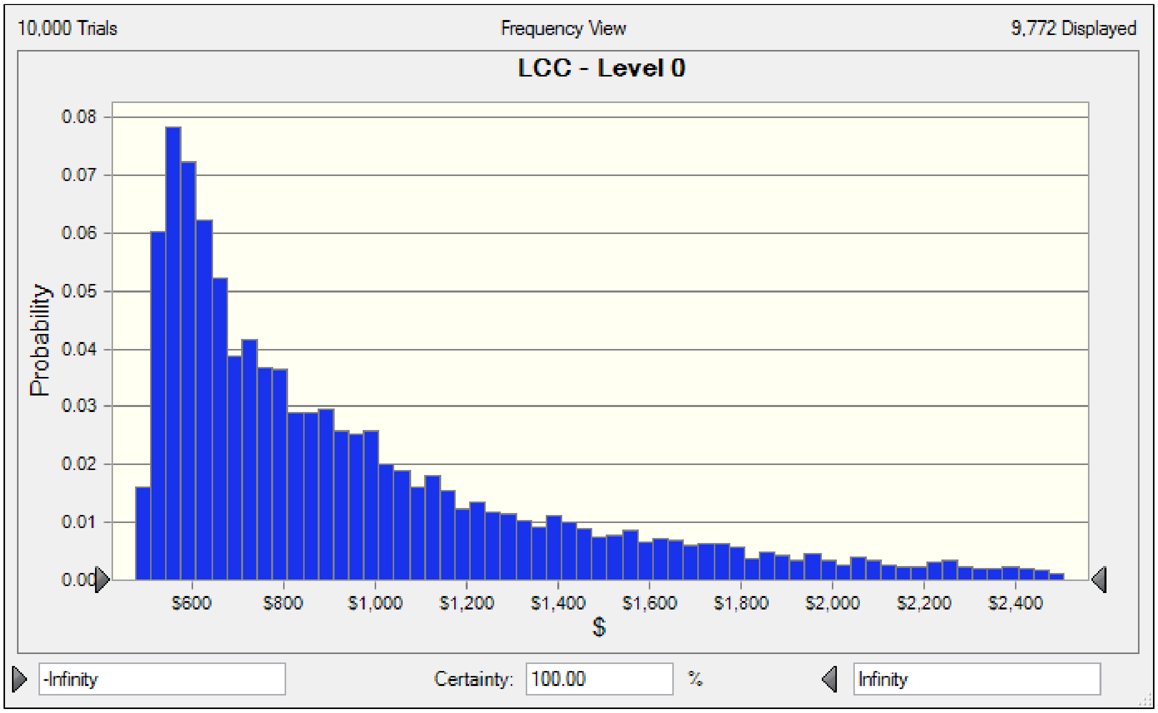
**Table 8.4.2 Summary of Life-Cycle Cost Savings Relative to the Base Case Efficiency Distribution for Standard-Sized Dishwashers**

| TSL | Efficiency Level | Life-Cycle Cost Savings | |
|---|---|---|---|
| | | % of Consumers that Experience Net Cost | Average Savings 2013$ |
| 1 | 1 | 6 | 2 |
| - | 2 | 39 | -2 |
| 2 | 3 | 53 | 21 |
| 3 | 4 | 33 | 112 |

Note: The LCC savings for each TSL are calculated relative to the base case efficiency distribution. The calculation includes households with zero LCC savings (no impact).

The figures below are presented as frequency charts that show the distribution of LCCs, LCC impacts, and PBPs with their corresponding probability of occurrence. DOE generated the figures for the distributions from a Monte Carlo simulation run based on 10,000 samples. DOE can generate frequency charts similar to those shown for every TSL.

Figure 8.4.1 shows the frequency charts for the baseline LCC for standard-sized dishwashers.



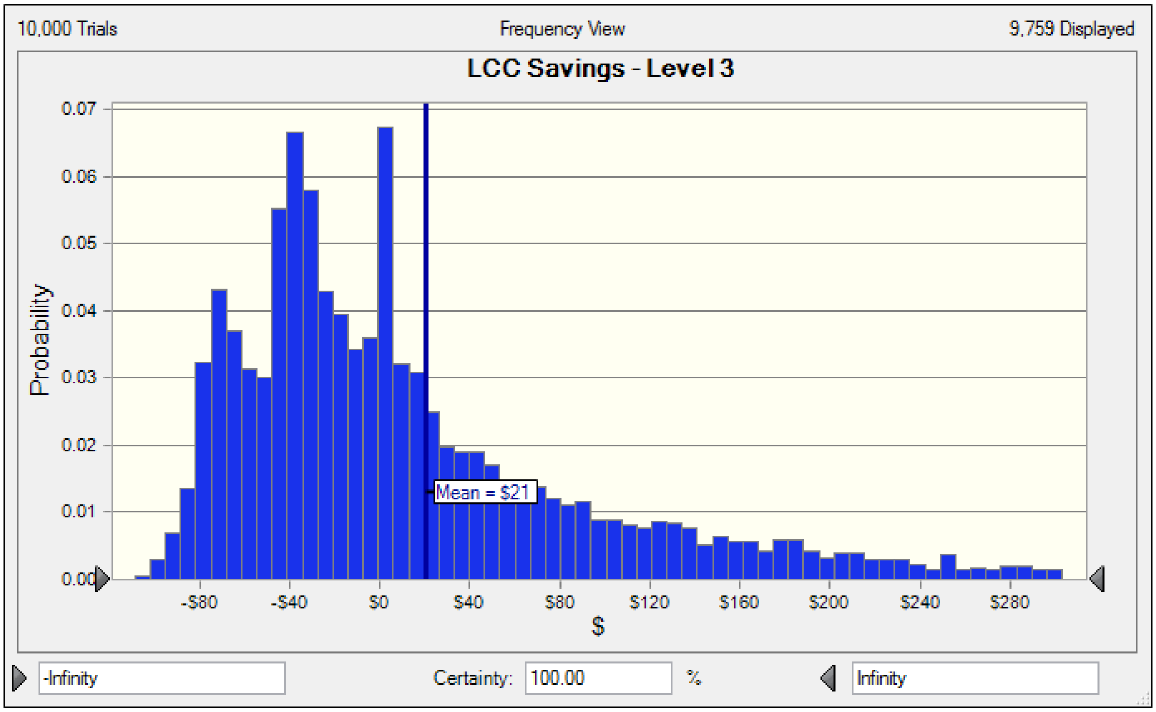
-Infinity

Certainty: 100.00 %

Infinity

**Figure 8.4.1 Standard-Sized Dishwashers: Base-Case LCC Distribution**

Figure 8.4.2 is a frequency chart showing the distribution of LCC differences for standard-sized dishwashers at the efficiency levels corresponding to TSL 2. Refer back to section 8.2.6 for a discussion of the distribution of product efficiencies under the base case. DOE can generate frequency charts similar to those shown for every TSL.



10,000 Trials Frequency View 9,759 Displayed

-Infinity Certainty: 100.00 % Infinity

**Figure 8.4.2 Standard-Sized Dishwashers: Distribution of LCC Impacts for Efficiency Level 3**

Figure 8.4.3 shows the range of LCC savings for all efficiency levels considered for standard-sized dishwashers. For each efficiency level, the top and the bottom of the box indicate the 75th and 25th percentiles, respectively. The bar in the middle of the box indicates the median, which means that with that efficiency level, 50 percent of the households have LCC savings above this value. The ‘whiskers’ at the bottom and the top of the box indicate the 5th and 95th percentiles, respectively. The small box shows the average LCC savings for each efficiency level.

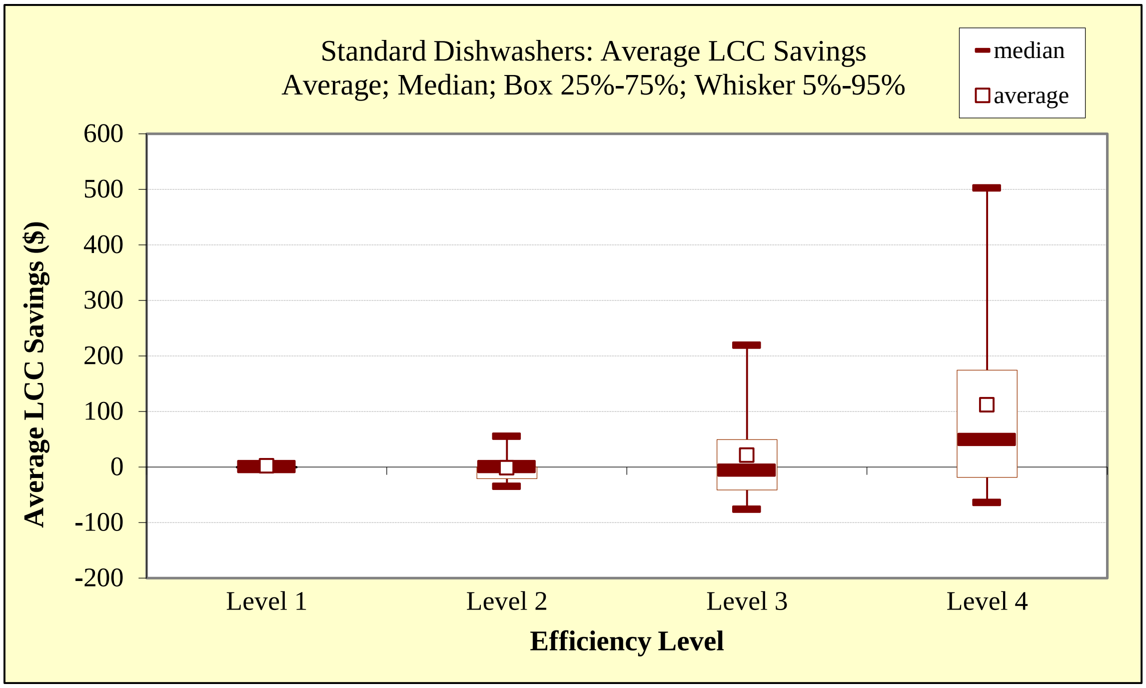


**Figure 8.4.3 Range of LCC Savings for Standard-Sized Dishwashers**

### 8.4.2 Compact Dishwashers

Table 8.4.3 and Table 8.4.4 show the LCC and PBP results by TSL for compact dishwashers. The average operating cost is the discounted sum.

**Table 8.4.3 Summary of LCC and PBP Results by Efficiency Level for Compact Dishwashers**

| TSL | Efficiency Level | Average Costs 2013$ | | | | Simple Payback years |
|---|---|---|---|---|---|---|
| | | Installed Cost | First Year's Operating Cost | Lifetime Operating Cost | LCC | |
| 1 | 0 | 456 | 26 | 302 | 758 | -- |
| 2 | 1 | 467 | 24 | 274 | 741 | 4.5 |
| 3 | 2 | 485 | 16 | 188 | 673 | 2.9 |

Note: The average LCC, LCC savings, and simple payback for each TSL are calculated assuming that all consumers use products with that EL. This allows the results for each TSL to be compared under the same conditions.

**Table 8.4.4 Summary of Life-Cycle Cost Savings Relative to the Base Case Efficiency Distribution for Compact Dishwashers**

| TSL | Efficiency Level | Life-Cycle Cost Savings | |
|---|---|---|---|
| | | % of Consumers that Experience Net Cost | Average Savings 2013$ |
| 1 | 0 | -- | -- |
| 2 | 1 | 9 | 8 |
| 3 | 2 | 6 | 51 |

Note: The LCC savings for each TSL are calculated relative to the base case efficiency distribution. The calculation includes households with zero LCC savings (no impact).

The figures below are presented as frequency charts that show the distribution of LCCs, LCC impacts, and PBPs with their corresponding probability of occurrence. DOE generated the figures for the distributions from a Monte Carlo simulation run based on 10,000 samples.

Figure 8.4.4 shows the frequency charts for the baseline LCC for compact dishwashers.

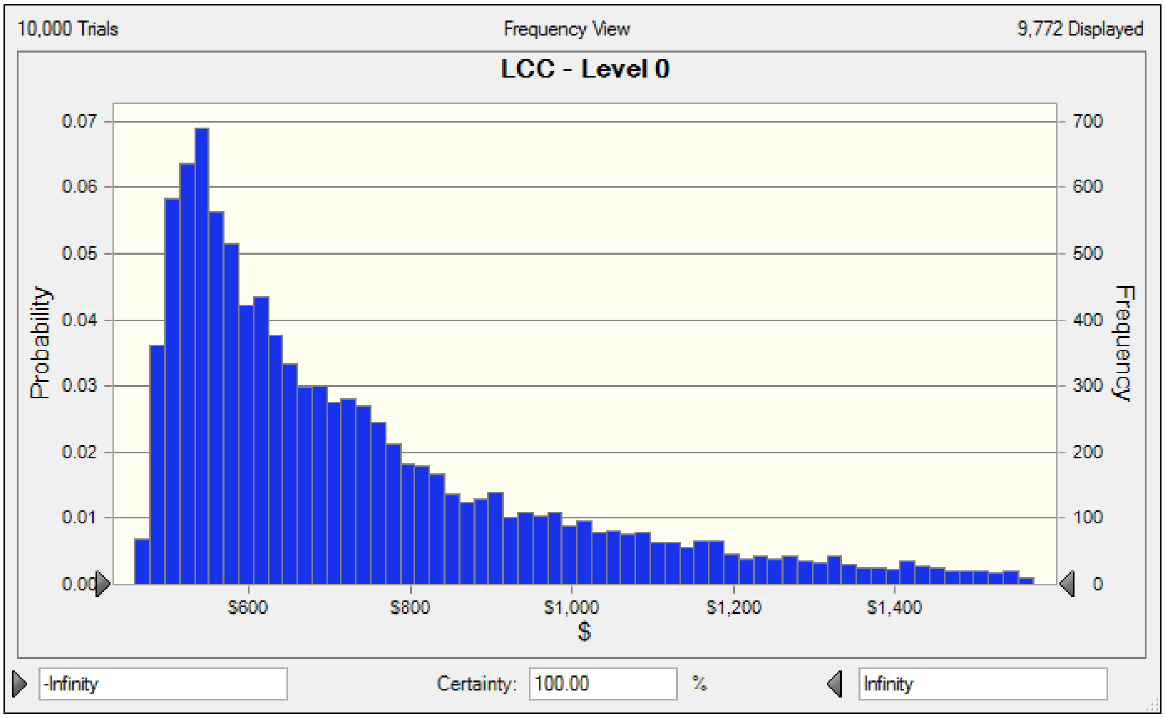
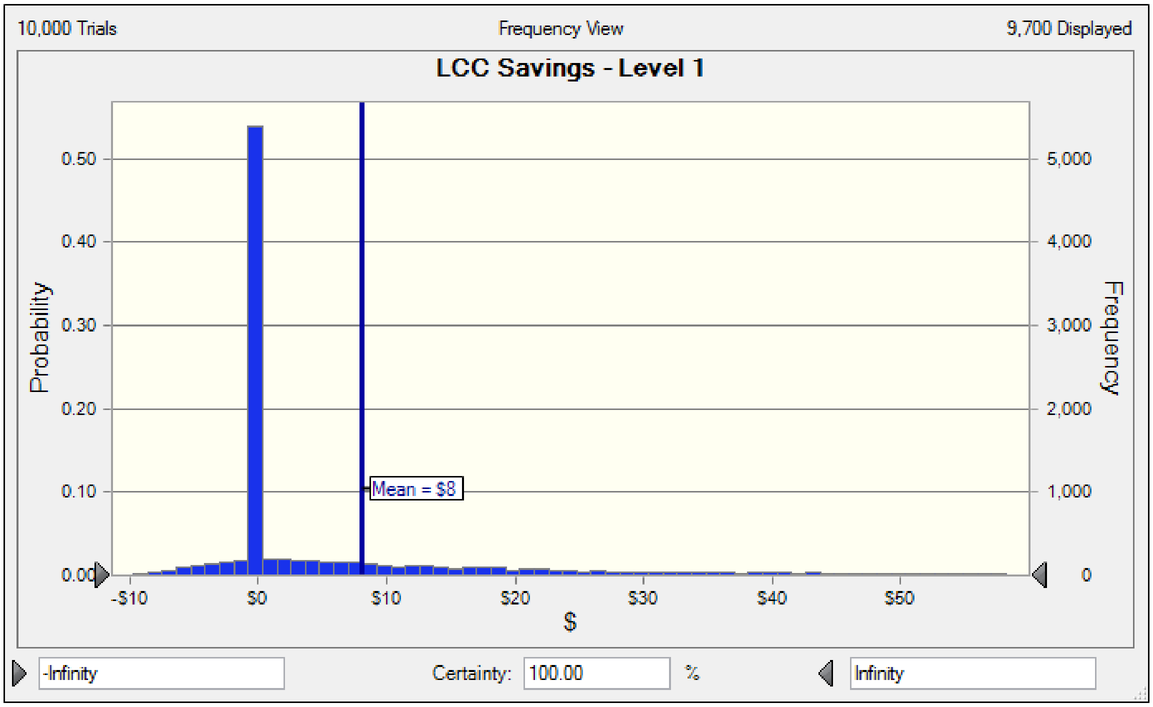


**Figure 8.4.4 Compact Dishwashers: Base-Case LCC Distribution**

Figure 8.4.5 is a frequency chart showing the distribution of LCC differences for compact dishwashers at the efficiency levels corresponding to TSL 2. Refer back to section 8.2.6 for a discussion of the distribution of product efficiencies under the base case. DOE can generate a frequency chart like the one shown in Figure 8.4.5 for every standard level.



-Infinity

Certainty: 100.00 %

Infinity

**Figure 8.4.5 Compact Dishwashers: Distribution of LCC Impacts for Efficiency Level 1**

Figure 8.4.6 shows the range of LCC savings for all efficiency levels considered for compact dishwashers. For each efficiency level, the top and the bottom of the box indicate the 75th and 25th percentiles, respectively. The bar in the middle of the box indicates the median, which means that with that efficiency level, 50 percent of the households have LCC savings above this value. The 'whiskers' at the bottom and the top of the box indicate the 5th and 95th percentiles, respectively. The small box shows the average LCC savings for each efficiency level.

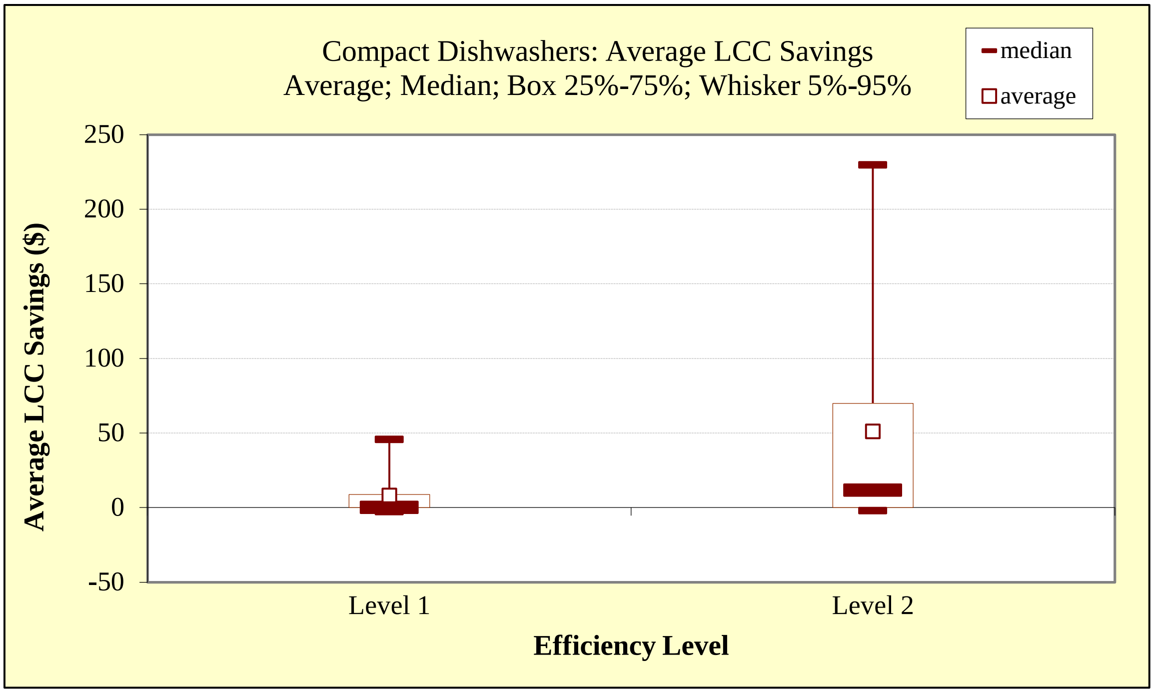


**Figure 8.4.6 Range of LCC Savings for Compact Dishwashers**

## 8.5 REBUTTABLE PAYBACK PERIOD

DOE develops rebuttable PBPs to support the legally established rebuttable presumption that an energy efficiency standard is economically justified if the additional product costs attributed to the standard are less than three times the value of the first-year energy and water cost savings. (42 U.S.C. §6295 (o)(2)(B)(iii))

The basic equation for rebuttable PBP is the same as that shown in section 8.3 on inputs to the payback period analysis. Unlike the analyses described in sections 8.2 and 8.3, however, the rebuttable PBP is not based on the use of household samples. Rather, the rebuttable PBP is based on discrete, single-point values.

The most notable difference between the simple PBP and the rebuttable PBP is the latter's reliance on the DOE test procedure to determine a product's annual energy and water consumption. To determine the rebuttable PBP for dishwashers, DOE based the annual energy and water consumption values on the number of cycles per year specified in the DOE test procedure.[24] The number of cycles from the DOE test procedure in this case, however, (215 cycles per year), is equal to the average number of cycles that DOE used in its determination of simple PBPs.

### 8.5.1 Inputs

DOE used the following single-point values in determining the rebuttable PBP.

- Manufacturing costs, markups, sales taxes, and installation costs were the same as the single-point values used in the general LCC and PBP analyses.

- As described in section 8.5.1, annual energy and water consumption were based on the usage in the DOE test procedure.

- Energy and water prices were based on national average values for the year that new standards are assumed to take effect.

- Neither an average discount rate nor a lifetime is required in the rebuttable PBP calculation.

### 8.5.2 Results

DOE calculated rebuttable PBPs for each efficiency level relative to the distribution of product efficiencies assumed for the base case. (Refer back to section 8.2.6 for more details on the base-case efficiency distributions for each product.) In other words, DOE did not determine the rebuttable PBP relative to the baseline efficiency level, but relative to the current distribution of product efficiencies DOE determined for the base case (*i.e.*, the case without new standards).

Table 8.5.1 and Table 8.5.2 present the rebuttable PBPs for standard-sized and compact dishwashers, respectively.

**Table 8.5.1 Standard-Sized Dishwashers: Rebuttable Payback Periods**

| Efficiency Level | AEU (kWh/year) | Water Use (gal/cycle) | Rebuttable PBP (years) |
|---|---|---|---|
| Baseline | 307 | 5.00 | -- |
| 1 | 295 | 4.25 | 3.9 |
| 2 | 280 | 3.50 | 7.1 |
| 3 | 234 | 3.10 | 7.1 |
| 4 | 180 | 2.22 | 4.2 |

Table 8.5.2 Compact Dishwashers: Rebuttable Payback Periods

| Efficiency Level | AEU (kWh/year) | Water Use (gal/cycle) | Rebuttable PBP (years) |
|---|---|---|---|
| Baseline | 222 | 3.50 | -- |
| 1 | 203 | 3.10 | 3.1 |
| 2 | 141 | 2.00 | 2.0 |

## REFERENCES

---

1 U.S. Department of Energy–Energy Information Administration. *Residential Energy Consumption Survey, 2009 Public Use Data Files*. 2013. Washington, D.C. (Last accessed March 25, 2013.) < http://www.eia.gov/consumption/residential/data/2009/index.cfm?view=characteristics >

2 Raftelis Financial Consulting, *2012 RFC/AWWA Water and Wastewater Rate Survey*. 2013. Charlotte, NC.

3 Desroches, L-B, K. Garbesi, C. Kantner, R. D. Van Buskirk and H.-C. Yang (2013). “Incorporating Experience Curves in Appliances Standards Analysis”, Energy Policy, Vol. 52, p.402-416. < http://dx.doi.org/10.1016/j.enpol.2012.09.066>

4 Association of Home Appliance Manufacturers (AHAM). *AHAM 2010*. Washington, D.C.

5 RS Means. *Residential Cost Data 2013, 32nd Annual Edition*. Kingston, MA. p.672.

6 U.S. Department of Energy–Energy Information Administration, Form EIA-861 for 2012. 2013. (Last accessed December 5, 2013.) <http://www.eia.gov/electricity/data/eia861/>

7 U.S. Department of Energy–Energy Information Administration. *Natural Gas Navigator*. 2013. (Last accessed March 26, 2013.) <http://tonto.eia.doe.gov/dnav/ng/ng_pri_sum_dcu_nus_m.htm>

8 U.S. Department of Commerce–Census Bureau, Population Estimates, Vintage 2012. (Last accessed March 26, 2013). <http://www.census.gov/popest/data/national/totals/2012/index.html>

9 U.S. Department of Energy–Energy Information Administration, State Energy Data System (SEDS): 2012. (Last accessed June 28, 2014). <http://www.eia.gov/state/seds/seds-data-fuel.cfm?sid=US>

10 Raftelis Financial Consulting, *2012 RFC/AWWA Water and Wastewater Rate Survey*. 2013. Charlotte, NC.

11 Energy Information Administration, *Annual Energy Outlook 2014 with Projections to 2040*, 2014. Washington, DC. Report Number: DOE/EIA-0383(2014). (Last accessed May22, 2014.) < http://www.eia.gov/forecasts/aeo/ >

---

12 U.S. Department of Labor-Bureau of Labor Statistics. *Consumer Price Indexes, Item: Water and sewerage maintenance, Series Id: CUUR0000SEHG01, U.S. city average (not seasonally adjusted).* 2013. Washington, DC. (Last accessed April 10, 2013.) <http://www.bls.gov/cpi/>

13 U.S. Census Bureau–Housing and Household Economic Statistics Division. *American Housing Survey*. Washington, DC. (Last accessed July 11, 2012; data has been updated to 2011.) <http://www.census.gov/hhes/www/housing/ahs/ahs.html>

14 The Federal Reserve Board, Survey of Consumer Finances 1989, 1992, 1995, 1998, 2001, 2004, 2007, 2010. <http://www.federalreserve.gov/pubs/oss/oss2/scfindex.html>

15 U.S. Department of Labor - Bureau of Labor Statistics, *Bureau of Labor Statistics Data, Prices & Living Conditions*, 2012. <http://data.bls.gov>

16 National Bureau of Economic Research, *U.S. Federal and State Average Marginal Income Tax Rates*, 2010. (Last accessed February 25, 2011.) <http://users.nber.org/~taxsim/marginal-tax-rates/>

17 The Federal Reserve Board, *Federal Reserve Statistical Release, Selected Interest Rates, Historical Data, Instrument: CDs (secondary market), Maturity: 6-month, Frequency: Annual, Description: Average rate on 6-month negotiable certificates of deposit (secondary market), quoted on an investment basis*, 2013. <www.federalreserve.gov/releases/H15/data.htm>

18 The Federal Reserve Board, *Federal Reserve Statistical Release, Selected Interest Rates, Historical Data, Instrument: State and local bonds, Maturity: 20-year, Frequency: Monthly, Description: Bond buyer go 20-bond municipal bond index*, 2013. <www.federalreserve.gov/releases/H15/data.htm>

19 The Federal Reserve Board, *Federal Reserve Statistical Release, Selected Interest Rates, Historical Data, Instrument: Corporate bonds/Moody's Seasoned AAA, Frequency: Annual, Description: Moody's yield on seasoned corporate bonds—all industries, AAA*, 2013. <www.federalreserve.gov/releases/H15/data.htm>

20 Mortgage-X - Mortgage Information Service, *Cost of Savings Index (COSI) Index History*, 2013. <http://mortgage-x.com/general/indexes/default.asp>

21 Damodaran Online Data Page, *The Data Page: Historical Returns on Stocks, Bonds and Bills - United States*, 2013. Damodaran. <http://pages.stern.nyu.edu/~adamodar/>

22 Association of Home Appliance Manufacturers. AHAM Data on Dishwashers for Efficiency Standards Rulemaking, September 7, 2006. Letter to Building Technologies Program, U.S. Department of Energy.

---

23 DOE Compliance Certification Database for Dishwashers. (Last accessed on Aug. 6, 2013). <http://www.regulations.doe.gov/certification-data/CCMS-41431681025.html>

24 U.S. Office of the Federal Register, *Code of Federal Regulations, Title 10, Part 430–Energy Conservation Program for Consumer Products, Subpart B, Appendix C: Uniform Test Method for Measuring the Energy Consumption of Dishwasher*, January 1, 2007. Washington, DC.

# CHAPTER 9. SHIPMENTS ANALYSIS

## TABLE OF CONTENTS

## LIST OF TABLES

## LIST OF FIGURES

# CHAPTER 9. SHIPMENTS ANALYSIS

## 9.1 INTRODUCTION

The U.S. Department of Energy (DOE) analyzes shipments of appliances affected by a rulemaking for new or amended energy efficiency standards. Estimates of product shipments are a necessary input to calculating the national energy savings (NES) and net present value (NPV), which are required to justify potential new standards. Shipments also are a necessary input to the manufacturer impact analysis. This chapter describes DOE's method and results of projecting annual shipments of standard and compact dishwashers under base-case and standards-case efficiency levels.

DOE estimated shipments for dishwashers using a computer model calibrated against historical shipments. To estimate the impacts of prospective standard levels on product shipments, the model accounts for the combined effects of changes in purchase price, annual operating costs, and household income on the consumer purchase decision. The shipments model estimates shipments for specific market segments, then aggregates those results to estimate total product shipments. DOE considered two market segments: (1) shipments to new construction, and (2) shipments of replacement products going into existing buildings. The shipments models are prepared as Microsoft Excel spreadsheets that are accessible on the Internet (http://www1.eere.energy.gov/buildings/appliance_standards/residential/dishwashers.html).

The rest of this chapter explains the shipments model in more detail. Section 9.2 describes the method used to develop the model; section 9.3 describes the data inputs and the model calibration; section 9.4 discusses impacts on shipments from changes in product purchase price, operating cost, and household income; and section 9.5 discusses the affected stock. Section 9.6 presents the model results for various energy-efficiency standard levels, identified as trial standard levels (TSLs), for standard and compact dishwashers.

## 9.2 SHIPMENTS MODEL

For this standards rulemaking, DOE estimated annual dishwasher shipments by developing a model of the national stock of in-service residential dishwashers. Market segments represent distinct inputs to the shipments forecast. As expressed in the following equation, the two primary market segments are new installations and replacements.

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

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*, and
$NI_p(j)$ = number of new installations of product *p* in year *j*.

DOE's shipments model takes an accounting approach, tracking the market shares of each product class, vintage of units in the current stock, and expected construction trends. In principle, each market segment and product class responds differently to the demographic and economic trends in the base case (the case without new standards) than in any of the standards cases. Furthermore, retirements, early replacements, and efficiency trends[a] are dynamic variables that can differ among product classes. Rather than simply extrapolating a current shipments trend, the base-case shipments analysis uses critical (driver) variables, such as construction forecasts and distributions of product lifetimes, to forecast sales in each market segment. For example, the model assumes that construction of new housing units drives new installations. The product shipments for the new construction market segment are equal to the number of new housing units built times the purchase rate, which is determined by the market share of the product class and the market saturation of dishwashers.

The model estimates shipments of replacement units using shipments data from previous years and assumptions about the lifetime of dishwashers. Therefore, estimated sales of replacement units in a given year are equal to the total stock of the appliance minus those units shipped in previous years that still remain in the stock. DOE determined the useful service life of standard and compact dishwashers to estimate how long the appliance is likely to remain in stock. The following equation shows how DOE estimated replacement shipments.

$$Rpl_p(j) = Stock_p(j-1) - \sum_{age=0}^{ageMax} \sum_{j=N}^{j-1} Ship_j \times prob_{Rtr}(age)$$

Where:

$Stock_p(j-1)$ = total stock of in-service appliances in year *j-1*,
$prob_{Rtr}(age)$ = probability that an appliance of a particular age will be retired, and
$N$ = year in which the shipments model begins the stock accounting.

Stock accounting provides an estimate of the age distribution of product stock for all years based on inputs of product shipments, a retirement function, and initial product stock. The age distribution of in-service product stocks is a key input to both the NES and NPV calculations, because the operating costs for any year depend on the age distribution of the stock. As units are added to the in-service stock, some older units retire and exit the stock. A standards-case scenario produces increasing efficiency over time, in that older, less efficient units have higher operating costs than younger, more efficient units. For early replacements, units are removed from the in-service stock before the end of their expected lifetime and are replaced with more efficient units.

---

[a] Efficiency trends affect shipments only in standards cases. A change in the efficiency distribution of the stock results in a change in the purchase price and operating costs, which affect shipments. This effect is discussed further in section 9.4.

DOE calculated the total in-service stock of dishwashers by integrating historical shipments data starting from the year in which such data became available. To estimate future shipments, DOE developed a series of equations that define the dynamics and accounting of in-service stocks. For new units, the equation is:

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

Where:

*Stock(j, age)* = number 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 purchased in year *j*.

The above equation states that the number of one-year-old units is equal to the number of new units purchased the previous year. Slightly more complicated equations, such as the following, describe the accounting for the in-service stock of units.

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

In this equation, as the year is advanced from *j* to *j+1*, the age increases from *age* to *age+1*. Over time, a fraction of the in-service stock is removed, a fraction determined by a retirement probability function, $prob_{Rtr}(age)$, which is described in chapter 8. Because the dishwashers considered in this rulemaking are common appliances that have a long history of use by U.S. consumers, replacements typically constitute the majority of shipments.

## 9.3 DATA INPUTS AND MODEL CALIBRATION

As noted previously, shipments are driven primarily by two market segments: new construction and replacements. To determine new construction shipments of dishwashers, DOE used two inputs—forecasts of market saturations combined with forecasts of housing starts. DOE estimated replacements using product retirement functions developed from product lifetimes. The retirement function is described in detail in chapter 8.

DOE designed its shipments model for residential dishwashers by developing a single model for all dishwashers and then disaggregating the shipments into the two product classes—standard and compact dishwashers.

### 9.3.1 Historical Shipments

DOE used data on historical shipments (both domestic and imports) to calibrate its shipments model. It relied on two sources to establish historical shipments: (1) data for 1972–

2010 used in the 2012 rulemaking for residential dishwashers,[1] and (2) data published by Appliance Design for 2011–2012.[2] Figure 9.3.1 summarizes the historical data regarding dishwasher shipments. DOE identified a total stock of dishwashers by integrating historical shipments starting in 1972. Over time, some of the units are retired and removed from the stock, triggering the shipment of a new unit. Because of the relationship between retirements and total stock, there is a strong correlation between past and future shipments, independent of efficiency standards.

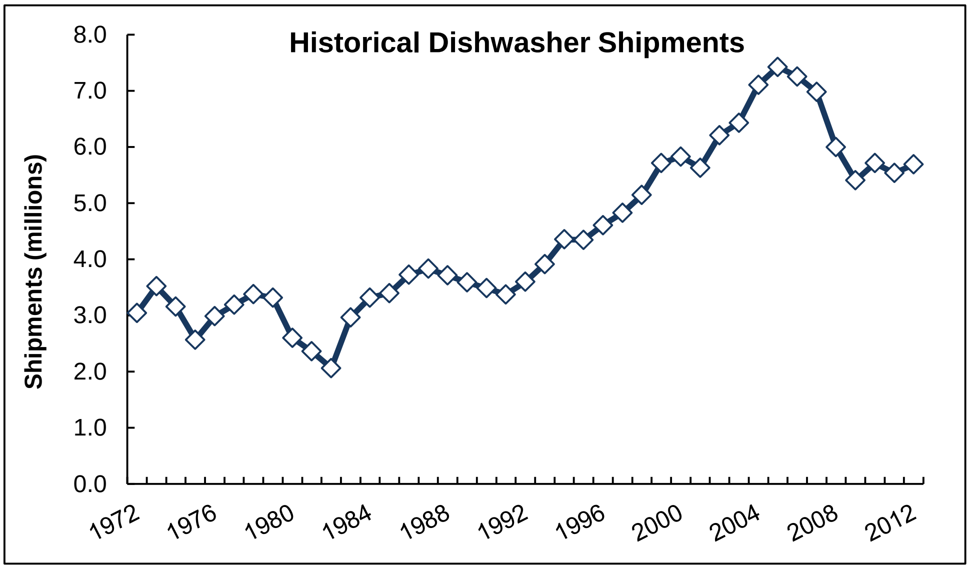


**Figure 9.3.1 Historical Dishwasher Shipments, Domestic plus Imports**

To determine the percentage of shipments that are compact dishwashers, DOE used data from The NPD Group, Inc., which revealed that 0.8 percent of dishwasher shipments were compact dishwashers between 2001 and 2011.[3]

### 9.3.2 Markets and Model Calibration

Total dishwasher shipments are represented by the following equation.

$$Ship_{DW}(j) = Rpl_{DW}(j) + NI_{DW}(j)$$

Where:

$Ship_{DW}(j)$ = total shipments of dishwashers in year *j*,
$Rpl_{DW}(j)$ = replacement shipments in year *j*, and
$NI_{DW}(j)$ = shipments to new housing in year *j*.

The following sections discuss the new construction and replacement markets in further detail.

### 9.3.2.1 New Housing

To forecast the shipments to new construction for any given year, DOE multiplied the forecasted housing starts by the forecasted saturation of dishwashers in new housing. DOE used historical and forecasted new housing starts to calibrate its model.

New housing includes newly constructed single- and multi-family units, termed “new housing completions,” and mobile home placements. For new housing completions and mobile home placements, DOE used recorded data through 2014 and adopted the projections from the DOE’s Energy Information Administration (EIA)’s *Annual Energy Outlook 2014* (*AEO2014*) for 2011–2040.[4] *AEO2014* provides three scenarios for housing starts: a reference case, a high economic growth case, and a low economic growth case, as shown on Figure 9.3.2. DOE used only the forecasts from the reference case to estimate shipments to new construction. For 2041−2048, DOE froze completions at the level in 2040.

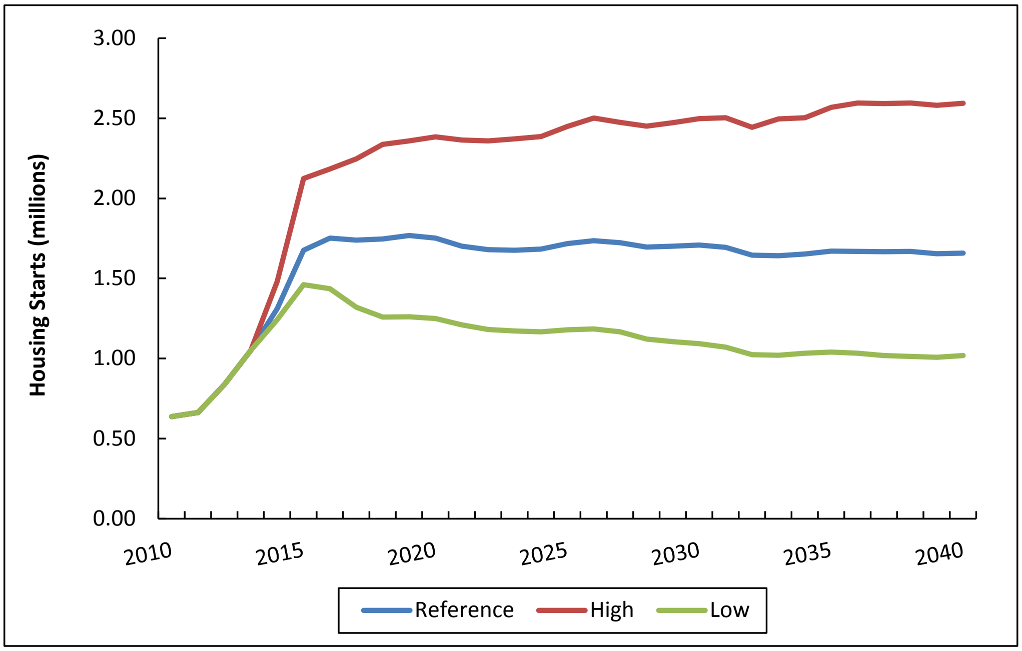


**Figure 9.3.2 Forecasted Housing Starts, 2010–2040**

Table 9.3.1 presents historical data on the market saturation of dishwashers based on various sources: the AHAM 2005 *Fact Book*,[5] various issues of *Appliance Magazine*,[6] NFO World Group,[7] and EIA’s Residential Energy Consumption Survey (RECS) for 1993,[8] 1997,[9] 2001,[10] 2005,[11] and 2009.[12] The table presents dishwasher market saturations for both the overall housing stock and for new construction. Because the forecast of shipments for the new housing market depends on the saturation of dishwashers in new housing, DOE focused its attention on the market saturations for new housing. According to RECS, dishwasher saturation in new housing for 1997, 2001, 2005, and 2009 was 78.1 percent, 81.5 percent, 85.1 percent, and 87.4 percent, respectively. Because of the increasing rate of saturation, DOE decided to use the most recent RECS data point to forecast saturations throughout the forecast period.

**Table 9.3.1 Dishwashers: Historical Market Saturations**

| | Overall Household Saturation (%) | | | | New Households (%) RECS[§] |
|---|---|---|---|---|---|
| Year | AHAM* | Appl[†] | NFO[‡] | RECS[§] | |
| 1970 | 18.9 | | | | |
| 1978 | | 41.9 | | | |
| 1982 | 44.5 | | | | |
| 1983 | | 45.0 | | | |
| 1987 | | 47.7 | | | |
| 1990 | 53.9 | | 45.4 | | |
| 1991 | | 47.7 | | | |
| 1992 | | 50.0 | | | |
| 1993 | | 51.0 | | 45.4 | 74.9 |
| 1994 | | 52.2 | | | |
| 1995 | | 54.4 | | | |
| 1996 | | 54.9 | 49.9 | | |
| 1997 | | 55.6 | | 50.3 | 78.1 |
| 1998 | | 56.3 | | | |
| 1999 | | 56.5 | | | |
| 2000 | | 59.0 | | | |
| 2001 | 59.3 | 59.3 | 53.6 | 53.0 | 81.5 |
| 2002 | | 59.5 | | | |
| 2003 | | 59.5 | | | |
| 2004 | | 60.0 | | | |
| 2005 | 73.7 | 60.5 | | 58.3 | 85.1 |
| 2006 | | 61.0 | | | |
| 2007 | | 61.0 | | | |
| 2008 | | 61.0 | | | |
| 2009 | | | | 59.3 | 87.4 |
| 2010 | | | | | |

Sources: *AHAM *Fact Book,* 2005; [†]*Appliance Magazine,The Saturation Picture* and *Market Research Report*, January 2010 and September 1993, 1995, 2004, and 2005; [‡]NFO World Group, 2001; and [§]DOE-EIA, RECS 1997, 2001, 2005, and 2009.

### 9.3.2.2 Replacements

To estimate shipments to the replacement market, DOE used an accounting method that tracks the total stock of units by vintage. DOE estimated a stock of dishwashers by vintage by integrating historical shipments starting from 1972. Depending on the vintage, a certain percentage of units will fail and need to be replaced. To estimate how long a unit will function before failing, DOE used a survival function based on a product lifetime distribution having an average value of 15.4 years. For a more complete discussion of dishwasher lifetimes, refer to chapter 8, section 8.2.3.3. Figure 9.3.3 shows the survival and retirement functions that DOE used to estimate replacement shipments.

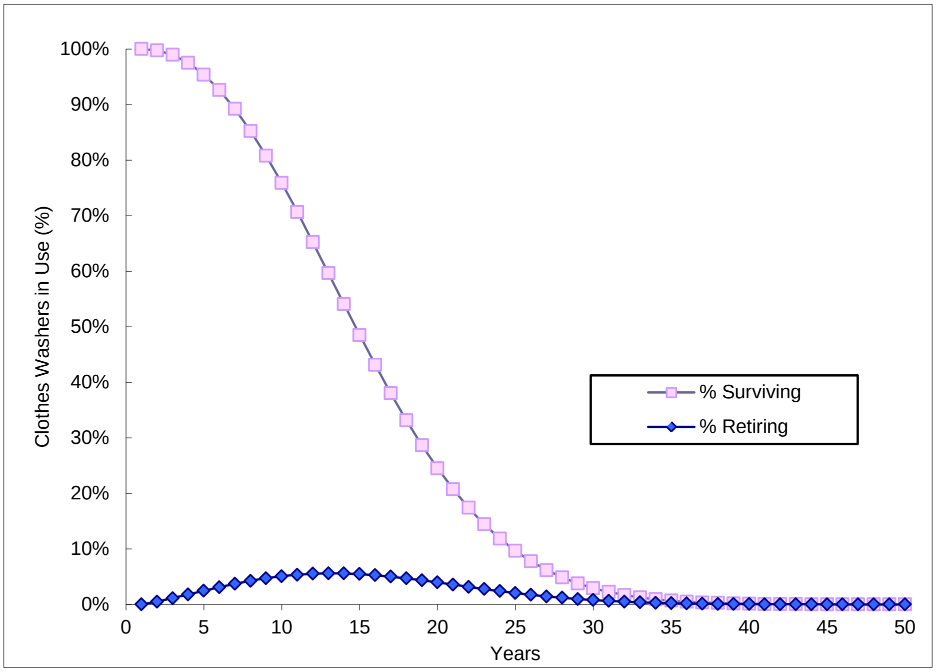


**Figure 9.3.3 Dishwashers: Survival and Retirement Functions**

#### 9.3.2.3 Base-Case Shipments

Figure 9.3.4 shows the forecasted shipments in the base case (the case without new energy efficiency standards) and the historical shipments DOE used to calibrate that forecast.

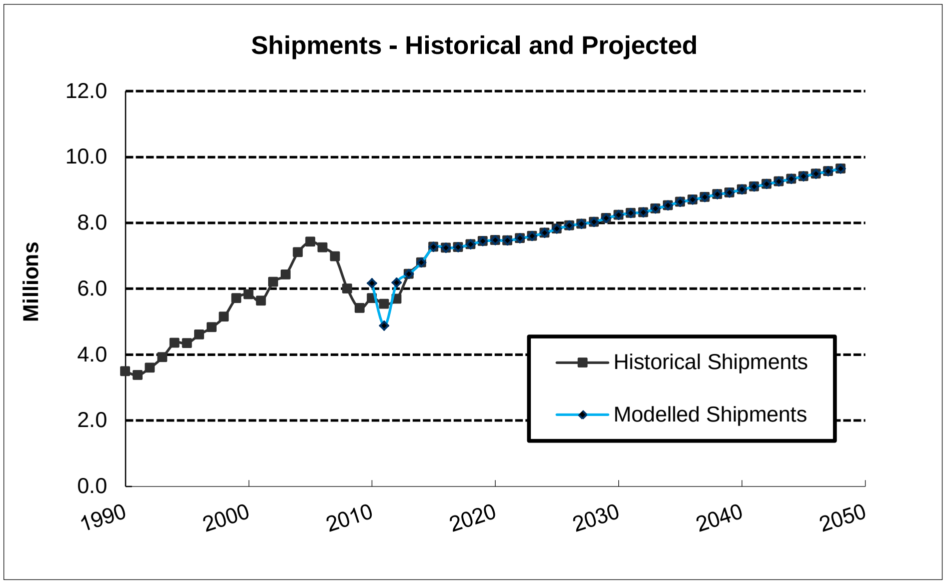


**Figure 9.3.4 Dishwashers: Historical and Base-Case Shipments Forecast**

## 9.4 IMPACTS OF STANDARDS ON SHIPMENTS

For replacements, consumer purchase decisions are influenced by the purchase price and operating cost of equipment and, therefore, will likely be different in the base case and under different TSLs. These decisions are modeled by estimating the purchase price elasticity for furnaces. The purchase price elasticity is defined as the change in the percentage of consumers acquiring a furnace divided by a change in the *relative price* (defined subsequently) for that equipment. This elasticity and information obtained from the life-cycle cost (LCC) and payback period (PBP) analysis on the change in purchase price and operating costs under different TSLs are used in the shipments model to estimate the change in shipments.

### 9.4.1 Relative Price and Relative Price Elasticity

DOE conducted a literature review and an analysis of appliance price and efficiency data to estimate the combined effects on product shipments from increases in product purchase price, decreases in product operating costs, and changes to household income. Appendix 9-A provides a detailed explanation of the methodology DOE used to quantify the impacts from these variables.

Existing studies of appliance markets suggest that the demand for 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 1980-2002 on large 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 price and operating costs over the time period. Household income has also risen during this time. Because purchase decisions are sensitive to income, as well as to potential savings in the operating cost of the appliance, DOE combined the available economic information into one variable, termed the *relative price*. This variable was used in a regression analysis to parameterize historical market trends. The relative price is defined with the following expression:

$$RP = \frac{TP}{Income} = \frac{PP + PVOC}{Income}$$

**Eq. 9.1**

Where:

$RP$ = relative price,
$TP$ = total price,
$Income$ = household income,
$PP$ = appliance purchase price, and
$PVOC$ = present value of operating cost.

In this equation, DOE used real prices, as opposed to nominal, and an implicit discount rate of 37 percent to estimate the present value of operating costs. The rate of 37 percent is based on a survey of several studies of different appliances that suggest that the consumer implicit discount rate has a broad range and averages about 37 percent.[12]

DOE's regression analysis suggests that the relative price elasticity of demand is -0.34. This implies that a relative price increase of 10 percent results in a 3.4 percent decrease in shipments. Note that the relative price elasticity incorporates the impacts from purchase price, operating cost, and household income, so the impact from any single effect can be mitigated by changes in the other two effects.

The relative price elasticity of -0.34 is consistent with estimates in the literature. Nevertheless, DOE stresses that the measure is based on a small data set, using a simple

---

[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.

statistical analysis. More importantly, the measure is based on an 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 since 1980. Changes in appliance quality and consumer preferences may have occurred during this period, but DOE did not account for them in this analysis. Despite these uncertainties, DOE believes that its estimate of the relative price elasticity of demand provides a reasonable assessment of the impact that purchase price, operating cost, and household income have on product shipments.

Because DOE's forecasts of shipments and national impacts attributable to standards is calculated for a long time period, it needed to consider how the *relative price* elasticity is affected after a new standard takes effect. DOE considered the *relative price* elasticity, described previously, to be a short-term value. It was unable to identify sources specific to household durable goods, such as appliances, to indicate how short-run and long-run price elasticities differ. Therefore, to estimate how the *relative price* elasticity changes over time, DOE relied on a study pertaining to automobiles.[13] This study shows that the automobile price elasticity of demand changes in the years following a purchase price change, becoming smaller (more inelastic) until it reaches a terminal value around the tenth year after the price change. Table 9.3.2 shows the relative change in the price elasticity of demand for automobiles over time. DOE developed a time series of relative price elasticities based on the relative change in the automobile price elasticity of demand. For years not shown in Table 9.3.2, DOE performed a linear interpolation to obtain the relative price elasticity.

**Table 9.4.1 Change in Relative Price Elasticity Following a Purchase Price Change**

| | **Years Following Price Change** | | | | | |
|---|---|---|---|---|---|---|
| | **1** | **2** | **3** | **5** | **10** | **20** |
| Relative Change in Elasticity to 1st year | 1.00 | 0.78 | 0.63 | 0.46 | 0.35 | 0.33 |
| Relative Price Elasticity | -0.34 | -0.26 | -0.21 | -0.16 | -0.12 | -0.11 |

### 9.4.2 Impact from Increase in Relative Price

Using the relative price elasticity, DOE was able to estimate the impact of the increase in relative price from a particular TSL. The impact, as shown in the equation below, is expressed as a percentage drop in market share for each year, $dMS^p_j$, which is applied in the decision for replacement versus extended repair.

$$dMS_j^p = \left[1 - \left(\frac{RP\_std_p(j)}{RP\_base_p(j)}\right)\right] \times e_{RP}(j)$$

**Eq. 9.2**

Where:

$dMS^p_j$ = percentage market share drop for class $p$, year $j$,
$RP\_std_p(j)$= relative price in the standards case for product class $p$, year $j$,

$RP_p(j)$= relative price in the base case for product class *p*, year *j*, and
$e_{RP}(j)$ = relative price elasticity in year *j*.

Because the percentage change in the cost of furnaces due to potential furnace fan standards is relatively small, DOE assumed that the new construction market is unaffected by changes in either the total installed cost or operating costs of the equipment. That is, home builders are not likely to choose to not install a furnace if the installed cost rises by a small amount.

To model the impact of the increase in relative price from a particular TSL on furnace shipments, DOE assumed consumers affected by an increase in total installed cost would repair their equipment rather than replace it, extending the life of the product by six years. When the extended repaired units fail after six more years, they will be replaced with new ones.

The model calculates, for each year after the standard, the relative percentage market drop, $dMS^p{}_j$, due to the equipment price increase. The extended repair is only applicable to failed equipment that is purchased before 2019.

The number of failed furnaces that will be repaired instead of being replaced is calculated as follows:

$$XR_i = \sum_a \mathrm{Re}\,m\left(j,a\right) \times dMS_i^p \qquad for\,(j-a) < 2019$$

$$Rpl\left(j\right) = \sum_a Re\,m(\,j,a\,) - XR_i + XR_{j-6} - Dem\left(j\right)$$

**Eq. 9.3**

Where:

$dMS^p{}_j$ = percentage market share drop for class *p*, year *j*,
*a* = age of equipment,
*j* = year,
*Rem(j,a)* = retiring units in year *j* of age *a*,
$XR_j$ = extended repair units, year *j*,
*Rpl(j)* = replacement units in year *j*, and
*Dem (j)* = number of units gone with demolished buildings in analysis year *j*.

## 9.5 AFFECTED STOCK

The in-service stock of a product that is affected by an energy efficiency standard is termed the affected stock. In addition to the forecast of product shipments under the base case and each standards case (each TSL), a key output of DOE’s shipments model is the affected stock, which represents the difference in the quantity of stock under the base case and each TSL. DOE calculates the affected stock to quantify the effect, attributable to a TSL, that shipments of new products will 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 the units (years), and
*Std_yr* = effective date of the standard.

As the above equation shows, DOE must define the effective date of a standard to calculate the affected stock. For the NES and NPV results presented in chapter 10, DOE assumed that new energy efficiency standards would become effective in 2019. Thus, the standard level would affect all appliances purchased beginning the first day of 2019. TSLs are described further in chapter 10, section 10.1.1.

## 9.6 IMPACTS OF POTENTIAL STANDARDS ON SHIPMENTS

This section presents the impacts on shipments resulting from each of the three TSLs that DOE is considering for dishwashers. Table 9.6.1 and Figure 9.6.1 show projected annual shipments of dishwashers in the base case and under each standard case. Because the elasticity is modeled as a delay in replacing a dishwasher, the projections for TSL 2 and TSL 3 show a decline in early years, a pattern that diminishes as delayed replacements are made.

**Table 9.6.1 Projected Annual Shipments of Standard and Compact Dishwashers**

| **TSL** | **Annual Shipments (million units)** | | | | |
|---|---|---|---|---|---|
| | **2015** | **2020** | **2030** | **2040** | **2048** |
| Base case | 7.3 | 7.5 | 8.2 | 9.0 | 9.6 |
| 1 | 7.3 | 7.5 | 8.2 | 9.0 | 9.6 |
| 2 | 7.3 | 7.3 | 8.2 | 9.0 | 9.6 |
| 3 | 7.3 | 7.4 | 8.2 | 9.0 | 9.7 |

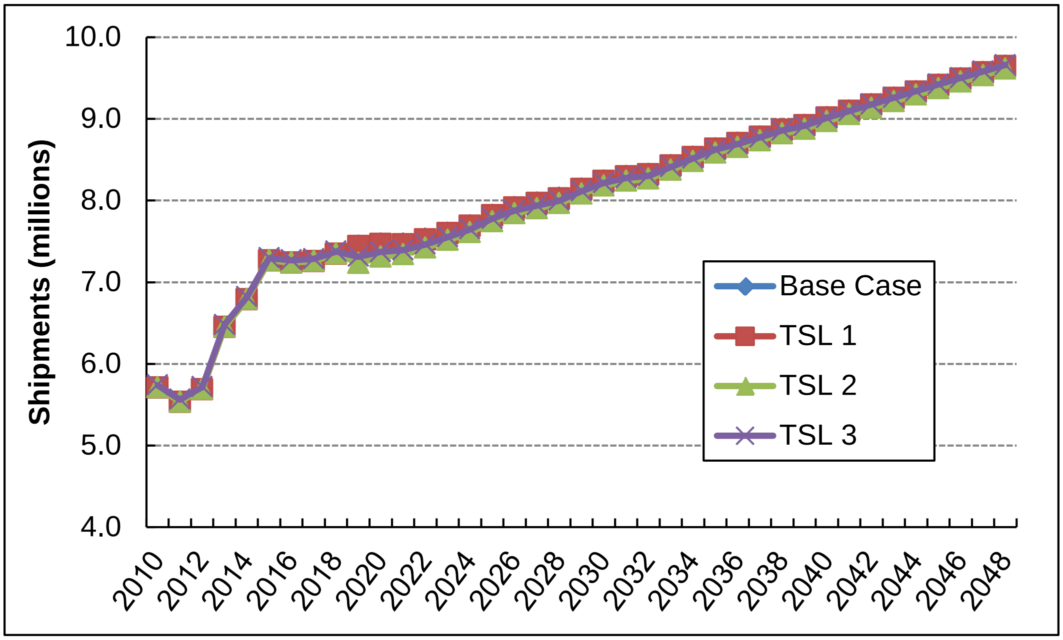


**Figure 9.6.1 Projected Standard and Compact Dishwasher Shipments in the Base Case and Each Standards Case**

## REFERENCES

---

1 Association of Home Appliance Manufacturers. AHAM Data on Dishwashers for Efficiency Standards Rulemaking, September 7, 2006. Letter to Building Technologies Program, U.S. Department of Energy.

2 Appliance Design. Forecasts/Shipments Archives. (Last accessed June 18, 2014). < http://www.appliancedesign.com/ForecastShipmentArchives>

3 The NPD Group, Inc. *The NPD Group/NPD Houseworld—POS, Dishwashers 2001-2011*. Port Washington, NY.

4 U.S. Department of Energy—Energy Information Administration. *Annual Energy Outlook 2014 with Projections to 2040*. 2014. Washington, D.C. Report Number DOE/EIA-0383(2014). (Last accessed May 18, 2014.) <http://www.eia.gov/forecasts/aeo/>

5 Association of Home Appliance Manufacturers. *AHAM 2005 Fact Book*. 2005. Washington, D.C.

6 The Saturation Picture. *Appliance Magazine*. September 1993, 1995, 2004, and 2005.

7 NFO World Group. *Final Report: Home Appliance Saturation and Length of First Ownership Study*. May 2001. Prepared for Association of Home Appliance Manufacturers by NFO World Group, Boston, MA.

8 U.S. Department of Energy—Energy Information Administration. *Residential Energy Consumption Survey, 1993 Survey Data*. 1993. Washington, D.C. (Last accessed June 18, 2014.) <http://www.eia.gov/consumption/residential/data/1993/>

9 U.S. Department of Energy—Energy Information Administration. *Residential Energy Consumption Survey, 1997 Survey Data*. 1997. Washington, D.C. (Last accessed June 18, 2014.) <http://www.eia.gov/consumption/residential/data/1997/>

10 U.S. Department of Energy–Energy Information Administration. *Residential Energy Consumption Survey, 2001 Survey Data*. 2001. Washington, D.C. (Last accessed June 18, 2014.) <http://www.eia.gov/consumption/residential/data/2001/>

11 U.S. Department of Energy–Energy Information Administration. *Residential Energy Consumption Survey, 2005 Survey Data*. 2005. Washington, D.C. (Last accessed June 18, 2014.) <http://www.eia.gov/consumption/residential/data/2005/>

12 U.S. Department of Energy–Energy Information Administration. *Residential Energy Consumption Survey, 2009 Survey Data*. 2009. Washington, D.C. (Last accessed June 18, 2014.) <http://www.eia.gov/consumption/residential/data/2009/>

# CHAPTER 10: NATIONAL IMPACT ANALYSIS

## TABLE OF CONTENTS

## LIST OF TABLES

## LIST OF FIGURES

# CHAPTER 10. NATIONAL IMPACT ANALYSIS

## 10.1 INTRODUCTION

This chapter describes the method the U.S. Department of Energy's (DOE's) used to estimate the impacts on national energy and water consumption of trial standard levels (TSLs) for both product classes of dishwashers (standard and compact). DOE evaluated the following impacts: (1) national energy and water consumption and savings (NES and NWS) attributable to each potential standard, (2) monetary value of energy savings for consumers of dishwashers, (3) increased total installed cost of the products because of standards, and (4) the net present value (NPV) of energy and water savings (*i.e.*, the difference between the savings in operating costs and the increase in total installed costs).

DOE determined both the NES and NPV for three TSLs considered for residential dishwashers. It performed all calculations for each product class using a Microsoft Excel spreadsheet model, which is accessible on the Internet (http://www1.eere.energy.gov/buildings/appliance_standards/residential/dishwashers.html). The spreadsheets, which implement the National Impact Analysis (NIA) model, combine the calculations for determining the NES and NPV for each product class with input from the relevant shipments model. Details and instructions for using the NIA model are provided in appendix 10-A.

Chapter 9 provides a detailed description of the shipments models DOE developed and used to forecast future purchases of residential dishwashers. Chapter 9 includes descriptions of consumers' sensitivities to total installed cost (purchase price plus installation costs), operating costs, and household income, and how DOE captured those sensitivities within the model.

### 10.1.1 Trial Standard Levels

DOE analyzed the benefits and burdens of three TSLs for residential dishwashers. The TSLs reflect efficiency levels analyzed in the life-cycle cost and payback period analysis (chapter 8). The TSLs were developed using combinations of efficiency levels for the standard and compact product classes.

TSL 3 represents the maximum technologically feasible ("max-tech") improvements in energy efficiency for residential dishwashers. TSL 2 represents the next efficiency level below the max-tech level for standard-sized dishwashers and an intermediate efficiency level between TSL 1 and TSL 3 for compact dishwashers. For standard-sized dishwashers, TSL 1 is the first efficiency level considered aboved the baseline. For compact dishwashers, TSL 1 represents the baseline efficiency level. Table 10.1.1 presents the TSLs and corresponding efficiency levels for dishwashers.

**Table 10.1.1 Trial Standard Levels for Residential Dishwashers**

| TSL | Standard | | Compact | |
|---|---|---|---|---|
| | Efficiency Level | Annual Energy Use (kWh/year) | Efficiency Level | Annual Energy Use (kWh/year) |
| 1 | 1 | 295 | Baseline | 222 |
| 2 | 3 | 234 | 1 | 203 |
| 3 | 4 | 180 | 2 | 141 |

## 10.2 FORECASTED EFFICIENCIES FOR BASE AND STANDARDS CASES

This section describes the method DOE used to forecast the energy efficiencies of dishwashers under the base case (without new energy eficiency standards) and each potential standards case. This section provides efficiency distributions for both product classes. The trend in forecasted energy efficiency is a key factor in estimating NES and NPV for the base case and each standards case. In calculating the NES, per-unit annual energy consumption is a direct function of product efficiency. For the NPV, two inputs, the per-unit total installed cost and the per-unit annual operating cost, depend on efficiency. The per-unit total installed cost is a direct function of efficiency. The per-unit annual operating cost, because it is a function of per-unit annual energy consumption, is indirectly dependent on product efficiency.

To assign a base-case energy efficiency distribution for 2019 (the year potential standards would become effective), DOE first considered the historical shipment-weighted base-case efficiency trend that AHAM submitted for the previous rulemaking for residential dishwashers.[1] Based on the historical data, DOE used an exponential function to project a future decline in annual energy use for the base case. This projection was not performed for compact dishwashers, because too few data were available. DOE then developed an efficiency distribution for dishwashers based on DOE's Compliance Certification Database for Dishwashers.[2] Figure 10.2.1 presents the historical base-case efficiency trend and the base-case efficiency projected for 2019 for standard dishwashers. DOE assumed that in the base case, shipment-weighted annual energy use will decrease from 288 kWh/year in 2019 to 280 kWh/year in 2048 for standard dishwashers. DOE extroplated shipment-weighted annual energy use employing estimated weighted annual energy use between 2019 and 2048.

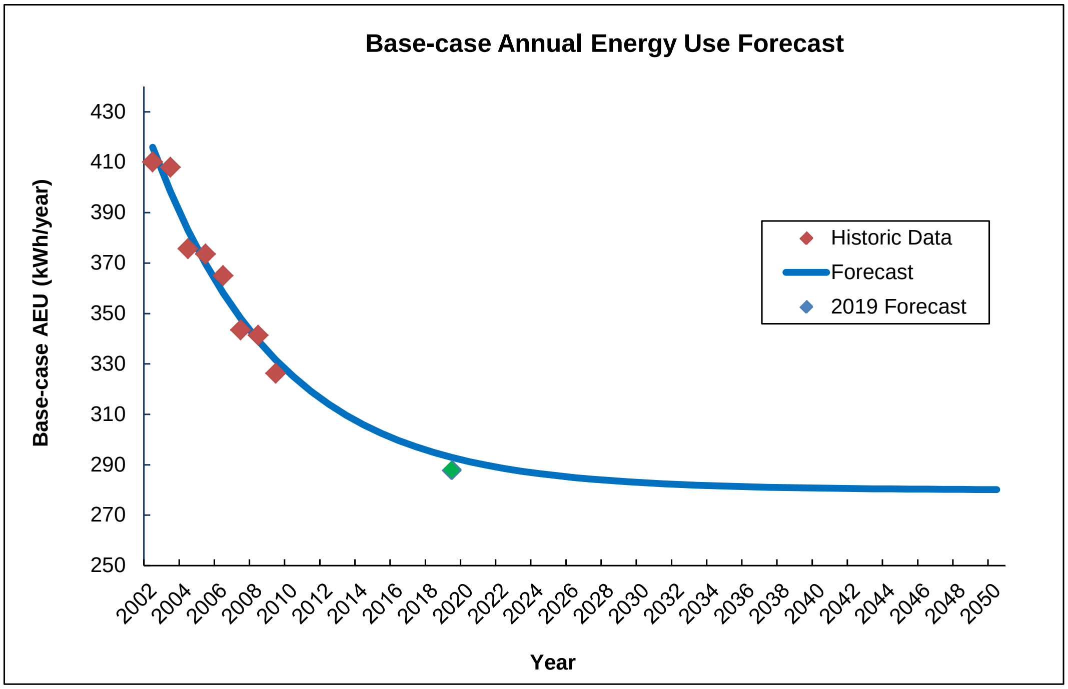


**Figure 10.2.1 Historical and Projected Base-Case Trend in Annual Energy Use (Standard Dishwashers)**

To determine the standards-case forecasted efficiencies, DOE assumed a “roll-up” scenario to establish the shipment-weighted efficiency for the year that standards are assumed to take effect (2019). DOE assumed that product efficiencies in the base case that did not meet the standard under consideration would “roll up” to meet the new standard level. DOE also assumed that all product efficiencies in the base case that exceeded the standard would not be affected. Taking the historical shipment-weighted efficiency and market share projections for 2019 as a starting point, DOE projected standards-case efficiencies based on assumptions regarding future efficiency improvements. For standards cases, DOE assumed that projected efficiencies for both product classes would remain frozen at the 2019 efficiency level until the end of the projection period.

Table 10.2.1 and Table 10.2.2 show the product efficiency distributions for the base-case and each TSL in 2019, based on the annual energy use (AEU) for each product class that DOE is considering. The tables also present the shipment-weighted annual energy use (SWAEU) and shipment-weighted water use (SWWU) associated with the base case and each TSL.

**Table 10.2.1 Standard Dishwashers:2019 Market Share Efficiency Distributions for Base and Standards Cases**

| Efficiency Level | TSL | AEU (kWh/year) | Water Use (gal/cycle) | Market Share Efficiency Distribution (%) | | | |
|---|---|---|---|---|---|---|---|
| | | | | Base Case | Trial Standard Level | | |
| | | | | | 1 | 2 | 3 |
| Baseline | - | 307 | 5.00 | 12.1 | 0.0 | 0.0 | 0.0 |
| 1 | 1 | 295 | 4.25 | 43.9 | 56.1 | 0.0 | 0.0 |
| 2 | - | 280 | 3.50 | 40.3 | 40.3 | 0.0 | 0.0 |
| 3 | 2 | 234 | 3.10 | 3.2 | 3.2 | 99.6 | 0.0 |
| 4 | 3 | 180 | 2.22 | 0.4 | 0.4 | 0.4 | 100.0 |
| | | | **SWAEU** | 288 | 286 | 234 | 180 |
| | | | **SWWU** | 3.99 | 3.90 | 3.10 | 2.22 |

SWAEU: shipment-weighted annual energy use.
SWWU: shipment-weighted water use.

**Table 10.2.2 Compact Dishwashers: 2019 Efficiency Distributions for Base and Standards Cases**

| Efficiency Level | TSL | AEU (kWh/year) | Water Use (gal/cycle) | Market Share (%) | | | |
|---|---|---|---|---|---|---|---|
| | | | | Base Case | Trial Standard Level | | |
| | | | | | 1 | 2 | 3 |
| Baseline | 1 | 222 | 3.50 | 48.1 | 48.1 | 0.0 | 0.0 |
| 1 | 2 | 203 | 3.10 | 14.8 | 14.8 | 63.0 | 0.0 |
| 2 | 3 | 141 | 2.00 | 37.0 | 37.0 | 37.0 | 100.0 |
| | | | **SWAEU** | 189 | 189 | 180 | 141 |
| | | | **SWWU** | 2.89 | 2.89 | 2.69 | 2.00 |

SWAEU: shipment-weighted annual energy use.
SWWU: shipment-weighted water use.

## 10.3 NATIONAL ENERGY AND WATER SAVINGS

DOE calculated the national energy and water savings (NES and NWS) associated with the difference between the base case and each potential standards case for dishwashers. DOE calculated cumulative energy savings throughout the forecast period, from 2019 to 2048. The equations in section 10.3.1 calculate energy savings; DOE used similar equations to calculate water savings.

### 10.3.1 Definitions

The following equation shows that DOE calculated national annual energy and water savings as the difference between two projections: a base case (without new standards) and a standards case. Positive values of NES represent energy savings (*i.e.*, national annual energy consumption under a standard is less than under the base case).

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

Cumulative energy and water savings are the sum of the national annual energy and water savings throughout the forecast period, which begins in the compliance year of 2019 and ends after 30 years (2048). The calculation is represented by the following equations.

$$NES_{cumulative} = \sum NES_y$$

$$NWS_{cumulative} = \sum NWS_y$$

DOE calculated the national annual energy and water consumption by multiplying the number or stock of each product class (by vintage) by its unit energy and water consumption (also by vintage). The calculation of the national annual energy consumption is represented by the following equation.

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

Where:

$AEC$ = National annual energy consumption each year in quadrillion British thermal units (quads) summed over vintages of the product stock, $STOCK_V$.
$NES_y$ = National annual energy savings (quads).
$STOCK_V$ = Stock of product (millions of units) of vintage $V$ surviving in the year for which DOE calculated annual energy consumption.
$UEC_V$ = Annual energy consumption per product class in either kilowatt-hours (kWh) or million Btus (MMBtu); electricity, gas, and oil consumption are converted from site energy to source energy (quads) by applying a time-dependent conversion factor. Water heaters consume gas and oil.
$V$ = Year in which the product was purchased as a new unit.
$y$ = 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 base case and each standards case. DOE estimated that the shipments under some trial standards cases initially could be lower than under the base case, because of the higher purchase price of more efficient products. In other words, DOE believes that the higher purchase price would cause some consumers to forego purchasing new products.

To avoid including savings attributable to shipments displaced because of standards, DOE used the projected standards-case shipments and, in turn, the standards-case stock, to calculate the annual energy consumption for the base case.

### 10.3.2 Inputs

The inputs to the calculation of NES are:

- shipments,
- product stock ($STOCK_V$),
- annual energy consumption per unit (*UE*C),
- national annual energy consumption (*AEC*), and
- site-to-source conversion factor (*src_conv*).

#### 10.3.2.1 Shipments

DOE forecasted shipments of dishwashers under the base case and all standards cases. Chapter 9, Shipments Analysis, describes in detail the method DOE used to calculate and generate the shipments forecasts. Several factors affect forecasted shipments, including total installed costs (purchase price plus installation costs), operating costs, household income, and product lifetime. As noted earlier, the increased total installed cost of more efficient products causes some customers to forego purchasing the product. Consequently, shipments forecasted under the standards cases initially are lower than under the base case. DOE believes it would be inappropriate to count energy savings that result from shipments that decline because of standards. Therefore, DOE did not calculate annual energy consumption for the base case using the base-case shipments forecast. Instead, each time a standards case was compared with the base case, DOE used shipments associated with that particular standards case. As a result, all of the calculated energy savings are attributable to higher energy efficiency in the standards case.

#### 10.3.2.2 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 provides additional details about the survival functions that DOE used.

#### 10.3.2.3 Annual Energy Consumption per Unit

DOE used the SWAEUs presented in Table 10.2.1 and Table 10.2.2, along with the data on annual energy consumption presented in chapters 7 and 8, to estimate the shipment-weighted average annual per-unit energy consumption under the base and standards cases. The average annual per-unit energy and water consumptions projected for 2019 for each product class and TSL are shown in Table 10.3.2.1.

**Table 10.3.1 Shipment-Weighted Average Annual Per-Unit Energy and Water Consumption**

| Product Class | | Trial Standard Level | | |
|---|---|---|---|---|
| **Standard** | **Baseline** | **1** | **2** | **3** |
| Annual energy use (kWh/yr) | 288 | 286 | 234 | 180 |
| Avg. elec use (kWh/yr) | 205 | 206 | 170 | 134 |
| Avg. gas use (MMBtu/yr) | 0.33 | 0.32 | 0.25 | 0.18 |
| Avg. oil use (MMBtu/yr) | 0.02 | 0.02 | 0.02 | 0.01 |
| Water use (1,000 gal/yr) | 0.86 | 0.84 | 0.67 | 0.48 |
| **Compact** | **Baseline** | **1** | **2** | **3** |
| Annual energy use (kWh/yr) | 189 | 189 | 180 | 141 |
| Avg. elec use (kWh/yr) | 129 | 129 | 124 | 100 |
| Avg. gas use (MMBtu/yr) | 0.24 | 0.24 | 0.22 | 0.16 |
| Avg. oil use (MMBtu/yr) | 0.01 | 0.01 | 0.01 | 0.01 |
| Water use (1,000 gal/yr) | 0.62 | 0.62 | 0.58 | 0.43 |

As described in section 9.4 of chapter 9, DOE forecasts an initial drop in dishwasher shipments in response to the increase in purchase price atttributable to standards-related efficiency increases. DOE assumed that those consumers who forego buying a dishwasher because of the higher purchase price would then wash their dishes by hand. To properly account for the impacts of dishwasher standards on energy and water use, DOE included the energy and water use of washing dishes by hand.

Several studies have compared the energy and water use of hand-washing dishes to using a dishwasher. All the studies found that the effects of moving from machine-washing to hand-washing dishes differ widely based on consumer habits. A 2005 study conducted at Bonn University in Germany found that, on average, hand washing used 67 percent more energy and more than 450 percent more water than machine washing.[3] A United Kingdom (UK) study in 2006 quantified the energy and water consumption of washing by hand as a function of place settings.[4] The study demonstrated that, on average, washing eight place settings by hand used approximately 210 percent more energy and 250 percent more water than washing them by machine. DOE decided to average the results from the two studies to estimate that hand washing would use 140 percent more energy and 350 percent more water than machine washing. In the NIA model for dishwashers, DOE incorporated that estimate to quantify the energy and water impacts of consumers who forego purchasing a dishwasher.Table 10.3.2 summarizes the average results from the Bonn and UK studies and the estimates DOE incorporated in its NIA.

**Table 10.3.2 Impacts on Energy and Water Use of Hand Washing Compared to Machine Washing**

| | Increase for Hand Washing Relative to Machine Washing (%) | |
|---|---|---|
| **Source** | **Energy Use** | **Water Use** |
| Bonn University* | 67 | 450 |
| UK† | 210 | 250 |
| DOE estimate | 140 | 350 |

Sources: *Bonn University, 2005.[3] †UK, Market Transformation Programme, 2006.[4]

### 10.3.2.4 National Annual Energy and Water Consumption

The national annual energy or water consumption (AEC or AWC) is the product of the annual energy or water consumption per unit and the number of units of each vintage (V). This approach accounts for differences in unit energy and water consumption from year to year. As described in section 10.3.1, DOE used the following equation to calculate the annual energy consumption; the equation for water consumption is the same as the equation for energy consumption.

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

To determine national annual energy consumption, DOE calculated the annual energy consumption at the site and then applied a conversion factor to calculate primary energy consumption, as described in the next section. Annual water consumption is calculated at the site without the application of a conversion factor.

### 10.3.2.5 Site-to-Power-Plant Energy Use Factor

In determining national annual energy consumption, DOE initially calculated the annual energy consumption at the site (for electricity, the energy in kWh consumed at the household. DOE then applied a conversion factor to site energy consumption to account for losses associated with the generation, transmission, and distribution of electricity. This multiplicative site-to-power-plant conversion factor converts 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 DOE's Energy Information Administration's (EIA's) *Annual Energy Outlook 2014* (*AEO2014*).[5] The factors are marginal values, which represent the response of the system to an incremental decrease in consumption. For electricity, the conversion factors change over time in response to projected changes in generation sources (that is, the types of power plants projected to provide electricity to the Nation). Figure 10.3.1 shows the site-to-power-plant conversion factors from 2019 to the end of the forecast period. The value *AEO2014* reported for 2040 (the last year available in *AEO2014*) was extrapolated through the end of the projection period.

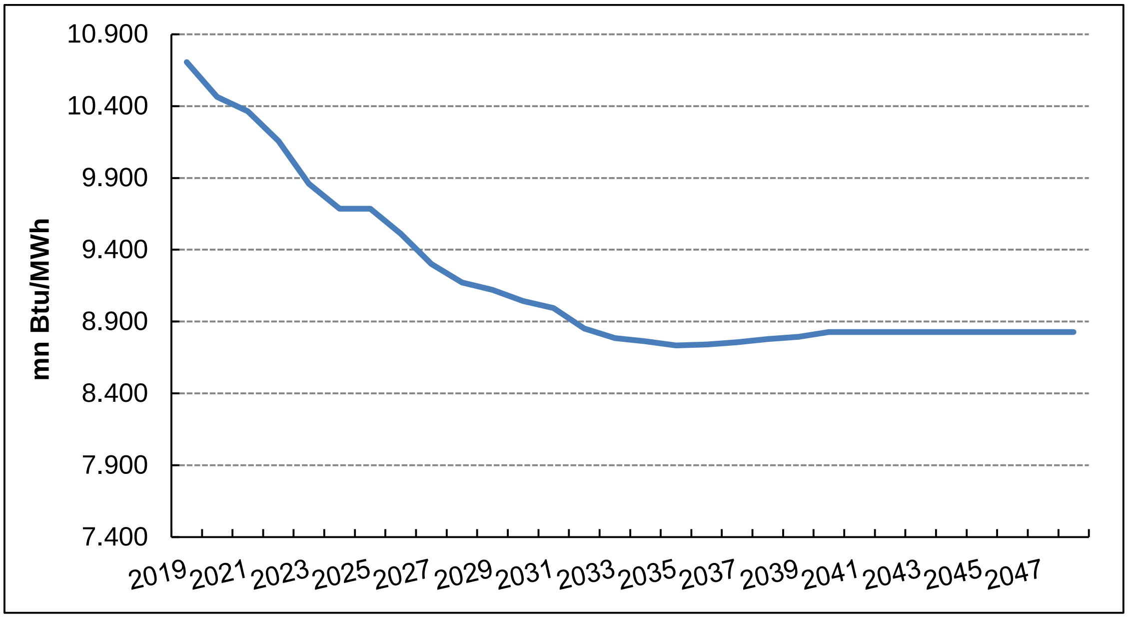


**Figure 10.3.1 Site-to-Power-Plant Energy Use Conversion Factors for Residential Dishwashers**

### 10.3.2.6 Full-Fuel-Cycle Energy Factors

The full-fuel-cycle (FFC) 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. To estimate the FFC by including the energy consumed in extracting, processing, and transporting or distributing primary fuels, which we refer to as "upstream" activities, DOE developed FFC multipliers[b] using the data

---

[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. Because this analysis entails minor code modifications, and the model is run under policy scenarios that are variations on EIA assumptions, DOE refers to the model as NEMS-BT (BT is DOE's Building Technologies Program, under whose aegis this work was performed). NEMS-BT previously was called NEMS-BRS.

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

and projections generated for *AEO2014*. The *AEO2014* 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. This 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 10-B.

Table 10.3.3 shows the FFC energy multipliers used for residential dishwashers for selected years. The 2040 values were used for the years after 2040.

**Table 10.3.3 Full-Fuel-Cycle Energy Multipliers (Based on *AEO 2014*)**

| Energy Source | 2019 | 2020 | 2025 | 2030 | 2035 | 2040 |
|---|---|---|---|---|---|---|
| Electricity<br>(power plant energy use) | 1.043 | 1.044 | 1.045 | 1.046 | 1.047 | 1.047 |
| Natural gas (site) | 1.108 | 1.109 | 1.111 | 1.113 | 1.114 | 1.114 |
| Petroleum fuels (site) | 1.176 | 1.176 | 1.176 | 1.174 | 1.172 | 1.170 |

## 10.4 NET PRESENT VALUE

DOE calculated the net present value (NPV) of the increased product cost and reduced operating costs associated with the difference between the base case and each potential standards case for the considered residential dishwasher product classes.

### 10.4.1 Definition

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 using 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 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 a given product class (by vintage) by its per-unit savings in operating costs (also by vintage). DOE calculated the total annual increases in consumer product prices by multiplying the number or shipments of the given product class (by vintage) by its per-unit increase in consumer product cost (also by vintage). Total annual operating cost savings and total annual product price increases are calculated using 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 is calculating annual energy consumption,
$UOCS_V$ = annual per-unit savings in operating costs,
$V$ = year in which the product was purchased new,
$SHIP_y$ = shipments of product in year $y$, and
$UTIC_y$ = annual per-unit increase in installed product cost in year $y$.

DOE determined the total increased product installed cost for each year from the effective date of a potential standard (2019) to 2048. DOE determined the present value of operating cost savings for each year from the effective date of the standard to the year when all units purchased by 2048 will be retired. DOE calculated costs and savings as the difference between a standards case and a base case with no new standards.

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

### 10.4.2 Inputs

Inputs to the calculation of net present value (NPV) are:

- total installed cost per unit,
- annual operating cost savings per unit,total annual increases in product price,
- total annual savings in operating costs,
- discount factor,
- present value of costs, and
- present value of savings.

The increase in the *total annual installed cost* is equal to the annual change in the per-unit total installed cost (difference between base case and standards case) multiplied by the shipments forecasted for the standards case. As with the calculation of NES, DOE did not use base-case shipments to calculate total annual installed costs for all products. To avoid including savings attributable to shipments displaced by consumers deciding not to buy higher-cost products, DOE used the standards-case projection of shipments and, in turn, the standards-case stock, to calculate installed product costs. Additionally, DOE assumed that any consumers foregoing the purchase of a new unit because of standards would shift to washing by hand.

The *total annual operating cost savings* are equal to the change in annual operating costs (difference between base case and standards case) per unit multiplied by the shipments forecasted in the standards case. DOE did not calculate operating cost savings using base-case shipments. Annual operating costs includes repair and maintenance costs, as well as the primary costs for energy and water.

#### 10.4.2.1 Total Installed Cost per Unit

As discussed in chapter 8, DOE developed a trend for prices of dishwashers based on an experience rate for miscellaneous household appliances. DOE used the trend to project the prices of dishwashers sold in each year of the forecast period. DOE applied the same values to project prices for each product class at each trial standard level.

To examine the uncertainty regarding price trends, DOE investigated the effect of different dishwasher price projections on the consumer's net present value for the considered TSLs. In addition to the default price trend, DOE considered two price sensitivity cases: (1) a high price decline based on an exponential fit using producer price index (PPI) data for 1991 to 2013; (2) a low price decline based on an experience rate derived using PPI and shipments data for 1991 to 2000. The approach used to project the price trends and the results of analyzing the sensitivity cases are described in further detail in appendix 10-C.

Total installed cost includes both the product price and the installation cost. DOE first considered the per-unit total installed cost as a function of product efficiency in section 8.2 of chapter 8. Because the annual per-unit total installed cost depends directly on efficiency, DOE used the base- and standards-case SWAEUs presented in Table 10.2.1 and Table 10.2.2, in combination with the total installed costs presented in chapter 8, to estimate the shipment-weighted average annual per-unit total installed cost under the base and standards cases. Table 10.4.1 shows the average shipment-weighted total installed cost based on the SWAEUs that correspond to the base case and each standards case in 2019.

**Table 10.4.1 Shipment-Weighted Average Per-Unit Total Installed Costs for Base and Standards Cases (2013$)**

| Product Class | Base Case | Trial Standard Level | | |
|---|---|---|---|---|
| | | 1 | 2 | 3 |
| **Standard** | | | | |
| SWAEU | 288 | 286 | 234 | 180 |
| Avg. product cost (2013$) | 362 | 363 | 433 | 433 |
| **Compact** | | | | |
| SWAEU | 189 | 189 | 180 | 141 |
| Avg. product cost (2013$) | 319 | 319 | 324 | 335 |

#### 10.4.2.2 Annual Operating Cost Savings per Unit

The per-unit annual operating costs include the costs for energy and water, repair, and maintenance. As described in section 8.2.2.4 of chapter 8, DOE assumed that potential standards would not increase maintenance or repair costs for dishwashers. Therefore, DOE determined the per-unit annual operating cost savings based only on the savings in energy and water costs due to a standard level. DOE determined the per-unit annual operating cost savings by multiplying the per-unit annual savings in energy and water consumption for each product class by the appropriate energy and water price.

As described in chapter 8, DOE forecasted energy prices based on EIA's *AEO2014*. DOE forecasted water prices based on trends in the national water price index provided by the Bureau of Labor Statistics. The trends in energy and water prices are described in section 8.2.2.3 of chapter 8.

#### 10.4.2.3 Total Annual Increases in Installed Cost

The total annual increase in installed cost for a given standards case is the product of the total installed cost increase per unit due to the standard and the number of units of each vintage. This approach accounts for differences in total installed cost from year to year. As also shown in section 10.4.1, the equation to calculate the total annual increase in installed cost for a given standards case is:

$$TIC = \sum STOCK_V \times UTIC_V$$

### 10.4.2.4 Total Annual Savings in Operating Costs

The total annual savings in operating costs for a given standards case is the product of the annual operating cost savings per unit due to the standard and the number of units of each vintage. This approach accounts for differences in annual operating cost savings from year to year. As also shown in section 10.4.1, the equation to calculate the total annual operating cost savings for a given standards case is:

$$OCS = \sum STOCK_V \times UOCS_V$$

As noted earlier, DOE accounted for the energy and water use of those consumers who respond to the new standard by washing dishes by hand. The total annual operating cost savings take into account the additional energy and water costs for washing by hand versus machine dishwashing for consumers who forego dishwasher purchases because of standards.

### 10.4.2.5 Discount Factors

DOE multiplies monetary values in future years by a discount factor to determine the present value. The discount factor (DF) is described by the equation:

$$DF = \frac{1}{(1+r)^{(y-yp)}}$$

Where:

$r$ = discount rate,
$y$ = year of the monetary value, and
$y_P$ = year in which the present value is being determined.

DOE estimated national impacts using both a three-percent and a seven-percent real discount rate, in accordance with the Office of Management and Budget (OMB)'s guidance to Federal agencies on the development of regulatory analysis (OMB Circular A-4, September 17, 2003, and section E., "Identifying and Measuring Benefits and Costs," therein). DOE defines the present year as 2014.

### 10.4.2.6 Present Value of Increased Costs

The present value of increased installed costs is the increase in installed cost in each year (*i.e.*, the difference between a standards case and base case), discounted to the present and summed over the period for which DOE considered the installation of products (that is, from the effective date of the standard, 2019, through 2048).

The increase in total installed costs refers to both product price and installation cost associated with the higher energy efficiency of products purchased in the standards case. For the

NIA, DOE excludes sales tax from the product cost, because sales tax is essentially a transfer and therefore is more appropriate to include when estimating consumer benefits. DOE calculated annual increases in installed cost as the difference in total installed cost for new products purchased each year multiplied by the shipments in the standards case.

#### 10.4.2.7 Present Value of Savings

The present value of operating cost savings is the annual operating cost savings (the difference between the base case and a standards case) discounted to the present and summed from the compliace year, 2019, to the time when the last unit installed in 2048 is retired from service. Savings are decreases in operating costs associated with the higher energy efficiency of products purchased in the standards case compared to the base case. Total annual operating cost savings are the savings per unit multiplied by the number of units of each vintage that survive in a given year.

## 10.5 RESULTS OF CALCULATIONS

The NIA model provides estimates of the NES and NPV attributable to a given trial standard level. The inputs to the NIA model were discussed in sections 10.3.2 (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 (http://www1.eere.energy.gov/buildings/appliance_standards/residential/dishwashers.html). Details and instructions for using the spreadsheet are provided in appendix 10-A.

### 10.5.1 Summary of Inputs

Table 10.5.1 summarizes the inputs to the NIA model. A brief description of the data source is given for each input.

**Table 10.5.1 Inputs to Calculation of National Energy Savings and Net Present Value**

| Input | Data Description |
|---|---|
| Shipments | Annual shipments from shipments model (chapter 9). |
| Effective date of standard | 2019 |
| Forecasted efficiencies for base case | SWAEU determined in 2019 for both product classes. SWAEU held constant throughout forecast period of 2019–2048. (See section 10.2.) |
| Forecasted efficiencies for standards cases | Roll-up scenario assumed for determining SWAEU in 2019 for each standards case and for each product class. SWAEU held constant throughout forecast period of 2019–2048. (See section 10.2.) |
| Annual energy consumption per unit | Annual weighted average values are a function of SWAEU. (See section 10.3.2.3.) |
| Total installed cost per unit | Annual weighted average values are a function of the efficiency |

| Input | Data Description |
|---|---|
| | distribution. (See section 10.4.2.1.) |
| Energy and water costs per unit | Annual weighted-average values are a function of the annual energy and water consumption per unit and energy and water prices. (See chapter 8, section 8.2.2.3, for energy and water prices.) |
| Repair and maintenance costs per unit | No changes in repair and maintenance costs were assumed due to standards. |
| Forecast of installed cost per unit | Price forecast based on historical PPI data. |
| Forecast of energy and water prices | Energy Prices: EIA *AEO2014* forecasts. (See section 8.2.2.3 of chapter 8.)<br>Water Prices: linear extrapolation of inflation-adjusted historical national water price index. (See section 8.2.2.3 of chapter 8.) |
| Energy site-to-source conversion | A time-series conversion factor that includes losses due to electricity generation, transmission, and distribution. The conversion factor, which changes yearly, is generated by DOE/EIA's NEMS* program. |
| Discount rate | 3% and 7% real |
| Present year | Future expenses are discounted to 2014. |

* Section 10.3.2.5 provides more detail on NEMS.

### 10.5.2 National Energy and Water Savings Calculations

This section provides results of NES and NWS calculations for the standards cases analyzed for both product classes. NES results, which are cumulative from 2019 to 2048, represent primary energy savings and site water savings. 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 10.5.2 shows the NES and NWS results for all the TSLs analyzed, which represent specific efficiency level combinations for standard and compact dishwashers.

**Table 10.5.2 Cumulative National Energy and Water Savings**

| TSL | Efficiency Level Combination | | Primary Energy Savings (quads) | Full-Fuel-Cycle Energy Savings (quads) | National Water Savings (trillion gallons) |
|---|---|---|---|---|---|
| | Standard | Compact | | | |
| 1 | 1 | 0 | 0.00 | 0.01 | 0.03 |
| 2 | 3 | 1 | 1.00 | 1.06 | 0.24 |
| 3 | 4 | 2 | 2.39 | 2.53 | 0.99 |

### 10.5.3 Annual Costs and Savings

To illustrate the outputs of the NPV calculations, Figure 10.5.1 presents the non-discounted annual installed cost increases and annual operating cost savings at the national level for TSL 2. The figure also shows the 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 product class and TSL.

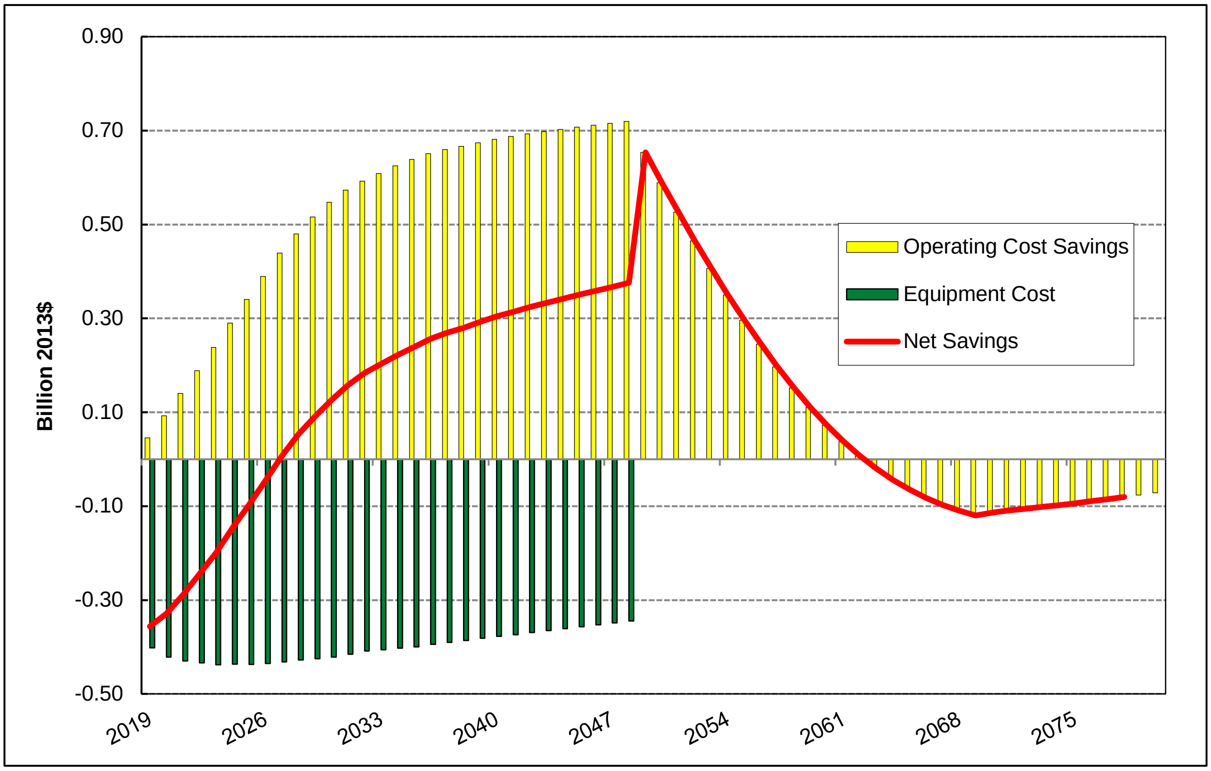


**Figure 10.5.1** **Non-Discounted Annual Installed Cost Increases and Annual Operating Cost Savings for Dishwashers, TSL 2**

### 10.5.4 Net Present Value of Consumer Benefit

This section provides NPV results for the potential efficiency standards for standard and compact dishwashers. Results, which are cumulative, are shown as the discounted value of savings in dollars. 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.

The present value of increased total installed costs is the cost difference between the standards case and base case discounted to the present and summed over the period in which DOE evaluated the impacts of standards (from the effective date of standards, 2019, to 2048). Total savings in operating costs are the savings per unit multiplied by the number of units of each vintage (*i.e.,* the year of manufacture) that survive in a given year. For units purchased through 2048, operating costs include energy and water consumed until the last unit is retired from service.

Table 10.5.3 presents the NPV results for the trial standard levels considered for standard and compact dishwashers. Results are based on both a three-percent and a seven-percent disocunt rate.

**Table 10.5.3 Discounted Cumulative Net Present Value of Consumer Savings**

| TSL | Efficiency Level Combination | | Net Present Value | |
|---|---|---|---|---|
| | Standard | Compact | 7% Discount Rate (billion 2013$) | 3% Discount Rate (billion 2013$) |
| 1 | 1 | 0 | 0.05 | 0.15 |
| 2 | 3 | 1 | 0.23 | 2.14 |
| 3 | 4 | 2 | 5.56 | 15.70 |

## REFERENCES

---

1 Association of Home Appliance Manufacturers. AHAM Data on Dishwashers for Efficiency Standards Rulemaking, September 7, 2006. Letter to Building Technologies Program, U.S. Department of Energy.

2 U.S. Department of Energy–Energy Efficiency and Renewable Energy. Compliance Certification Database for Dishwashers. (Last accessed June 18, 2014). <http://www.regulations.doe.gov/certification-data/CCMS-41431681025.html>

3 Stamminger, R., R. Badura, G. Broil, S. Dorr, and A. Elschenbroich. A European Comparison of Cleaning Dishes by Hand. 2003. *Proceedings of EEDAL conference.* University of Bonn: Germany. (Last accessed June 18, 2014.) <http://www.landtechnik-alt.uni-bonn.de/ifl_research/ht_1/EEDAL_03_ManualDishwashing.pdf >

4 Market Transformation Programme–Briefing Note. *BNW16: A comparison of washing up by hand with a domestic dishwasher*. February 13, 2006. Market Transformation Programme, United Kingdom.

5 U.S. Department of Energy–Energy Information Administration. *Annual Energy Outlook 2014 with Projections to 2040.* 2014. Washington, D.C. Report Number DOE/EIA-0383(2014). (Last accessed May 22, 2014.) < http://www.eia.gov/forecasts/aeo/ >

# CHAPTER 11. CONSUMER SUBGROUP ANALYSIS

## TABLE OF CONTENTS

## LIST OF TABLES

# CHAPTER 11. CONSUMER SUBGROUP ANALYSIS

## 11.1 INTRODUCTION

Chapter 8 of this TSD describes the life-cycle cost (LCC) and payback period (PBP) analysis that examines energy savings and costs impacts of energy conservation standards on the U.S. population. In analyzing the potential impacts of new or amended standards on consumers, the U.S. Department of Energy (DOE) further evaluates the impacts on identifiable groups of consumers (subgroups) that may be disproportionately affected by a national standard level. The consumer subgroup analysis evaluates effects by analyzing the LCCs and PBPs for subgroups of residential consumers. For both standard and compact dishwashers, DOE identified two consumer subgroups that warranted further study: (1) senior-only households and (2) low-income households.

DOE determined the impact on consumer subgroups for standard and compact dishwashers using the LCC spreadsheet model, which enables DOE to analyze the LCC for any subgroup by sampling only the data that apply to that subgroup. (Chapter 8 explains in detail the inputs to the model used in determining LCCs and PBPs.) As described in section 11.3, the energy use and energy price characteristics of the two subgroups (senior-only and low-income) differ from those for the general population.

This chapter describes the identification of the two subgroups and gives the results of the LCC and PBP analysis for those subgroups.

## 11.2 IDENTIFIED SUBGROUPS

The following two sections describe how DOE defined the two consumer subgroups identified for further examination.

### 11.2.1 Senior-Only Households

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.[1]

### 11.2.2 Low-Income Households

As defined in the RECS survey, low-income household residents are living at or below the poverty line. The poverty line varies with household size, age of head of household, and family income. The RECS survey classifies 15 percent of the country’s households as low-income.

## 11.3 INPUTS TO CONSUMER SUBGROUP ANALYSIS

Table 11.3.1 summarizes the overall household populations and the populations of senior-only and low-income households in RECS. Table 11.3.2 and Table 11.3.3 summarize the weighted-average annual energy use for the households analyzed in the consumer subgroup analysis. These values are compared against the weighted-average values for the national sample.

**Table 11.3.1 Household Population**

| | Count | Sum |
|---|---|---|
| National | 12,083 | 113,616,229 |
| Senior-Only | 1,939 | 19,562,375 |
| Senior-Only (%) | 16.0 | 17.2 |
| Low-Income | 1675 | 16,867,387 |
| Low-Income (%) | 13.9 | 14.8 |

**Table 11.3.2 Weighted-Average Annual Electricity Use for Standard Dishwashers**

| Efficiency Level | All RECS Households | Senior-Only | Low-Income |
|---|---|---|---|
| | (kWh/year) | | |
| Baseline | 207 | 162 | 210 |
| 1 | 211 | 166 | 211 |
| 2 | 212 | 167 | 209 |
| 3 | 174 | 137 | 172 |
| 4 | 137 | 108 | 135 |

**Table 11.3.3 Weighted-Average Annual Electricity Use for Compact Dishwashers**

| Efficiency Level | All Households | Senior-Only | Low-Income |
|---|---|---|---|
| | (kWh/year) | | |
| Baseline | 124 | 102 | 127 |
| 1 | 115 | 94 | 117 |
| 2 | 82 | 65 | 82 |

## 11.4 RESULTS

Table 11.4.1 through Table 11.4.4 summarize the LCC and PBP results from DOE's subgroup analysis. The results describe the financial effects of potential standards on senior-only and low-income households. The tables present the average installed price; average lifetime operating cost (discounted); average life-cycle cost; average life-cycle cost savings; percentage of each subgroup who are burdened with net costs, realize net savings, or are not affected; and the median payback period.

**Table 11.4.1 Senior-Only Households: Summary of LCC and PBP Results by Efficiency Level for Standard-Sized Dishwashers**

| TSL | Efficiency Level | Average Costs 2013$ | | | | Simple Payback years |
|---|---|---|---|---|---|---|
| | | Installed Cost | First Year's Operating Cost | Lifetime Operating Cost | LCC | |
| - | 0 | 483 | 35 | 403 | 885 | -- |
| 1 | 1 | 495 | 34 | 384 | 879 | 8.4 |
| - | 2 | 531 | 32 | 360 | 892 | 14.0 |
| 2 | 3 | 582 | 27 | 303 | 885 | 11.6 |
| 3 | 4 | 582 | 20 | 232 | 814 | 6.8 |

Note: The average LCC, LCC savings, and simple payback for each TSL are calculated assuming that all consumers use products with that EL. This allows the results for each TSL to be compared under the same conditions.

**Table 11.4.2 Senior-Only Households: Summary of LCC and PBP Results by Efficiency Level for Compact Dishwashers**

| TSL | Efficiency Level | Average Costs 2013$ | | | | Simple Payback years |
|---|---|---|---|---|---|---|
| | | Installed Cost | First Year's Operating Cost | Lifetime Operating Cost | LCC | |
| 1 | 0 | 456 | 21 | 241 | 698 | -- |
| 2 | 1 | 467 | 19 | 218 | 685 | 5.3 |
| 3 | 2 | 485 | 13 | 148 | 633 | 3.5 |

Note: The average LCC, LCC savings, and simple payback for each TSL are calculated assuming that all consumers use products with that EL. This allows the results for each TSL to be compared under the same conditions.

**Table 11.4.3 Senior-Only Households: Summary of Life-Cycle Cost Savings Relative to the Base Case Efficiency Distribution for Standard-Sized Dishwashers**

| TSL | Efficiency Level | Life-Cycle Cost Savings | |
|---|---|---|---|
| | | % of Consumers that Experience Net Cost | Average Savings 2013$ |
| 1 | 1 | 7 | 1 |
| 2 | 3 | 64 | 1 |
| 3 | 4 | 42 | 71 |

Note: The LCC savings for each TSL are calculated relative to the base case efficiency distribution. The calculation includes households with zero LCC savings (no impact).

**Table 11.4.4 Senior-Only Households: Summary of Life-Cycle Cost Savings Relative to the Base Case Efficiency Distribution for Compact Dishwashers**

| TSL | Efficiency Level | Life-Cycle Cost Savings | |
|---|---|---|---|
| | | % of Consumers that Experience Net Cost | Average Savings 2013$ |
| 1 | 0 | -- | -- |
| 2 | 1 | 12 | 6 |
| 3 | 2 | 8 | 40 |

Note: The LCC savings for each TSL are calculated relative to the base case efficiency distribution. The calculation includes households with zero LCC savings (no impact).

**Table 11.4.5 Low-Income Households: Summary of LCC and PBP Results by Efficiency Level for Standard-Sized Dishwashers**

| TSL | Efficiency Level | Average Costs 2013$ | | | | Simple Payback years |
|---|---|---|---|---|---|---|
| | | Installed Cost | First Year's Operating Cost | Lifetime Operating Cost | LCC | |
| - | 0 | 483 | 42 | 486 | 969 | -- |
| 1 | 1 | 496 | 40 | 460 | 956 | 6.2 |
| - | 2 | 532 | 37 | 430 | 962 | 10.8 |
| 2 | 3 | 583 | 31 | 362 | 944 | 9.5 |
| 3 | 4 | 583 | 24 | 276 | 859 | 5.6 |

Note: The average LCC, LCC savings, and simple payback for each TSL are calculated assuming that all consumers use products with that EL. This allows the results for each TSL to be compared under the same conditions.

**Table 11.4.6 Low-income Households: Summary of LCC and PBP Results by Efficiency Level for Compact Dishwashers**

| TSL | Efficiency Level | Average Costs 2013$ | | | | Simple Payback years |
|---|---|---|---|---|---|---|
| | | Installed Cost | First Year's Operating Cost | Lifetime Operating Cost | LCC | |
| 1 | 0 | 457 | 25 | 285 | 742 | -- |
| 2 | 1 | 467 | 22 | 258 | 726 | 4.7 |
| 3 | 2 | 485 | 15 | 176 | 661 | 3.1 |

Note: The average LCC, LCC savings, and simple payback for each TSL are calculated assuming that all consumers use products with that EL. This allows the results for each TSL to be compared under the same conditions.

**Table 11.4.7 Low-income Households: Summary of Life-Cycle Cost Savings Relative to the Base Case Efficiency Distribution for Standard-Sized Dishwashers**

| TSL | Efficiency Level | Life-Cycle Cost Savings | |
|---|---|---|---|
| | | % of Consumers that Experience Net Cost | Average Savings 2013$ |
| 1 | 1 | 6 | 2 |
| 2 | 3 | 59 | 15 |
| 3 | 4 | 42 | 100 |

Note: The LCC savings for each TSL are calculated relative to the base case efficiency distribution. The calculation includes households with zero LCC savings (no impact).

**Table 11.4.8 Low-income Households: Summary of Life-Cycle Cost Savings Relative to the Base Case Efficiency Distribution for Compact Dishwashers**

| TSL | Efficiency Level | Life-Cycle Cost Savings | |
|---|---|---|---|
| | | % of Consumers that Experience Net Cost | Average Savings |
| 1 | 0 | -- | -- |
| 2 | 1 | 13 | 8 |
| 3 | 2 | 9 | 48 |

Note: The LCC savings for each TSL are calculated relative to the base case efficiency distribution. The calculation includes households with zero LCC savings (no impact).

## REFERENCES

1. U.S. Department of Energy–Energy Information Administration. *Residential Energy Consumption Survey*, *2009 Public Use Data Files*. 2013. Washington, D.C. (Last accessed March 25, 2013.) < http://www.eia.gov/consumption/residential/data/2009/index.cfm?view=characteristics >

# CHAPTER 12. MANUFACTURER IMPACT ANALYSIS

## LIST OF TABLES

## LIST OF FIGURES

# CHAPTER 12. MANUFACTURER IMPACT ANALYSIS

## 12.1 INTRODUCTION

In determining whether an amended energy conservation standard for residential dishwashers is economically justified, DOE is required to consider “the economic impact of the standard on the manufacturers and on the consumers of the products subject to such standard.” (42 U.S.C. 6295(o)(2)(B)(i)(I)) The statute also calls for an assessment of the impact of any lessening of competition that is likely to result from the adoption of a standard as determined by the Attorney General. (42 U.S.C. 6295(o)(2)(B)(i)(V)) DOE conducted the manufacturer impact analysis (MIA) to estimate the financial impact of amended energy conservation standards on manufacturers, and to assess the impacts of such standards on employment and manufacturing capacity.

The MIA involves both quantitative analyses and qualitative evaluation. The quantitative elements of the MIA rely on the Government Regulatory Impact Model (GRIM), an industry cash-flow model customized for this rulemaking. The GRIM inputs include information on industry cost structure, shipments, and pricing strategies. The GRIM’s key output is the industry net present value (INPV), which is the sum of discounted annual industry cash-flows over the analysis period. The model estimates the financial impact of more stringent energy conservation standards by comparing changes in INPV between a base case and the various trial standard levels (TSLs) in the standards case. The qualitative part of the MIA addresses trends in product characteristics, manufacturer characteristics, and the impact of standards on 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 residential dishwasher 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,” DOE created a GRIM to model the economic impact of amended energy conservation standards on the residential dishwasher manufacturing industry as a whole. In Phase III, “Subgroup Impact Analysis,” DOE evaluated the impacts of amended energy conservation standards on manufacturer cash flows, investments, and employment. Phase III also included an evaluation of any impacts on manufacturer sub-groups, specifically focusing on the potential for disproportionate impacts on small business manufacturers of residential dishwashers.

### 12.2.1 Phase I: Industry Profile

In Phase 1 of the MIA, DOE prepared a profile of the residential dishwasher manufacturing industry based on the market and technology assessment prepared for this rulemaking (see chapter 3 of this Notice of Proposed Rulemaking (NOPR) 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 data, product attributes, product shipments, manufacturer markups, and the cost structure for various manufacturers.

The profile also included an analysis of manufacturers in the industry using Security and Exchange Commission (SEC) 10-K filings, Standard & Poor's (S&P) stock reports, 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 including industry revenues, cost of goods sold, and depreciation, as well as selling, general, and administrative (SG&A), and research and development (R&D) expenses. DOE used the same industry average financial parameters developed in support of the direct final rule published in the Federal Register on May 30, 2012 (77 FR 31918) (May 2012 direct final rule).

### 12.2.2 Phase II: Industry Cash-Flow Analysis

Phase 2 focused on the financial impacts of potential amended energy conservation standards on the residential dishwasher manufacturing industry as a whole. Amended 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. In performing this analysis, DOE used the financial parameters from the May 2012 direct final rule, the cost-efficiency curves from the engineering analysis as presented in chapter 5 of the NOPR TSD, and the shipment assumptions from the national impact analysis (NIA) as presented in chapter 10 of the NOPR TSD. DOE developed alternative markup scenarios for each GRIM based on discussions with manufacturers conducted in support of the May 2012 direct final rule. DOE used the GRIM to model a series of annual cash flows from the announcement year of amended energy conservation standards until several years after the standards' compliance date. The key output of the GRIM is the INPV, which is the sum of these annual cash flows discounted by the industry weighted average cost of capital. DOE used the GRIM to compare INPV in the base 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 amended standard on manufacturers.

### 12.2.3 Phase III: Subgroup Analysis

DOE interviewed a representative cross-section of residential dishwasher manufacturers in support of the May 2012 direct final rule. These MIA interviews broadened the discussion to include business-related topics. DOE sought to obtain feedback from industry on the approaches used in the GRIM and to isolate key issues and concerns. During these interviews, DOE did not identify any manufacturer subgroups that would warrant a subgroup analysis.

#### 12.2.3.1 Manufacturing Interviews

DOE used information gathered during manufacturer interviews held in support of the May 2012 direct final rule. For that rulemaking, DOE interviewed manufacturers representing more than 80 percent of residential dishwasher sales. These interviews were in addition to those DOE conducted as part of the engineering analysis supporting the May 2012 direct final rule.

DOE used these interviews to tailor the GRIM to incorporate unique financial characteristics of the industry. All interviews provided information that DOE used to evaluate the impacts of potential amended energy conservation standards on manufacturer cash flows, manufacturing capacities, and employment levels. See appendix 12-A of this NOPR TSD for additional information on the previous MIA interviews.

#### 12.2.3.2 Manufacturer Subgroup Analysis

Using average cost assumptions to develop an industry-cash-flow estimate may not adequately assess differential impacts of amended energy conservation standards among manufacturer subgroups. For example, small businesses, manufacturers of niche products, or companies exhibiting a cost structure that differs significantly from the industry average could be more negatively affected. While DOE did not identify any other subgroup of manufacturers of residential dishwashers that would warrant a separate analysis, DOE specifically investigated the potential for impacts on small business manufacturers.

#### 12.2.3.3 Small-Business Manufacturer

For manufacturers of residential dishwashers, the Small Business Administration (SBA) has set a size threshold, which defines those entities classified as “small businesses” for the purposes of the statute. DOE used the SBA’s small business size standards as effective January 22, 2014, 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.[a] For the product classes 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.

**Table 12.2.1 SBA and NAICS Classification of Small Businesses Potentially Affected by This Rulemaking**

| Industry Description | Revenue Limit | Employee Limit | NAICS |
|---|---|---|---|
| Other Major Household Appliance Manufacturing | N/A | 500 | 335228 |

DOE conducted a market survey using publicly available information to estimate the number of small businesses on which amended energy conservation standards may have an impact. To identify small business manufacturers of residential dishwashers, DOE surveyed the May 2012 direct final rule, the Association of Home Appliance Manufacturers (AHAM)[1] member directory, several product databases (DOE’s Compliance Certification Database[2], the California Energy Commission (CEC) Appliance Efficiency Database,[3] and the ENERGY STAR[4] database) as well as individual company websites. DOE then checked this list of dishwasher manufacturers against the employee limit for small businesses using reports from vendors such as Dun & Bradstreet. DOE also consulted publicly available data from the SBA to determine the presence of any additional small business manufacturers in the industry. DOE screened out companies that did not themselves manufacture products covered by this rulemaking, did not meet the definition of a “small business,” or are foreign owned and operated.

---

[a] The size standards are available on the SBA’s website at *www.sba.gov/content/table-small-business-size-standards*

During its research, DOE identified no manufacturer of residential dishwashers that meets the small business criteria as specified by the SBA.

#### 12.2.3.4 Manufacturing Capacity Impact

One significant outcome of amended energy conservation standards could be the obsolescence of existing manufacturing assets, including tooling and production equipment. The MIA interviews conducted in support of the May 2012 direct final rule posed a series of questions to help identify impacts of amended standards on manufacturing capacity, specifically capacity utilization and plant location decisions in the United States and North America, with and without amended 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 (PPE). As the efficiency levels considered in this rulemaking do not extend beyond those evaluated in the May 2012 direct final rule, previous manufacturer comments on these topics were used to inform DOE’s analysis of the impact on manufacturing capacity and the estimated capital and product conversion costs. DOE’s discussion of the capacity impact can be found in section 12.7.2., and its estimate of product and capital conversion costs can be found in section 12.4.8.

#### 12.2.3.5 Employment Impact

The impact of amended energy conservation standards on employment is an important consideration in the rulemaking process. The MIA interviews conducted in support of the May 2012 direct final rule posed a series of questions to help identify impacts of amended standards on domestic manufacturing employment. These questions explored employment trends in the residential dishwasher industry focusing on employment levels at each production facility, expected future employment levels with and without amended energy conservation standards, as well as differences in workforce skills and issues related to the retraining of employees. The employment impacts are reported in section 12.7.1.

#### 12.2.3.6 Cumulative Regulatory Burden

DOE seeks to mitigate the overlapping effects on manufacturers due to amended energy conservation standards and other regulatory actions affecting the same products. DOE analyzed the impact on manufacturers of multiple, product-specific regulatory actions. Based on its own research, DOE identified regulations relevant to residential dishwasher manufacturers, such as Federal regulations that impact other products made by the same manufacturers. Discussion of the cumulative regulatory burden can be found in section 12.7.3.

## 12.3 MANUFACTURER IMPACT ANALYSIS KEY ISSUES

For the manufacturer impact analysis in the May 2012 direct final rule, DOE interviewed manufacturers representing more than 80 percent of domestic residential dishwasher sales. These interviews were in addition to those DOE conducted as part of the engineering analysis for the May 2012 direct final rule. These interviews provided information that DOE used to evaluate the impacts of potential amended energy conservation standards on manufacturer cash flows, manufacturing capacities, and employment levels. See appendix 12-A of the NOPR TSD for additional information on the previous MIA interviews.

Each MIA interview started by asking: "What are the key issues for your company regarding the energy conservation standard rulemaking?" This question prompted manufacturers to identify the issues they feel DOE should explore and discuss further during the interview. The following section describes key issues manufacturers identified in interviews supporting the May 2012 direct final rule.

### 12.3.1 Impact on Dishwasher Performance

All manufacturers interviewed expressed concerns about the potential impacts of amended standards on product performance, citing several adverse and possibly severe consequences of standards above those later adopted as standards in the May 2012 direct final rule. For higher efficiency standards, the performance metrics manufacturers expect to be most severely impacted include wash performance, drying performance, cycle time, and the noise levels reached in operation. In considering these metrics, manufacturers anticipated negative reactions ranging from small but meaningful changes in consumer behavior to higher rates of service calls and returns. For efficiency standards well above those later adopted as standards in the May 2012 direct final rule, manufacturers expected blanket rejection of poorly performing products in the market. In considering impacts to wash performance, manufacturers cited an increase in unnecessary rinsing or washing of dishes prior to loading the dishwasher, switching to a more aggressive cycle, and running multiple cycles when dishes are not adequately cleaned in a single cycle as the most likely changes in consumer behavior. Manufacturers went on to suggest that any of these changes would result in an increase in both energy and water consumption over that used by a dishwasher of satisfactory performance. To mitigate the impact of future standards on product performance, several manufacturers recommended the adoption of a performance metric into the test procedure and standard.

While all manufacturers suggested that the efficiency levels specified in the May 2012 direct final rule would not likely have a substantial negative impact on wash performance, some manufacturers noted that standards above these levels would result in a decrease in performance unless substantially higher-cost technology changes were implemented. The comments did not indicate the specific technology changes that would be required. Even without such technology changes, however, several manufacturers already sell products at efficiency levels above those adopted as standards in the 2012 direct final rule, including the max-tech efficiency level. Accordingly, DOE evaluated these efficiency levels as part of this rulemaking.

As noted in chapter 5 of this NOPR TSD, DOE conducted investigative testing and also considered testing conducted in support of developing the ENERGY STAR Test Method for Determining Dishwasher Cleaning Performance (Cleaning Performance Test Method)[b] to consider how energy and water consumption affect cleaning performance. The testing included multiple units from different manufacturers at multiple efficiency levels. Based on this testing, DOE determined that products ranging from the baseline efficiency level to Efficiency Level 3 for standard residential dishwashers are able to maintain cleaning performance.

---

[b] The Cleaning Performance Test Method is available at *https://www.energystar.gov/products/specs/sites/products/files/ENERGY%20STAR%20Final%20Test%20Method%20for%20Determining%20Residential%20Dishwasher%20Cleaning%20Perfor%20%20%20.pdf*

### 12.3.2 Issues with Test Procedures

During interviews conducted in support of the May 2012 direct final rule, manufacturers raised concerns over the DOE dishwasher test procedure and the multitude of additional dishwasher test procedures in the field at that time. Several manufacturers suggested that the DOE test procedure did not accurately capture the energy used by dishwashers in the field. These manufacturers cited the single cycle specification and lack of performance metrics in the test procedure as providing an easy avenue for circumvention of the standards. In the scenario described, manufacturers could optimize a particular cycle to perform well on the DOE test procedure with the implicit understanding that this cycle will not meet customer expectations and thus will not be used in the field as customers opt for a different, more energy-intensive cycle.

In contrast, other manufacturers raised concerns over expanding the test procedure to cover multiple cycles, citing the additional testing burden this would generate. Similarly, some manufacturers raised concerns over how DOE would implement a performance test, noting that there already exist numerous performance tests in the industry including those developed by AHAM, the International Electrotechnical Commission, and Consumer Reports, and that each performance test procedure favors a different machine cycle algorithm.

The DOE test procedure for residential dishwashers is found at Title 10 of the CFR part 430, subpart B, appendix C1. Although appendix C1 does not include provisions for measuring cleaning performance, the ENERGY STAR program recently finalized the Cleaning Performance Test Method, as discussed in chapter 5 of this NOPR TSD. The Cleaning Performance Test Method harmonizes with the procedures in appendix C1, requiring manufacturers to test on the same cycles. DOE expects the Cleaning Performance Test Method, along with the requirement in appendix C1 that testing be conducted on the cycles recommended for completely washing a full load of normally soiled dishes, to prevent manufacturers from circumventing the energy and water consumption tests.

### 12.3.3 Increased Competition

During interviews conducted in support of the May 2012 direct final rule, manufacturers of both baseline and high efficiency products anticipated an increase in competition resulting from amended standards.  While the standard levels in consideration have changed between the 2012 rulemaking and today, many of the competitive pressures still hold. Manufacturers whose market share was largely attributed to baseline products expected to see either the removal of features from higher efficiency units as a means to cut costs to maintain low-cost minimally-compliant product offerings, or the disappearance of entry-level models as other features and cost are added making these units resemble current higher efficiency products. If the latter approach prevails, manufacturers of higher efficiency products expect to see increased competition as manufacturers that previously focused on low efficiency products move into their target segment of the market.

### 12.3.4 Concern over Cumulative Regulatory Burden

During interviews conducted in support of the May 2012 direct final rule, several manufacturers noted that residential dishwashers are but one of a suite of appliances they produce and that the cumulative burden of research and development to meet standards, capital expenditures and retraining of staff to produce products at the new standards, and product testing to certify compliance of new products represent a significant burden when taken in combination across their various product lines. Manufacturers suggested that receiving adequate notice of DOE's plans for amended standards is necessary in mitigating the cumulative burden and aligning changes in efficiency regulations with the product development cycle.

## 12.4 GRIM INPUTS AND ASSUMPTIONS

The GRIM serves as the main tool for assessing the impacts on industry due to amended 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 amended energy conservation standards.

### 12.4.1 Overview of the GRIM

The basic structure of the GRIM, illustrated in Figure 12.4.1, 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, 2014, and continuing to 2048. The model calculates the INPV by summing the annual discounted cash flows during this period.[5]

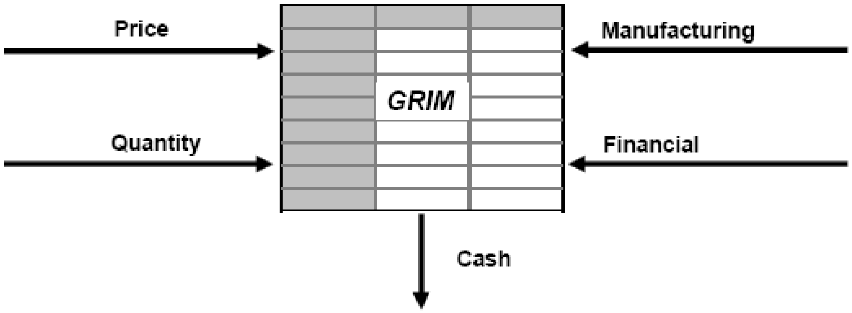


**Figure 12.4.1 Using the GRIM to Calculate Cash Flow**

The GRIM projects cash flows using standard accounting principles and compares changes in INPV between the base-case and the standard-case scenarios induced by amended energy conservation standards including changes in costs, investments, and associated margins. The difference in INPV between the base case and the standard case(s) represents the estimated financial impact of the amended energy conservation standards on manufacturers. Appendix 12-B of the NOPR TSD provides more technical details and user information for the GRIM.

### 12.4.2 Sources for GRIM Inputs

The GRIM uses several different sources for data inputs in determining industry cash flow. These sources include the manufacturer interviews and financial inputs in support of the May 2012 direct final rule, U.S. Census data, the shipments model, and the engineering analysis.

#### 12.4.2.1 Corporate Annual Reports

The financial parameters used in the GRIM are the same as those developed for the May 2012 direct final rule. These were developed using corporate annual reports for publicly held companies, which 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 for the May 2012 direct final rule by examining the publicly available annual reports of companies primarily engaged in the manufacture of home appliances whose combined product range includes residential dishwashers. 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 residential dishwashers. These figures were later revised using feedback from interviews to be representative of manufacturing for each product. 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 property, plant, and equipment (PPE).

#### 12.4.2.2 Standard and Poor 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 for the May 2012 direct final rule. This same weighted average cost of capital was used in the GRIM prepared for the present proposal.

#### 12.4.2.3 Shipment Model

The GRIM used shipment projections derived from DOE's shipments model in the national impact analysis (NIA). The model relied on historical shipments data for residential dishwashers. Chapter 10 of the NOPR TSD describes the methodology and analytical model DOE used to forecast shipments.

#### 12.4.2.4 Engineering Analysis

DOE conducted the engineering analysis for this rulemaking using a hybrid approach of the efficiency-level, design-option, and cost-assessment approaches. DOE used a manufacturing cost model to develop manufacturer production cost (MPC) estimates for each efficiency level of each product class of residential dishwashers. The analysis yielded the labor, materials, overhead, depreciation, and total production costs for products at each efficiency level. Chapter 5 of the NOPR TSD describes the engineering analysis in greater detail.

#### 12.4.2.5 Manufacturer Interviews

DOE relied on information gathered during interviews conducted in support of the May 2012 direct final rule. For that rulemaking, DOE interviewed manufacturers representing more than 80 percent of residential dishwasher sales. 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 PPE);
- 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 shipment and shipment distribution mix; and
- MPCs estimated in the engineering analysis.

### 12.4.3 Financial Parameters

In the previous manufacturer interviews, DOE used the financial parameters from 2003 to 2010 for four appliance manufacturers with a combined market share of over 90 percent as a starting point for determining the residential dishwasher industry financial parameters. The industry financial parameters were determined by weighting each manufacturer's individual financial parameters by their respective market share, and correcting for the fraction of the market that was not represented. Table 12.4.1 below shows the data used to determine the initial financial parameter estimates.

**Table 12.4.1 GRIM Financial Parameters based on 2003–2010 Weighted Company Financial Data**

| Parameter | Industry-Weighted Average | Manufacturer | | | |
|---|---|---|---|---|---|
| | | A | B | C | D |
| **Tax Rate** ***(% of Taxable Income)*** | 33.3 | 42.6 | 25.4 | 14.0 | 30.7 |
| **Working Capital** ***(% of Revenue)*** | 7.0 | 11.9 | 20.7 | 3.8 | 3.9 |
| **SG&A** ***(% of Revenue)*** | 13.3 | 17.8 | 24.3 | 13.1 | 10.4 |
| **R&D** ***(% of Revenues)*** | 2.3 | 1.8 | 2.8 | 2.8 | 2.4 |
| **Depreciation** ***(% of Revenues)*** | 3.1 | 2.8 | 3.4 | 2.2 | 3.1 |
| **Capital Expenditures** ***(% of Revenues)*** | 3.2 | 3.1 | 4.2 | 2.6 | 3.2 |
| **Net Property, Plant, and Equipment** ***(% of Revenues)*** | 16.7 | 14.4 | 16.3 | 20.9 | 17.6 |

During interviews, manufacturers were asked to provide their own figures for the parameters listed in Table 12.4.1. DOE adjusted the tax rate, depreciation and capital expenditures according to the manufacturers' feedback.

### 12.4.4 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 residential dishwasher industry based on several representative companies, using the following formula:

WACC = After-Tax Cost of Debt x (Debt Ratio) + Cost of Equity x (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 + $\beta$ x 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. As the risk-free rate was estimated in 2011, DOE used the average 10-year T-Bill return between 1928 and 2010. The resulting risk-free rate was estimated to be approximately 5.2 percent. *Risk premium* is the difference between the expected return on stocks and the risk-free rate of return. As with the risk-free rate, DOE used the average annual return on the S&P 500 between 1928 and 2010 as the expected return on stocks to arrive at an estimated market risk premium of 6.1 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 three publicly traded dishwasher manufacturers whose combined market share is over 90 percent. DOE determined that the industry-average cost of equity for the residential dishwasher industry is 16.7 percent (see Table 12.4.2).

**Table 12.4.2 Cost of Equity Calculation**

| **Parameter** | **Industry-Weighted Average %** | **Manufacturer** | | | |
|---|---|---|---|---|---|
| | | A | B | C | D |
| **(1) Average Beta** | 1.9 | 1.5 | n/a | 1.7 | 2.0 |

| | | | | | |
|---|---|---|---|---|---|
| **(2) Yield on 10-Year T-Bill (1928–2010)** | 5.2 | - | - | - | - |
| **(3) Market Risk Premium (1928–2010)** | 6.1 | - | - | - | - |
| **Cost of Equity (2)+[(1)*(3)]** | 16.7 | 14.4 | n/a | 15.5 | 17.5 |
| **Equity/Total Capital** | 68.6 | 71.0 | 86.5 | 92.7 | 65.8 |

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 three manufacturers by using S&P ratings and adding the relevant spread to the risk-free rate.

Since 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 residential dishwasher industry is 4.5 percent. Table 12.4.3 presents the derivation of the cost of debt and the capital structure of the industry (*i.e.* the debt ratio (debt/total capital)).

**Table 12.4.3 Cost of Debt Calculation**

| **Parameter** | **Industry-Weighted Average %** | **Manufacturer** | | | |
|---|---|---|---|---|---|
| | | A | B | C | D |
| **S&P Bond Rating** | -- | BBB | A | AA | BBB |
| **(1) Yield on 10-Year T-Bill (1928–2010)** | 5.2 | - | - | - | - |
| **(2) Gross Cost of Debt** | 6.8 | 6.8 | 6.2 | 5.9 | 6.8 |
| **(3) Tax Rate** | 33.3 | 42.6 | 25.4 | 14.0 | 30.7 |
| **Net Cost of Debt [(2) x ((1)-(3))]** | 4.5 | - | - | - | - |
| **Debt/Total Capital** | 31.4 | 29.0 | 13.5 | 7.3 | 34.2 |

Correcting for an inflation rate of 3.1 percent over the analysis period, DOE's calculated value for the residential dishwasher industry's inflation-adjusted WACC and the initial estimate of the discount rate is 8.1 percent. DOE adjusted this figure to 8.5 percent for the GRIM based on feedback received during manufacturer interviews conducted in support of the May 2012 direct final rule.

### 12.4.5 Trial Standard Levels

DOE developed TSLs to analyze the impact on manufacturers of amended energy efficiency standards for two product classes of residential dishwashers—standard dishwashers and compact dishwashers. Table 12.4.4 presents the TSLs and the corresponding product class efficiency levels based on estimated annual energy use (EAEU) and water consumption (WC) according to the current test procedure (10 CFR part 430, subpart B, appendix C1).

TSL 3 represents the maximum technologically feasible ("max-tech") improvements in energy efficiency for all residential dishwashers. TSL 2 consists of the next efficiency level below the max-tech level for both standard-size and compact dishwashers. The efficiency levels in TSL 1 correspond to the ENERGY STAR efficiency level for both standard size and compact dishwashers. The baseline efficiency level for compact products corresponds to the ENERGY STAR specifications for those products.

**Table 12.4.4 Trial Standard Levels for Residential Dishwashers**

| Product Class | | Baseline | TSL 1 | TSL 2 | TSL 3 |
|---|---|---|---|---|---|
| Standard Dishwashers | **Efficiency Level** | Baseline | EL 1 | EL 3 | EL 4 |
| | **EAEU *(%)*** | 307 | 295 | 234 | 180 |
| | **WC *(gal/cycle)*** | 5.00 | 4.25 | 3.10 | 2.22 |
| Compact Dishwashers | **Efficiency Level** | Baseline | Baseline | EL 1 | EL 2 |
| | **EAEU *(%)*** | 222 | 222 | 203 | 141 |
| | **WC *(gal/cycle)*** | 3.50 | 3.50 | 3.10 | 2.00 |

### 12.4.6 NIA Shipment Forecast

The GRIM estimates manufacturer revenues based on total-unit-shipment 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 residential dishwasher shipment data from the NIA. Chapter 10 of the NOPR TSD explains DOE’s calculations of total shipments in detail. Table 12.4.5 shows total shipments forecasts for residential dishwashers in 2019.

**Table 12.4.5 Total Base-Case 2018 NIA Shipments in the Reference NIA Shipment Scenario**

| Product Class | Total Industry Shipments |
|---|---|
| **Standard Dishwashers** | 7,399,221 |
| **Compact Dishwashers** | 44,478 |

#### 12.4.6.1 Base-Case Shipments Forecast

As part of the shipment analysis, DOE estimated the shipment distribution by efficiency level for residential dishwashers. As described in chapter 10 of the NOPR TSD, DOE’s shipment forecast indicates a trend toward higher efficiency products over the forecast period. Table 12.4.6 shows the 2019 base-case distributions of shipments by efficiency level estimated in the NIA for the residential dishwasher product classes.

**Table 12.4.6 Base-Case Distribution of Efficiencies for Residential Dishwashers in 2019**

| Product Class | | Baseline | EL 1 | EL 2 | EL 3 | EL 4 |
|---|---|---|---|---|---|---|
| **Standard Dishwashers** | **EAEU** | 307 | 295 | 280 | 234 | 180 |
| | **% of the Market at EL** | 12.1 | 43.9 | 40.3 | 3.2 | 0.4 |
| **Compact Dishwashers** | **EAEU** | 222 | 203 | 141 | | |
| | **% of the Market at EL** | 48.2 | 14.8 | 37.0 | | |

### 12.4.6.2 Standards-Case Shipments Forecast

To examine the impact of amended energy conservation standards on shipments, which in turn affect the INPV, DOE used the base-case shipments described in the previous section as a point of comparison for shipments forecast in the standards case. For each TSL described in the standards case, DOE used the shipments forecasts developed in the NIA for residential dishwashers. DOE used a roll-up scenario to determine efficiency distributions for the standards case. In this scenario, products that fall below the amended energy conservation standards are assumed to "roll-up" to the new standards on the compliance date and thereafter.

Additionally, as in the shipments analysis, DOE assumed there was relative price elasticity of -0.34 in the residential dishwasher market, meaning that amended energy conservation standards that increase the first cost of residential dishwashers would result in lower total shipments.

## 12.4.7 Production Costs

Changes in the MPCs of residential dishwashers can affect revenues, gross margins, and cash flow of the industry, making these product cost data key GRIM inputs for DOE's analysis. In the engineering analysis, DOE created separate cost curves for standard and compact product classes using data from tear-downs to develop both the baseline MPCs and the incremental costs that correspond to the design options DOE expects manufacturers would incorporate at each efficiency level. Generally, manufacturing higher efficiency products is more costly than manufacturing baseline products due to the use of more complex components and higher-cost raw materials.

The cost model disaggregated the MPCs at each efficiency level into material, labor, overhead, and depreciation. For materials, DOE used the incremental component and raw material costs that correspond to the proposed design options at each efficiency level. For labor, DOE estimated the labor contribution at each efficiency level by examining how the proposed design options may influence manufacturing and assembly practices. For depreciation, DOE used a depreciation value that is consistent with historical information in SEC 10-Ks. The remainder of total overhead was allocated to factory overhead.

DOE used the resulting MPCs and cost breakdowns as described in section 12.4.2.4 above, and further detailed in chapter 5 of the NOPR TSD, for each efficiency level analyzed in the GRIM.

The MSP is comprised of production costs (the direct manufacturing costs or MPCs), non-production costs (indirect costs like SG&A), and profit. DOE calculated the MSPs for residential dishwashers by multiplying the MPCs by the manufacturer markup described in chapter 6 of this NOPR TSD. Table 12.4.7 and Table 12.4.8 show the production cost estimates used in the GRIM for the representative product classes for residential dishwashers.

**Table 12.4.7 MSP Breakdown for Standard Dishwashers**

| **EL** | **EAEU *(kWh/year)*** | **Material** | **Labor** | **Depreciation** | **Overhead** | **MPC** | **Mfr. Markup** | **MSP** |
|---|---|---|---|---|---|---|---|---|
| Baseline | 307 | $116.94 | $41.36 | $12.63 | $32.80 | $203.72 | 1.24 | $252.61 |
| EL 1 | 295 | $122.83 | $42.43 | $13.22 | $34.76 | $213.24 | 1.24 | $264.42 |
| EL 2 | 280 | $140.07 | $49.73 | $14.90 | $35.56 | $240.25 | 1.24 | $297.91 |
| EL 3 | 234 | $177.37 | $48.45 | $17.26 | $35.36 | $278.44 | 1.24 | $345.27 |
| EL 4 | 180 | $177.37 | $48.45 | $17.26 | $35.36 | $278.44 | 1.24 | $345.27 |

**Table 12.4.8 MSP Breakdown for Compact Dishwashers**

| **EL** | **EAEU *(kWh/year)*** | **Material** | **Labor** | **Depreciation** | **Overhead** | **MPC** | **Mfr. Markup** | **MSP** |
|---|---|---|---|---|---|---|---|---|
| Baseline | 222 | $128.37 | $29.65 | $11.64 | $18.02 | $187.68 | 1.24 | $232.72 |
| EL 1 | 203 | $130.72 | $33.85 | $12.13 | $18.98 | $195.69 | 1.24 | $242.66 |
| EL 2 | 141 | $143.71 | $32.63 | $12.97 | $19.87 | $209.19 | 1.24 | $259.40 |

## 12.4.8 Conversion Costs

Amended energy conservation standards typically cause manufacturers to incur one-time conversion costs to redesign products to comply with amended standards and upgrade production facilities to manufacture compliant products. For the MIA, DOE classified these one-time conversion costs into two major groups: capital conversion costs and product conversion costs. Capital conversion costs are investments in property, plant, and equipment necessary to adapt or change existing production facilities so that newly compliant product designs can be fabricated and assembled. Product conversion costs are investments in research, development, testing, marketing, and other non-capitalized costs focused on designing products that comply with the amended energy conservation standard. These one-time conversion costs are separate and do not directly impact the manufacturer production cost as described in chapter 5 of the NOPR TSD. The following sections describe these inputs in greater detail.

### 12.4.8.1 Residential Dishwasher Product and Capital Conversion Costs

DOE scaled the product and capital conversion cost estimates developed for the May 2012 direct final rule to reflect the new efficiency levels for each product class considered in this NOPR.

Additionally, DOE developed a separate capital conversion cost scenario using the engineering cost model. For this estimate, DOE identified the design pathways considered in the engineering analysis, estimated the cost of the changes in production equipment to implement each design option, and aggregated these costs to reflect the industry-wide investment using market information about the number of platform and product families currently on the market from each manufacturer. DOE estimated the number of standard and compact platforms using publicly available information from manufacturer websites and product databases.

Table 12.4.9 and Table 12.4.10 show DOE's estimates of the product and capital conversion costs necessary for both residential dishwasher product classes at each efficiency level.

**Table 12.4.9 Product and Capital Conversion Costs for Standard Dishwashers**

| **EL** | **EAEU** ***(kWh/year)*** | **Design Options Considered** | **Product Conversion Costs** ***(Based on 2012 Rulemaking - 2013$ millions)*** | **Capital Conversion Costs** ***(Based on May 2012 Direct Final Rule - 2013$ millions)*** | **Capital Conversion Costs** ***(Based on 2014 Engineering Cost Model - 2013$ millions)*** |
|---|---|---|---|---|---|
| Baseline | 307 | | $0.0 | $0.0 | $0.0 |
| EL 1 | 295 | Electronic controls<br>Multiple Spray Arms<br>Improved Water Filters<br>Separate Drain Pump<br>Tub Insulation | $38.3 | $79.2 | $35.4 |
| EL 2 | 280 | Improved Control Strategies<br>Soil Sensing<br>Hydraulic System Improvements | $45.3 | $110.0 | $48.4 |
| EL 3 | 234 | Improved Control Strategies<br>Temperature Sensor<br>Flow Meter<br>Water Diverter Assembly<br>Improved Water Filters<br>Hydraulic System Optimization<br>Heater Integrated to Pump<br>Condensation Drying | $58.0 | $165.9 | $191.2 |
| EL 4 | 180 | Improved Control Strategies | $75.6 | $228.8 | $191.2 |

**Table 12.4.10 Product and Capital Conversion Costs for Compact Dishwashers**

| EL | EAEU *(kWh/year)* | Design Options Considered | Product Conversion Costs *(Based on 2012 Rulemaking - 2013$ millions)* | Capital Conversion Costs *(Based on 2012 Rulemaking - 2013$ millions)* | Capital Conversion Costs *(Based on 2014 Engineering Cost Model - 2013$ millions)* |
|---|---|---|---|---|---|
| Baseline | 222 | | $0.0 | $0.0 | $0.0 |
| EL 1 | 203 | Permanent Magnet Motor<br>Reduced Sump Volume<br>Improved Controls<br>Tub Insulation | $3.7 | $6.1 | $28.5 |
| EL 2 | 141 | Permanent Magnet Motor<br>Hydraulic System Optimization<br>Optimized Control Systems<br>Tub Insulation<br>Improved Filters<br>Heater Incorporated into Tub Base | $4.6 | $7.9 | $44.9 |

## 12.4.9 Markup Scenarios

MSP is equal to MPC times a manufacturer markup. The MSP includes direct manufacturing production costs (*i.e.,* labor, material, and overhead estimated in DOE's MPCs) and all non-production costs (*i.e.,* SG&A, R&D, and interest), along with profit.

DOE used the same baseline markup described in the markups analysis (chapter 6 of this NOPR TSD) and used for the May 2012 direct final rule for all product classes. This was calculated by evaluating publicly available financial information for manufacturers of major household appliances whose product offerings include residential dishwashers. During manufacturer interviews conducted in support of the May 2012 direct final rule, DOE received feedback supporting the calculated 1.24 baseline manufacturer markup. For both GRIM markup scenarios, DOE assumed a predominantly flat markup structure, placing no premium on higher efficiency products. This assumption is informed by a market structure in which nearly 88 percent of products currently adhere to ENERGY STAR standards, leaving little to no room for differentiation by efficiency level alone.

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 amended energy conservation standards: (1) a preservation of gross margin markup scenario, and (2) a preservation of earnings before interest and taxes (EBIT) markup scenario. Modifying these markups from the base case to the standards cases yields different sets of impacts on manufacturers by changing industry revenue and cash flow.

#### 12.4.9.1 Preservation of Gross Margin Markup Scenario

The preservation of gross margin markup scenario assumes that the baseline markup of 1.24 is maintained for all products in the standards case. This represents the upper bound of industry profitability as manufacturers are able to fully pass through additional costs due to standards to their customers in this scenario.

#### 12.4.9.2 Preservation of EBIT Markup Scenario

DOE also modeled the preservation of EBIT markup scenario to estimate a lower bound of profitability for the industry. This is similar to the preservation of gross margin 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 matching the EBIT per unit in the year standards go into effect with the EBIT per unit in the same year in the base case. This scenario represents a more substantial impact to the dishwasher industry as manufacturers vie to maintain the lowest possible prices for entry level products while securing the same level of EBIT they saw prior to amended standards.

Table 12.4.11 through Table 12.4.14 list the products DOE analyzed with the corresponding markups at each TSL for residential dishwashers.

**Table 12.4.11 Preservation of Gross Margin Markups for Standard Dishwashers**

| **EL (EAEU)** | **Markups by TSL** | | | |
|---|---|---|---|---|
| | **Baseline** | **TSL 1** | **TSL 2** | **TSL 3** |
| Baseline (307) | 1.240 | | | |
| EL 1 (295) | 1.240 | 1.240 | | |
| EL 2 (280) | 1.240 | 1.240 | | |
| EL 3 (234) | 1.240 | 1.240 | 1.240 | |
| EL 4 (180) | 1.240 | 1.240 | 1.240 | 1.240 |

**Table 12.4.12 Preservation of EBIT Markups for Standard Dishwashers**

| **EL (EAEU)** | **Markups by TSL** | | | |
|---|---|---|---|---|
| | **Baseline** | **TSL 1** | **TSL 2** | **TSL 3** |
| Baseline (307) | 1.240 | | | |
| EL 1 (295) | 1.240 | 1.239 | | |
| EL 2 (280) | 1.240 | 1.240 | | |
| EL 3 (234) | 1.240 | 1.240 | 1.230 | |
| EL 4 (180) | 1.240 | 1.240 | 1.240 | 1.230 |

**Table 12.4.13 Preservation of Gross Margin Markups for Compact Dishwashers**

| EL (EAEU) | Markups by TSL | | | |
|---|---|---|---|---|
| | Baseline | TSL 1 | TSL 2 | TSL 3 |
| Baseline (222) | 1.240 | 1.240 | | |
| EL 1 (203) | 1.240 | 1.240 | 1.240 | |
| EL 2 (141) | 1.240 | 1.240 | 1.240 | 1.240 |

**Table 12.4.14 Preservation of EBIT Markups for Compact Dishwashers**

| EL (EAEU) | Markups by TSL | | | |
|---|---|---|---|---|
| | Baseline | TSL 1 | TSL 2 | TSL 3 |
| Baseline (222) | 1.240 | 1.240 | | |
| EL 1 (203) | 1.240 | 1.240 | 1.238 | |
| EL 2 (141) | 1.240 | 1.240 | 1.240 | 1.237 |

## 12.5 INDUSTRY FINANCIAL IMPACTS

Using the inputs and scenarios described in the previous sections, DOE used the GRIM to estimate the financial impacts on the residential dishwasher industry. The MIA uses two key financial metrics: INPV and annual cash flows. The main results of the MIA are reported in this section.

### 12.5.1 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 dishwasher manufacturing industry, and is the sum of all net cash flows discounted to the present year at the industry’s cost of capital. The GRIM for the residential dishwasher industry models cash flows from 2014 to 2048. This timeframe models both the short-term impacts on the industry from the announcement of the standard until the compliance date, and a long-term assessment over the 30-year analysis period immediately thereafter.

In the MIA, DOE compares the INPV of the base case (no amended energy conservation standards) to that of each TSL in the standards case. The difference between the base case and a standards case INPV is an estimate of the economic impact that implementing that particular TSL would have on the industry. For the residential dishwasher industry, DOE examined the two markup scenarios described above: the preservation of gross margin markup scenario and the preservation of EBIT markup scenario. While INPV is useful for evaluating the long-term effects of amended 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 access to capital. 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 does not capture. To get an idea of the behavior of annual net cash flows, Figure 12.5.1 and Figure 12.5.2 below present the annual free cash flows from 2014 through 2048 for the base case and each TSL in the standards case.

Annual cash flows are discounted to the base year, 2014. Between 2014 and the 2019 compliance date, annual 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 decline as companies use their financial resources to prepare for the amended energy conservation standard. The more stringent the amended 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 inflows from operations and capital conversion costs increase cash outflows for capital expenditures.

Free cash flow in the year the amended energy conservation standards take effect is driven by two competing factors. In addition to capital and product conversion costs, amended energy conservation standards could create stranded assets, *i.e.*, 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 undepreciated book value of existing tooling and equipment rendered obsolete by the amended energy conservation standard. This one time write down acts as a tax shield that alleviates 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 products with more expensive components, 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 markup scenario, more stringent TSLs typically have a positive impact on cash flows relative to the base case because manufacturers are able to earner higher operating profit at each TSL in the standards case, which increases cash flow from operations. There is very little impact on cash flow from operations under the preservation of EBIT scenario because this scenario is calibrated to have the same EBIT in the standards case as in the base case in the year after the standard takes effect. In this scenario, production costs increase, but EBIT remains approximately equal to the base case, effectively decreasing profit margins as a percentage of revenue.

### 12.5.2 Residential Dishwasher Industry Financial Impacts

The tables in this section provide the INPV estimates for the residential dishwashers for each combination of markup scenario and conversion cost scenario. Additionally, these impacts are presented for the industry as a whole, as well as both product classes individually. Figure 12.5.1 through Figure 12.5.4, present the annual net cash flows for all residential dishwasher manufacturing for each combination of markup scenario and conversion cost scenario.

### Table 12.5.1 Manufacturer Impact Analysis for All Residential Dishwashers – Preservation of Gross Margin Markup Scenario with Scaled Capital Conversion Costs from the 2012 Rulemaking.

| | | Base Case | Trial Standard Level | | |
|---|---|---|---|---|---|
| | | | 1 | 2 | 3 |
| **INPV** | ***(2013$ millions)*** | $586.6 | $507.3 | $483.0 | $426.0 |
| **Change in INPV** | ***(2013$ millions)*** | - | $(79.2) | $(103.6) | $(160.5) |
| | ***(%)*** | - | (13.5%) | (17.7%) | (27.4%) |

*For tables in section 12.5, values in parenthesis indicate negative numbers

### Table 12.5.2 Manufacturer Impact Analysis for All Residential Dishwashers – Preservation of EBIT Markup Scenario with Scaled Capital Conversion Costs from the 2012 Rulemaking.

| | | Base Case | Trial Standard Level | | |
|---|---|---|---|---|---|
| | | | 1 | 2 | 3 |
| **INPV** | ***(2013$ millions)*** | $586.6 | $506.1 | $404.2 | $346.8 |
| **Change in INPV** | ***(2013$ millions)*** | - | $(80.5) | $(182.3) | $(239.8) |
| | ***(%)*** | - | (13.7%) | (31.1%) | (40.9%) |

*For tables in section 12.5, values in parenthesis indicate negative numbers

### Table 12.5.3 Manufacturer Impact Analysis for All Residential Dishwashers – Preservation of Gross Margin Markup Scenario with Capital Conversion Costs from the 2014 Engineering Cost Model.

| | | Base Case | Trial Standard Level | | |
|---|---|---|---|---|---|
| | | | 1 | 2 | 3 |
| **INPV** | ***(2013$ millions)*** | $586.6 | $543.1 | $465.2 | $445.5 |
| **Change in INPV** | ***(2013$ millions)*** | - | $(43.5) | $(121.4) | $(141.1) |
| | ***(%)*** | - | (7.4%) | (20.7%) | (24.0%) |

*For tables in section 12.5, values in parenthesis indicate negative numbers

### Table 12.5.4 Manufacturer Impact Analysis for All Residential Dishwashers – Preservation of EBIT Markup Scenario with Capital Conversion Costs from the 2014 Engineering Cost Model.

| | | Base Case | Trial Standard Level | | |
|---|---|---|---|---|---|
| | | | 1 | 2 | 3 |
| **INPV** | ***(2013$ millions)*** | $586.6 | $541.8 | $382.9 | $362.6 |
| **Change in INPV** | ***(2013$ millions)*** | - | $(44.7) | $(203.7) | $(224.0) |
| | ***(%)*** | - | (7.6%) | (34.7%) | (38.2%) |

*For tables in section 12.5, values in parenthesis indicate negative numbers

### Table 12.5.5 Manufacturer Impact Analysis for Standard Residential Dishwashers – Preservation of Gross Margin Markup Scenario with Scaled Capital Conversion Costs from the 2012 Rulemaking.

| | | **Base Case** | **Trial Standard Level** | | |
|---|---|---|---|---|---|
| | | | **1** | **2** | **3** |
| **INPV** | ***(2013$ millions)*** | $583.6 | $504.4 | $486.5 | $431.3 |
| **Change in INPV** | ***(2013$ millions)*** | - | $(79.2) | $(97.1) | $(152.2) |
| | ***(%)*** | - | (13.6%) | (16.6%) | (26.1%) |

*For tables in section 12.5, values in parenthesis indicate negative numbers

### Table 12.5.6 Manufacturer Impact Analysis for Standard Residential Dishwashers – Preservation of EBIT Markup Scenario with Scaled Capital Conversion Costs from the 2012 Rulemaking.

| | | **Base Case** | **Trial Standard Level** | | |
|---|---|---|---|---|---|
| | | | **1** | **2** | **3** |
| **INPV** | ***(2013$ millions)*** | $583.6 | $503.1 | $407.8 | $352.2 |
| **Change in INPV** | ***(2013$ millions)*** | - | $(80.5) | $(175.8) | $(231.4) |
| | ***(%)*** | - | (13.8%) | (30.1%) | (39.6%) |

*For tables in section 12.5, values in parenthesis indicate negative numbers

### Table 12.5.7 Manufacturer Impact Analysis for Standard Residential Dishwashers – Preservation of Gross Margin Markup Scenario with Capital Conversion Costs from the 2014 Engineering Cost Model.

| | | **Base Case** | **Trial Standard Level** | | |
|---|---|---|---|---|---|
| | | | **1** | **2** | **3** |
| **INPV** | ***(2013$ millions)*** | $583.6 | $540.1 | $485.9 | $479.2 |
| **Change in INPV** | ***(2013$ millions)*** | - | $(43.5) | $(97.7) | $(104.4) |
| | ***(%)*** | - | (7.4%) | (16.7%) | (17.9%) |

*For tables in section 12.5, values in parenthesis indicate negative numbers

### Table 12.5.8 Manufacturer Impact Analysis for Standard Residential Dishwashers – Preservation of EBIT Markup Scenario with Capital Conversion Costs from the 2014 Engineering Cost Model.

| | | **Base Case** | **Trial Standard Level** | | |
|---|---|---|---|---|---|
| | | | **1** | **2** | **3** |
| **INPV** | ***(2013$ millions)*** | $583.6 | $538.8 | $403.6 | $396.4 |
| **Change in INPV** | ***(2013$ millions)*** | - | $(44.7) | $(180.0) | $(187.2) |
| | ***(%)*** | - | (7.7%) | (30.8%) | (32.1%) |

*For tables in section 12.5, values in parenthesis indicate negative numbers

### Table 12.5.9 Manufacturer Impact Analysis for Compact Residential Dishwashers – Preservation of Gross Margin Markup Scenario with Scaled Capital Conversion Costs from the 2012 Rulemaking.

| | | Base Case | Trial Standard Level | | |
|---|---|---|---|---|---|
| | | | 1 | 2 | 3 |
| **INPV** | ***(2013$ millions)*** | $3.0 | $3.0 | $(4.2) | $(6.2) |
| **Change in INPV** | ***(2013$ millions)*** | - | - | $(7.2) | $(9.2) |
| | ***(%)*** | - | - | (241.2%) | (308.6%) |

*For tables in section 12.5, values in parenthesis indicate negative numbers

### Table 12.5.10 Manufacturer Impact Analysis for Compact Residential Dishwashers – Preservation of EBIT Markup Scenario with Scaled Capital Conversion Costs from the 2012 Rulemaking.

| | | Base Case | Trial Standard Level | | |
|---|---|---|---|---|---|
| | | | 1 | 2 | 3 |
| **INPV** | ***(2013$ millions)*** | $3.0 | $3.0 | $(4.2) | $(6.3) |
| **Change in INPV** | ***(2013$ millions)*** | - | - | $(7.2) | $(9.3) |
| | ***(%)*** | - | - | (242.2%) | (311.9%) |

*For tables in section 12.5, values in parenthesis indicate negative numbers

### Table 12.5.11 Manufacturer Impact Analysis for Compact Residential Dishwashers – Preservation of Gross Margin Markup Scenario with Capital Conversion Costs from the 2014 Engineering Cost Model.

| | | Base Case | Trial Standard Level | | |
|---|---|---|---|---|---|
| | | | 1 | 2 | 3 |
| **INPV** | ***(2013$ millions)*** | $3.0 | $3.0 | $(21.3) | $(34.6) |
| **Change in INPV** | ***(2013$ millions)*** | - | - | $(24.3) | $(37.6) |
| | ***(%)*** | - | - | (817.4%) | (1261.9%) |

*For tables in section 12.5, values in parenthesis indicate negative numbers

### Table 12.5.12 Manufacturer Impact Analysis for Compact Residential Dishwashers – Preservation of EBIT Markup Scenario with Capital Conversion Costs from the 2014 Engineering Cost Model.

| | | Base Case | Trial Standard Level | | |
|---|---|---|---|---|---|
| | | | 1 | 2 | 3 |
| **INPV** | ***(2013$ millions)*** | $3.0 | $3.0 | $(21.4) | $(34.7) |
| **Change in INPV** | ***(2013$ millions)*** | - | - | $(24.4) | $(37.7) |
| | ***(%)*** | - | - | (818.5%) | (1265.4%) |

*For tables in section 12.5, values in parenthesis indicate negative numbers

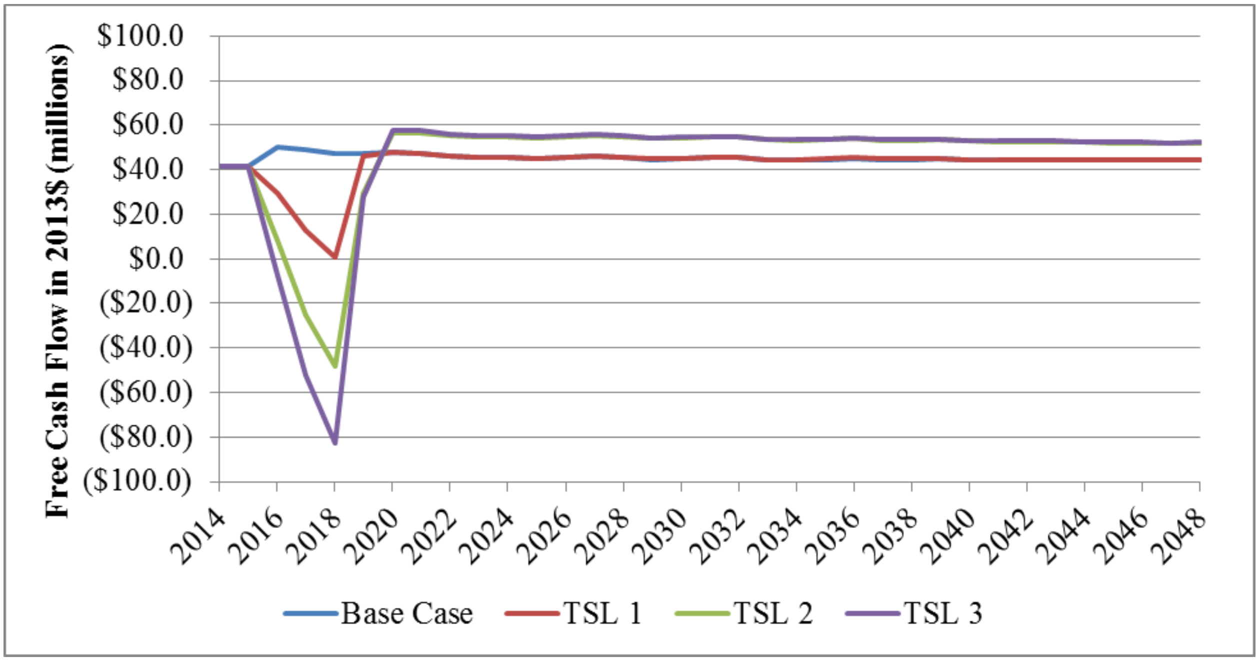


**Figure 12.5.1 Industry Annual Free Cash Flows for All Residential Dishwashers - Preservation of Gross Margin Markup Scenario with Scaled Capital Conversion Costs from the 2012 Rulemaking.**

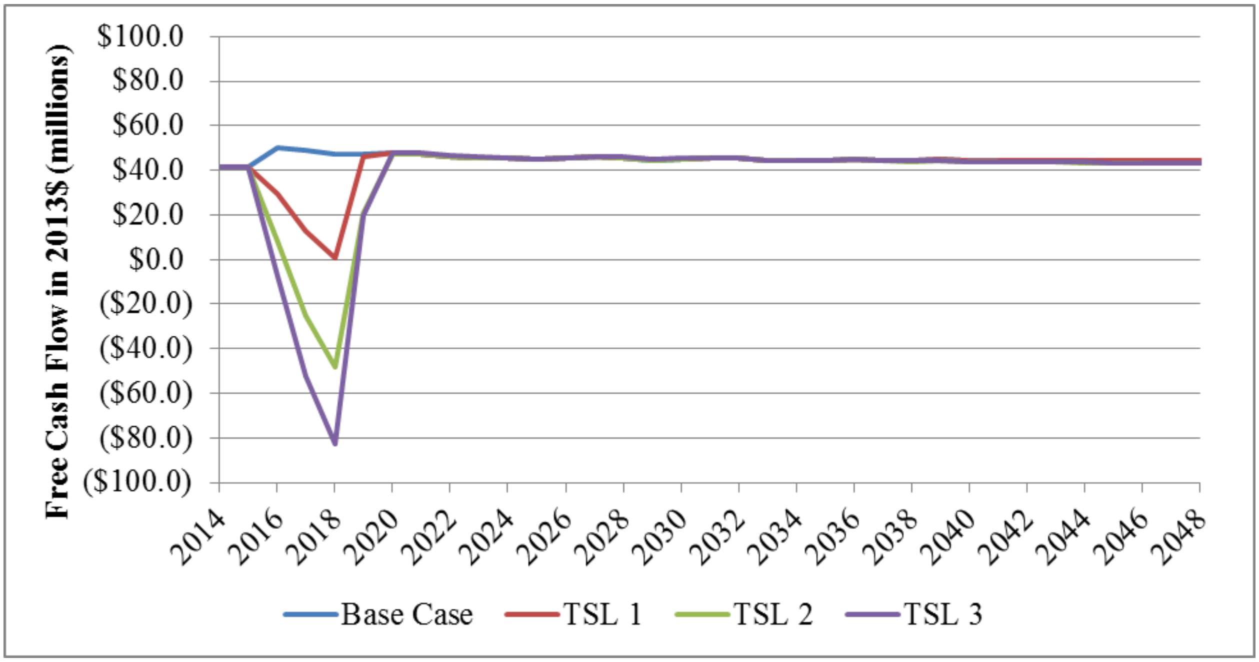


**Figure 12.5.2 Industry Annual Free Cash Flows for All Residential Dishwashers - Preservation of EBIT Markup Scenario with Scaled Capital Conversion Costs from the 2012 Rulemaking.**

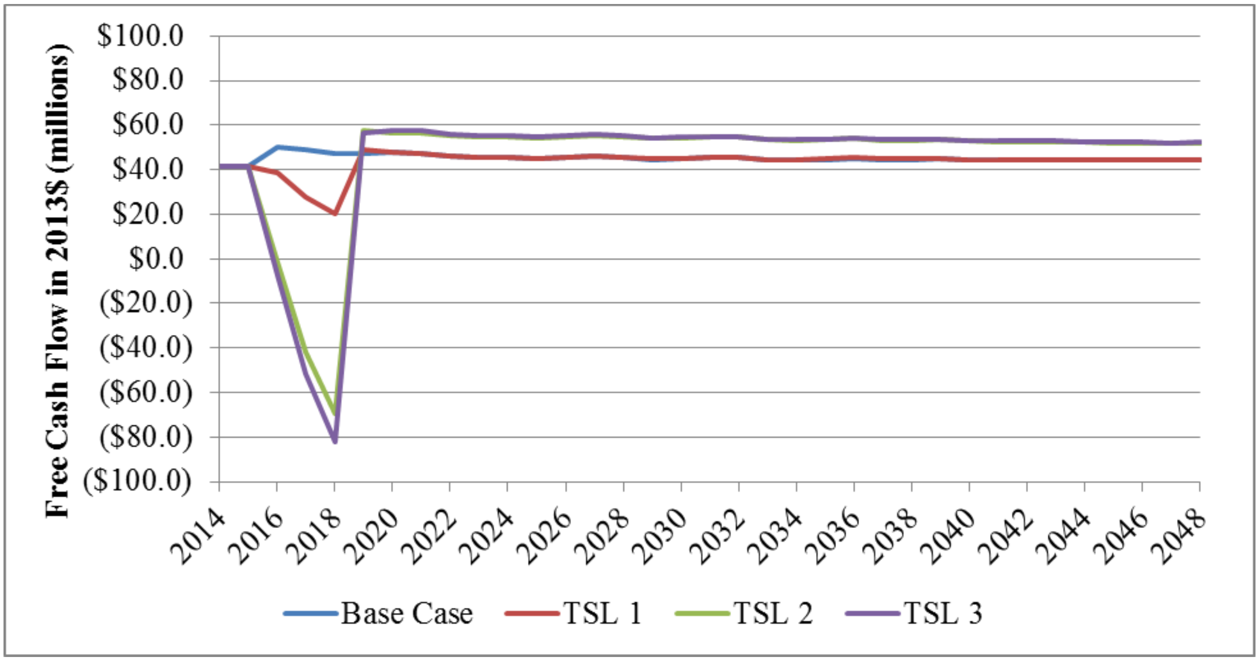


**Figure 12.5.3 Industry Annual Free Cash Flows for All Residential Dishwashers - Preservation of Gross Margin Markup Scenario with Capital Conversion Costs from the 2014 Engineering Cost Model.**

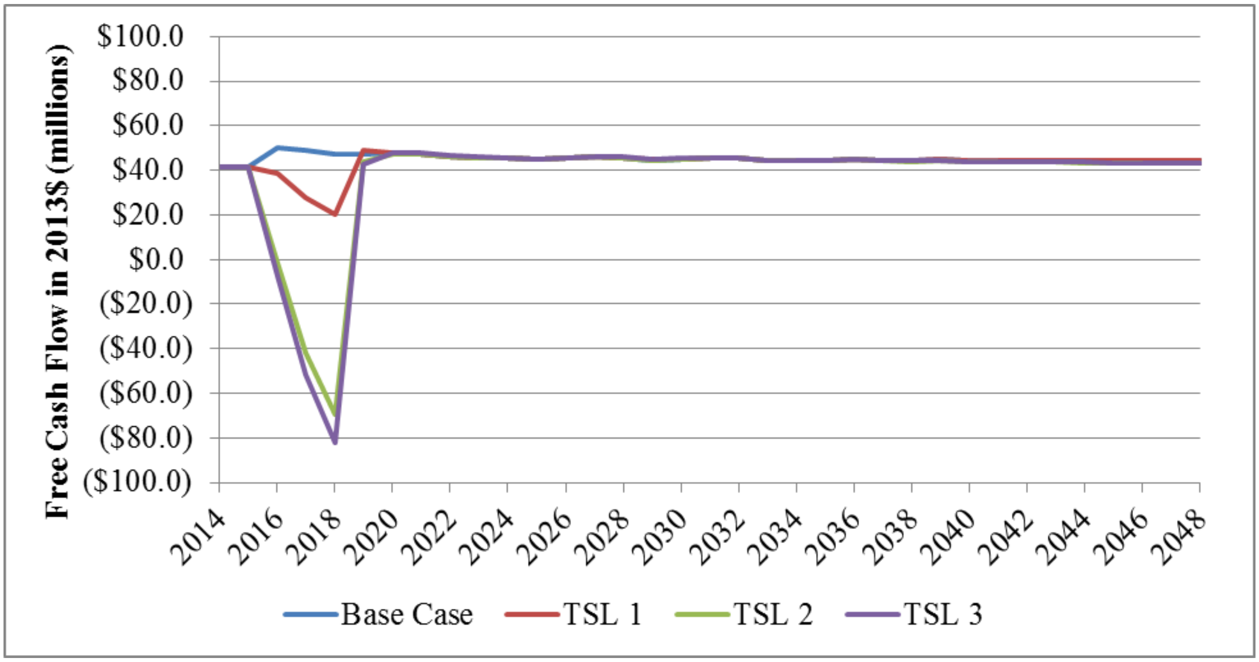


**Figure 12.5.4 Industry Annual Free Cash Flows for All Residential Dishwashers - Preservation of EBIT Markup Scenario with Capital Conversion Costs from the 2014 Engineering Cost Model.**

## 12.6 IMPACTS ON SMALL RESIDENTIAL DISHWASHER MANUFACTURERS

To estimate the number of small businesses on which amended energy conservation standards may have impacts; DOE conducted a market survey using all available public information to identify potential small business manufacturers. DOE's research included the AHAM membership directory, product databases (Consortium for Energy Efficiency, CEC, and ENERGY STAR databases) and individual company websites to find potential small business manufacturers. During interviews and public meetings supporting the May 2012 direct final rule, DOE also asked interested parties and industry representatives if they were aware of any other small business manufacturers. DOE reviewed all publicly available data and contacted various companies, as necessary, to determine whether they met the SBA's definition of a small business manufacturer of covered residential dishwashers. DOE screened out companies that did not themselves manufacture products covered by this rulemaking, did not meet the definition of a "small business," or are foreign owned and operated.

Almost half of residential dishwashers sold in the United States are currently manufactured domestically by one corporation. Together, this manufacturer and 3 other manufacturers that do not meet the definition of a small business manufacturer comprise 99 percent of the residential dishwasher market. The small portion of the remaining residential dishwasher market (approximately 68,000 shipments in 2014) is supplied by a combination of approximately 15 international and domestic companies, all of which have small market shares. These companies are foreign-owned and operated, do not themselves manufacture dishwashers, or exceed the SBA's employment threshold for consideration as a small business under the appropriate NAICS code. As such, DOE did not identify any small business manufacturers of dishwashers.

Based on the discussion above, DOE certifies that the standards for residential dishwashers set forth in today's rule would not have a significant economic impact on a substantial number of small business entities. Accordingly, DOE has not prepared a regulatory flexibility analysis for this rulemaking. DOE will transmit this certification to the SBA as required by 5 U.S.C. 605(b).

## 12.7 OTHER IMPACTS

### 12.7.1 Employment

For residential dishwashers, DOE used the GRIM to estimate the domestic labor expenditures and number of domestic production workers in the base case and at each TSL from 2014 to 2048. DOE used the labor content of each product and the manufacturing production costs from the engineering analysis to estimate the total annual labor expenditures associated with residential dishwashers sold in the United States. Using statistical data from the most recent U.S. Census Bureau's 2011 *Annual Survey of Manufactures* (*ASM*), and information received during interviews conducted in support of the May 2012 direct final rule, DOE estimates that 95 percent of residential dishwashers sold in the United States are manufactured domestically and hence that portion of total labor expenditures is attributable to domestic labor. Labor expenditures for the manufacture of a product are a function of the labor intensity of the product, the sales volume, and an assumption that wages in real terms remain constant.

Using the GRIM, DOE forecasts the domestic labor expenditure for residential dishwasher production labor in 2019 will be approximately $290.7 million. Using the $27.17 hourly wage rate including fringe benefits and 2,042 production hours per year per employee found in the 2011 *ASM*, DOE estimates there will be approximately 5,240 domestic production workers involved in manufacturing residential dishwashers in 2019, the year in which amended standards would go into effect. In addition, DOE estimates that 1,250 non-production employees in the United States will support residential dishwasher production.[c] The employment spreadsheet of the residential dishwasher GRIM shows the annual impacts on domestic manufacturing employment in further detail.

The production worker estimates in this section only cover workers up to the line-supervisor level who are directly involved in fabricating and assembling a product within an Original Equipment Manufacturer (OEM) facility. Workers performing services that are closely associated with production operations, such as material handling with a forklift, are also included as production labor. DOE's estimates account only for production workers who manufacture the specific products covered by this rulemaking.

Table 12.7.1 depicts the potential levels of production employment that could result following amended energy conservation standards as calculated by the GRIM. This potential increase reflects the scenario in which manufacturers continue to produce the same scope of covered products in domestic facilities and domestic production is not shifted to lower-labor-cost countries. If all existing production were moved outside of the United States, the expected impact to domestic manufacturing employment would be a loss of 5,240 jobs, the equivalent of the total base-case employment. Because there is a risk of manufacturers evaluating sourcing decisions in response to amended energy conservation standards, the expected impact to domestic production employment falls between the potential increases as shown in Table 12.7.1, and the levels of job loss associated with the total collapse of the domestic dishwasher manufacturing industry. The discussion below includes a qualitative evaluation of the likelihood of negative domestic production employment impacts at the various TSLs. Table 12.7.1

---

[c] As defined in the 2011 *ASM*, production workers number include "workers (up through the line-supervisor level) engaged in fabricating, processing, assembling, inspecting, receiving, storing, handling, packing, warehousing, shipping (but not delivering), maintenance, repair, janitorial and guard services, product development, auxiliary production for plant's own use (*e.g.*, power plant), recordkeeping, and other services closely associated with these production operations at the establishment covered by the report. Employees above the working-supervisor level are excluded from this item." Non-production workers are defined as "employees of the manufacturing establishment including those engaged in factory supervision above the line-supervisor level. It includes sales (including driver-salespersons), sales delivery (highway truck drivers and their helpers), advertising, credit, collection, installation and servicing of own products, clerical and routine office functions, executive, purchasing, financing, legal, personnel (including cafeteria, medical, etc.), professional, and technical employees. Also included are employees on the payroll of the manufacturing establishment engaged in the construction of major additions or alterations utilized as a separate work force."

illustrates the potential impacts of amended energy conservation standards on domestic production employment levels at each TSL for the residential dishwasher market.

**Table 12.7.1 Total Domestic Residential Dishwasher Production Workers in 2018***

| | Trial Standard Level | | | |
|---|---|---|---|---|
| | Base Case | 1 | 2 | 3 |
| **Total Number of Domestic Production Workers in 2019 (without changes in production location)** | 5,240 | 5,252 | 5,426 | 5,485 |

Figure 12.7.1 below shows total annual domestic employment levels for each TSL as calculated by the GRIM.

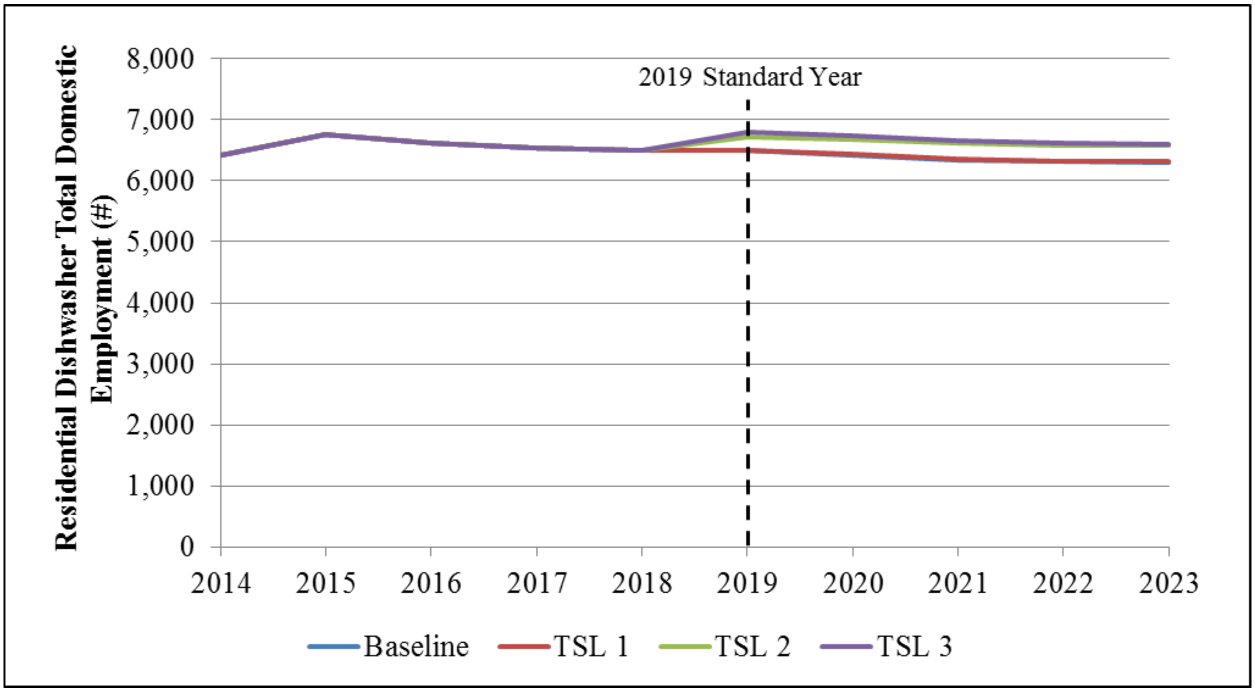


**Figure 12.7.1 Total Residential Dishwasher Industry Domestic Employment by Year**

At all TSLs, most of the design options analyzed by DOE do not greatly alter the labor content of the final product. For example, longer or more complex wash cycles or improved sump designs involve one-time changes to the final product, but do not significantly change the number of steps required for the final assembly of the dishwasher (which would add labor). As such, all examined TSLs show relatively minor impacts on domestic employment levels relative to total industry employment provided domestic production is not shifted to lower labor cost countries. However, at higher TSLs, some of the design options analyzed greatly impact the ability of manufacturers to make product changes within existing platforms. The very large upfront capital costs at these levels could influence the decision of some manufacturers to relocate some or all of the domestic production of these dishwashers to lower labor cost countries or to rely more heavily on foreign suppliers for higher efficiency products.

### 12.7.2 Production Capacity

Less than 5 percent of shipments of residential dishwashers already comply with the amended energy conservation standards proposed in this rulemaking. Not every manufacturer that ships standard residential dishwashers offers products that meet these amended energy conservation standards. Because manufacturers would need to make platform changes by the 2019 compliance date which would require substantial retooling and production line recapitalization, amended energy conservation standards may impact manufacturing capacity during this interim period as manufacturers change over existing production lines to produce compliant products.

### 12.7.3 Cumulative Regulatory Burden

While any one regulation may not impose a significant burden on manufacturers, the combined effects of several 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 product offerings, potentially reducing competition. Assessing the impact of a single regulation may overlook this cumulative regulatory burden. A proposed standard is not economically justified if it contributes to an unacceptable level of cumulative regulatory burden.

For the cumulative regulatory burden analysis, DOE looks at other significant product-specific regulations that will take effect 3 years before or after the compliance date of the amended energy conservation standards for residential dishwashers. In addition to amended energy conservation regulations, several other Federal regulations apply to residential dishwashers. While this analysis focuses on the impacts on manufacturers born of other Federal requirements, DOE also has described a number of other non-Federal regulations in section 12.7.3.2 because it recognizes that these regulations also impact the products covered by this rulemaking.

#### 12.7.3.1 DOE Regulations for Other Products Produced by Residential Dishwasher Manufacturers

Companies that produce a wide range of regulated products may face more capital and product development expenditures than competitors with a narrower scope of products. Many manufacturers of residential dishwashers also produce other appliances. In addition to the amended energy conservation standards for residential dishwashers, these manufacturers face several other Federal regulations and pending regulations that apply to other products. 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 12.7.2 lists the other DOE energy conservation standards as established by final rules or proposed in notices of proposed rulemakings that may also affect manufacturers of residential dishwashers in the 3 years leading up to and after the compliance date of amended energy conservation standards for these products.

### Table 12.7.2 Other DOE and Federal Actions Affecting the Residential Dishwasher Industry

| Regulation | Approximate Compliance Date* | Number of Companies from the Market and Technology Assessment (See Chapter 3 of the NOPR TSD) | Estimated Total Industry Conversion Costs |
|---|---|---|---|
| Residential Microwave Ovens | 2016 | 6 | \$94.7 million (2010\$)[d] |
| Commercial Distribution Transformers | 2016 | 1 | \$61 million (2011\$)[e] |
| Electric Motors | 2016 | 1 | \$84.6 million (2013\$)[f] |
| Commercial Refrigeration Equipment | 2017 | 1 | \$184 million (2012\$)[g] |
| General Service Fluorescent Lamps | 2017* | 1 | N/A† |
| Incandescent Reflector Lamps | 2017* | 1 | N/A† |
| Metal Halide Lamp Fixtures | 2017 | 1 | \$25.6 million (2012\$)[h] |
| Residential Clothes Washers | 2018 | 12 | \$418.5 million (2010\$)[i] |
| Commercial Clothes Washers | 2018* | 4 | N/A† |
| Residential Furnace Fans | 2019 | 4 | \$40.6 million (2013\$)[j] |

*The dates listed are an approximation. The exact dates are pending final DOE action.
† For energy conservation standards for rulemakings awaiting DOE final action, DOE does not have a finalized estimated total industry conversion cost.

---

[d] Estimated industry conversion expenses were published in the TSD for the June 2013 microwave ovens standby mode and off mode energy conservation standards final rule. 78 FR 36316. The TSD can be found at submission 2 in docket number EERE-2011-BT-STD-0048 at http://www.regulations.gov.

[e] Estimated industry conversion expenses were published in the TSD for the April 2013 commercial distribution transformers energy conservation standards final rule. 78 FR 23335. The TSD can be found at submission 760 in docket number EERE-2010-BT-STD-0048 at http://www.regulations.gov.

[f] Estimated industry conversion expenses were published in the TSD for the May 2014 electric motors energy conservation standards final rule. 79 FR 30933. The TSD can be found at submission 108 in docket number EERE-2010-BT-STD-0027 at http://www.regulations.gov.

[g] Estimated industry conversion expenses were published in the TSD for the March 2014 commercial refrigeration equipment energy conservation standards final rule. 79 FR 17725. The TSD can be found at submission 102 in docket number EERE-2010-BT-STD-0003 at http://www.regulations.gov.

[h] Estimated industry conversion expenses were published in the TSD for the February 2014 metal halide lamp fixtures energy conservation standards final rule. 79 FR 7745. The TSD can be found at submission 69 in docket number EERE-2009-BT-STD-0018 at http://www.regulations.gov.

[i] Estimated industry conversion expenses were published in the TSD for the May 2012 residential clothes washers energy conservation standards direct final rule. 77 FR 32308. The TSD can be found at submission 47 in docket number EERE-2008-BT-STD-0019 at http://www.regulations.gov.

[j] Estimated industry conversion expenses were published in the TSD for the July 2014 residential furnace fans energy conservation standards final rule. 79 FR 38129. The TSD can be found at submission 111 in docket number EERE-2010-BT-STD-0011 at http://www.regulations.gov.

Some Federal DOE regulations have a more significant impact on manufacturers of residential dishwashers than others because manufacturers hold a significant market share in those covered products. Where market share and company financial data is available, DOE attempts to quantify the regulatory burden as measured by the fraction of corporate revenues that are derived from the manufacture of products covered by other standards rulemakings. Table 12.7.3 shows the DOE energy conservation standards for products that manufacturers of residential dishwashers hold substantial market share and illustrates the fraction of corporate earnings derived from the sale of these covered products. As indicated, companies whose primary business is associated with appliance manufacturing are more exposed to the impacts of energy conservation standards rulemakings. Conversely, foreign manufacturers who command lower market shares are less exposed.

## Table 12.7.3 DOE Regulations on Products for which Residential Dishwasher Manufacturers Hold Significant Market Share

| | | **GE** | | **Whirlpool** | | **Electrolux** | | **Bosch** | |
|---|---|---|---|---|---|---|---|---|---|
| | **2013 Revenue *($MM)*** | $146,045[k] | | $18,769[l] | | $16,978[m] | | $63,464[n] | |
| | **2013 Industry Sales *($MM)*** | **Market share** | **% of Revenue** | **Market share** | **% of Revenue** | **Market share** | **% of Revenue** | **Market share** | **% of Revenue** |
| Refrigerators and Freezers[o] | $7,158 | 27% | 1.32% | 33% | 12.59% | 23% | 9.70% | | |
| Residential Clothes Dryers[p] | $1,941 | 16% | 0.21% | 70% | 7.24% | 8% | 0.91% | | |
| Room Air Conditioners[q] | $2,267 | | | 13% | 1.57% | 13% | 1.74% | | |
| Residential Clothes Washers[r] | $4,436 | 16% | 0.49% | 64% | 15.12% | 6% | 1.57% | | |
| Dishwashers | $1,801 | 27% | 0.33% | 49% | 4.70% | 18% | 1.91% | 5% | 0.14% |
| Cooking Products[s] | $3,074 | 48% | 1.01% | 29% | 4.75% | 9% | 1.63% | | |
| Microwave Ovens[t] | $2,211 | | | 3% | 0.35% | | | | |
| Totals | | | 3.37% | | 46.32% | | 17.45% | | 0.14% |

---

[k] 2013 revenues for GE are taken from the 2013 annual reports of Form 10-K, available at: *www.sec.gov/Archives/edgar/data/40545/000004055414000023/geform10k2013.htm*

[l] 2013 revenues for Whirlpool are taken from the 2013 annual reports of Form 10-K, available at: *www.sec.gov/Archives/edgar/data/106640/000010664014000008/whr12312013-10xk.htm*

[m] 2013 revenues for Electrolux are taken from the 2013 annual report, available at: *http://group.electrolux.com/en/electrolux-annual-report-2013-18535/*

[n] 2013 revenues for Bosch are taken from the 2013 annual report, available at: *www.bosch.com/en/com/bosch_group/bosch_figures/bosch-figures.php*

[o] Estimated industry revenues and manufacturer market shares for refrigerator and freezer manufacturing were published in the TSD and support spreadsheets for the September 2011 final rule. 76 FR 57516. The TSD can be found at submission 128 in docket number EERE-2008-BT-STD-0012 at *http://www.regulations.gov*.

[p] Estimated industry revenues and manufacturer market shares for residential clothes dryer manufacturing were published in the TSD and support spreadsheets for the April 2011 direct final rule. 76 FR 22454. The TSD can be found at submission 53 in docket number EERE-2007-BT-STD-0010 at *http://www.regulations.gov*.

[q] Estimated industry revenues and manufacturer market shares for room air conditioner manufacturing were published in the TSD and support spreadsheets for the April 2011 direct final rule. 76 FR 22454. The TSD can be found at submission 53 in docket number EERE-2007-BT-STD-0010 at *http://www.regulations.gov*.

[r] Estimated industry revenues and manufacturer market shares for residential clothes washer manufacturing were published in the TSD and support spreadsheets for the May 2012 direct final rule. 77 FR 32308. The TSD can be found at submission 47 in docket number EERE-2008-BT-STD-0019 at *http://www.regulations.gov*.

[s] Estimated industry revenues and manufacturer market shares for residential cooking product manufacturing were published in the TSD and support spreadsheets for the April 2009 final rule. 74 FR 16040. The TSD can be found at submission 97 in docket number EERE-2006-BT-STD-0127 at *http://www.regulations.gov*.

[t] Estimated industry revenues and manufacturer market shares for microwave oven manufacturing were published in the TSD and support spreadsheets for the June 2013 final rule. 78 FR 36316. The TSD can be found at submission 2 in docket number EERE-2011-BT-STD-0048 at *http://www.regulations.gov*.

Where specific market share data was not available, DOE identified manufacturers of other products covered by additional efficiency standards as shown in Table 12.7.4.

**Table 12.7.4 Other Covered Products**

| Manufacturer | Other Covered Products Manufactured |
|---|---|
| AM Appliance Group / Asko | Commercial clothes washers, residential clothes dryers, residential; clothes washers |
| Equator | Residential refrigerators and freezers, residential clothes dryers, residential clothes washers |
| Fagor | Cooking products, residential refrigerators and freezers, residential clothes dryers, residential clothes washers |
| Fisher & Paykel | Cooking products, residential clothes dryers, residential clothes washers |
| Haier | Cooking products, residential clothes dryers, room air conditioner, residential clothes washers |
| Indesit | Cooking products, residential refrigerators and freezers, residential clothes dryers, residential clothes washers |
| Miele | Cooking products, residential refrigerators and freezers, residential clothes dryers, residential clothes washers |
| Summit | Residential refrigerators and freezers, residential clothes dryers, commercial refrigeration equipment, residential clothes washers |
| Viking | Residential refrigerators and freezers, cooking products, microwave ovens, commercial refrigeration equipment, residential clothes washers |

### 12.7.3.2 Other Regulations That Could Impact Residential Dishwasher Manufacturers

While the cumulative regulatory burden focuses on the impacts on manufacturers of other Federal requirements, in this section DOE describes a number of other regulations that may also impact manufacturers of residential dishwashers.

#### *State Energy Conservation Standards*

During interviews conducted in support of the May 2012 direct final rule, manufacturers indicated that California has several programs that are either already in place or are currently in development that affect manufacturers of residential dishwashers. Various building, electrical, mechanical and plumbing codes in California affect dishwashers, and products are also subject to California's laws on the Restriction on the use of certain Hazardous Substances (RoHS). California's RoHS law took effect January 1, 2007 and was modeled after the European Union's (EU's) directive (described below), which bans certain hazardous substances from electrical and electronic equipment.

#### *International Energy Conservation Standards*

Residential dishwasher manufacturers that sell products outside of the United States are subject to several international energy conservation standards. In the EU, products are also subject to RoHS. This regulation bans the sale of new equipment in the EU that contains quantities in excess of agreed upon levels for lead, cadmium, mercury, hexavalent chromium, polybrominated biphenyl (PBB) and polybrominated diphenyl ether (PBDE) flame retardants. Waste Electrical and Electronic Equipment (WEEE) and the Registration, Evaluation, Authorization, and restriction of Chemicals (REACH) are additional regulations that create compliance costs for manufacturers that compete in Europe. REACH deals with chemicals and their safe use and has provisions that will be phased-in over 11 years, beginning June 1, 2007. The EU also sets limits for the amount of energy consumed by equipment when it is in standby mode and off mode. Additionally, HFCs are banned in refrigerants in several countries, such as Austria, Denmark, and Switzerland. Canada and several other foreign countries have regulations or have initiated regulations affecting dishwasher manufacturers.

## 12.8 CONCLUSION

The following sections summarize the different impacts for the scenarios DOE believes are most likely to capture the range of impacts on residential dishwasher 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.

### 12.8.1 Residential Dishwashers

At TSL 1, DOE estimates impacts on INPV to range from -$43.5 million to -$80.5 million, or a change in INPV of -7.4 percent to -13.7 percent. At this level, industry free cash flow is estimated to decrease by as much as 99.0 percent to $0.5 million, compared to the base-case value of $47.3 million in the year leading up to the amended energy conservation standards. As TSL 1 corresponds to the current ENERGY STAR criteria for standard residential dishwashers, and these products represent 88 percent of shipments in the year leading up to amended standards, only a small fraction of the market is affected at this efficiency level. In either markup scenario, the impact on INPV at TSL 1 stems largely from the conversion costs required to switch production lines from manufacturing baseline units to those meeting the standards set at Efficiency Level 1 for standard residential dishwashers.

As a large fraction of the energy used in dishwashing is associated with heating the wash water, the design options proposed to meet this efficiency level relate primarily to minimizing the amount of wash water through spray-arm optimization, filter improvements, and enabling greater control over the wash water temperature. Both of these practices are in common use in higher efficiency platforms across the industry and contribute to an MPC of $213.24 for standard dishwashers. Because the industry already produces a substantial number of products at this efficiency level, product and capital conversion costs are limited to $73.7 million based on the engineering cost model, or $117.5 million based on the scaled conversion costs taken from the May 2012 direct final rule.

At TSL 2, DOE estimates impacts on INPV to range from -$103.6 million to -$203.7 million, or a change in INPV of -17.7 percent to -34.7 percent. At this level, industry free cash flow is estimated to decrease by as much as 247.1 percent to -$69.6 million, compared to the base-case value of $47.3 million in the year leading up to the amended energy conservation standards.

DOE expects manufacturers would make more extensive improvements to meet TSL 2 compared to TSL 1. For standard dishwashers, these improvements include exchanging a heated drying system for a condensation drying system, further optimizing the hydraulic system (extending to a redesign of both the sump and water lines and further improvements to the filters), and incorporating a flow meter, temperature sensor, and soil sensor to finely tune water consumption, temperature, and the drying cycle. The component changes required to enable these improvements contribute to an MPC of $278.44 for standard dishwashers. For standard dishwashers, only 3.7 percent of shipments currently meet the standards specified at TSL 2. In contrast, 51.9 percent of shipments of compact dishwashers currently meet the standards specified at TSL 2. Because only a few standard residential dishwashers currently employ these energy and water saving measures, the product and capital conversion costs for standard dishwashers rise to $223.9 million based on the scaled conversion costs taken from the May 2012 direct final rule, or $249.2 million based on the engineering cost model, as the production lines responsible for producing over 95 percent of standard product shipments would need retooling and upgrades. For manufacturers of compact dishwashers, these investments total $9.8 million based on the scaled conversion costs taken from the May 2012 direct final rule, or $32.2 million based on the engineering cost model. Accordingly, the conversion costs required to design and produce compliant standard dishwashers contribute to the majority of impacts on INPV at TSL 2.

At TSL 3, DOE estimates impacts on INPV to range from -$141.1 million -$239.8 million, or a change in INPV of -24.0 percent to -40.9 percent. At this level, industry free cash flow is estimated to decrease by as much as 274.7 percent to -$82.6 million, compared to the base-case value of $47.3 million in the year leading up to the amended energy conservation standards. The impact to INPV is most severe at TSL 3 as less than 1 percent of shipments in the year leading up to amended standards meet this efficiency level. Only 0.4 percent of standard dishwasher shipments and 37.0 percent of compact dishwasher shipments currently meet the standards specified at TSL 3. As such, standards at TSL 3 would affect nearly all platforms and will result in substantial capital conversion costs associated with improvements to nearly all production facilities. Because so few products exist at this level, nearly all manufacturers would face complete redesigns for products to meet this standard. Accordingly, the product conversion costs increase to reflect this substantial research effort. The capital and product conversion costs required to bring products into compliance rise to a total of $316.9 million based on the scaled conversion costs taken from the May 2012 direct final rule, or $316.3 million based on the engineering cost model. Production lines responsible for producing over 99 percent of product shipments would need retooling and upgrades at TSL 3. The conversion costs at TSL 3 stem from both the research programs needed to develop such optimized products and the capital investment required to change over production lines responsible for producing over 99 percent of product shipments.

DOE expects manufacturers of standard residential dishwashers would incorporate similar design options at TSL 3 as at TSL 2, extended to include more highly optimized control strategies that would further reduce the wash and rinse water temperatures. Although the component changes required to enable these improvements contribute to the same MPC of $278.44 for standard dishwashers at TSL 3 as for TSL 2, the levels specified at TSL 3 significantly impact INPV because of the larger conversion costs associated with developing and producing these highly optimized products. For compact residential dishwashers, moving from TSL 2 to TSL 3 would require significant changes to the portion of the market that is not currently at the max-tech efficiency level. These changes would result in a range of INPV impacts for compact dishwasher manufacturers ranging from -309 percent to -1,265 percent. Because these impacts are attributed to manufacturers of baseline compact residential dishwashers in the countertop configuration, DOE expects that manufacturers would exit the market for these products at TSL 3.

## REFERENCES

---

1 Association of Home Appliance Manufacturers. *Current Members*. Last accessed January 2013. Available online at: *www.aham.org/ht/d/Organizations/pid/2344/divisions/Y*.

2 U.S. Department of Energy, *Compliance Certification Database*. Last accessed January 2013. Available online at: *www.regulations.doe.gov/certification-data/*

3 California Energy Commission. *Appliance Efficiency Database*. Last accessed January 2013. Available online at: *www.appliances.energy.ca.gov/QuickSearch.aspx*

4 ENERGY STAR. *Qualified Dishwashers*. Last accessed January 2013. Available online at : *www.energystar.gov/index.cfm?fuseaction=find_a_product.showProductGroup&pgw_code=DW*.

5 McKinsey & Company, Inc. *Valuation: Measuring and Managing the Value of Companies*, 3rd Edition, Copeland, Koller, Murrin. New York: John Wiley & Sons, 2000.

# CHAPTER 13. EMISSIONS IMPACT ANALYSIS

## TABLE OF CONTENTS

## LIST OF TABLES

## LIST OF FIGURES

# 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 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. As of 2014, DOE is using a new methodology based on results published for the *Annual Energy Outlook 2014 (AEO 2014)* reference case and a set of side cases that implement a variety of efficiency-related policies.[1] The new methodology is described in chapter 15 and in the report "Utility Sector Impacts of Reduced Electricity Demand" (Coughlin, 2014).[4] Site emissions of $CO_2$ and $NO_X$ are estimated using emissions intensity factors from a publication of the Environmental Protection Agency (EPA).[2]

Combustion emissions of $CH_4$ and $N_2O$ are estimated using emissions intensity factors published by the EPA, GHG Emissions Factors Hub.[a] The FFC upstream emissions are estimated based on the methodology developed by Coughlin (2013).[3] 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 (chapter 10).

## 13.2 AIR QUALITY REGULATIONS AND EMISSIONS IMPACTS

Each annual version of the AEO incorporates the projected impacts of existing air quality regulations on emissions. *AEO 2014* generally represents current Federal and State legislation and final implementation regulations in place as of the end of October 2013.

---

[a] http://www.epa.gov/climateleadership/inventory/ghg-emissions.html

$SO_2$ 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 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. See *EME Homer City Generation, LP v. EPA*, 696 F.3d 7, 38 (D.C. Cir. 2012). The court ordered EPA to continue administering CAIR. The *AEO 2014* emissions factors used for the present analysis assume that CAIR remains a binding regulation through 2040. [b]

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 2014* 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 CAIR, so it is unlikely that excess $SO_2$ emissions allowances resulting from the lower electricity demand would be needed or used to permit offsetting

---

[b] 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. 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. See *EPA v. EME Homer City Generation*, No 12-1182, slip op. at 32 (U.S. April 29, 2014). Because DOE is using emissions factors based on AEO 2013, the analysis assumes that CAIR, not CSAPR, is the regulation in force. The difference between CAIR and CSAPR is not relevant for the purpose of DOE's analysis of $SO_2$ emissions.

increases in $SO_2$ emissions by any regulated EGU. Therefore, DOE believes that efficiency standards will reduce $SO_2$ emissions in 2016 and beyond.

CAIR established a cap on $NO_x$ emissions in 28 eastern States and the District of Columbia. 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. However, standards would be expected to reduce $NO_x$ emissions in the States not affected by CAIR, 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 mercury emissions reductions using the NEMS-BT based on *AEO 2014*, which incorporates the MATS.

## 13.3 POWER SECTOR AND SITE EMISSIONS FACTORS

The analysis of power sector emissions uses marginal emissions intensity factors derived from analysis of the *AEO 2014* reference and a number of side cases incorporating enhanced equipment efficiencies. To model the impact of a standard, DOE calculates factors that relate a unit reduction to annual site electricity demand for a given end use to corresponding reductions to installed capacity by fuel type, fuel use for generation, and power sector emissions. Details on the approach used may be found in Coughlin (2014).[4]

Table 13.3.1 presents the average power plant emissions factors for selected years. These power plant emissions factors are derived from the emissions factors of the plant types used to supply electricity to homes. The average factors for each year take into account the projected shares of each of the sources in total electricity generation.

Table 13.3.2 presents the natural gas site combustion emissions factors for selected years and Table 13.3.3 presents fuel oil site combustion emissions factors for select years.

**Table 13.3.1 Power Plant Emissions Factors**

| | **Unit*** | **2020** | **2025** | **2030** | **2035** | **2040** |
|---|---|---|---|---|---|---|
| $CO_2$ | kg/MWh | 723 | 642 | 579 | 529 | 483 |
| $SO_2$ | g/MWh | 718 | 560 | 471 | 395 | 353 |
| NOx | g/MWh | 574 | 479 | 419 | 369 | 334 |
| Hg | g/MWh | 0.00222 | 0.00173 | 0.00145 | 0.00122 | 0.00109 |
| $N_2O$ | g/MWh | 7.2 | 7.1 | 6.9 | 6.6 | 6.4 |
| $CH_4$ | g/MWh | 50.2 | 49.4 | 47.9 | 46.4 | 44.8 |

* Refers to site electricity savings.

**Table 13.3.2 Natural Gas Site Combustion Emissions Factors**

| | **Unit*** | **2020** | **2025** | **2030** | **2035** | **2040** |
|---|---|---|---|---|---|---|
| $CO_2$ | kg/mcf | 54.2 | 54.2 | 54.2 | 54.2 | 54.2 |
| $SO_2$ | g/ mcf | 0.271 | 0.271 | 0.271 | 0.271 | 0.271 |
| NOx | g/ mcf | 69.9 | 69.9 | 69.9 | 69.9 | 69.9 |
| $N_2O$ | g/ mcf | 0.102 | 0.102 | 0.102 | 0.102 | 0.102 |
| $CH_4$ | g/ mcf | 1.022 | 1.022 | 1.022 | 1.022 | 1.022 |

* Refers to site gas savings.

**Table 13.3.3 Fuel Oil Site Combustion Emissions Factors**

| | **Unit*** | **2020** | **2025** | **2030** | **2035** | **2040** |
|---|---|---|---|---|---|---|
| $CO_2$ | kg/bbl | 446 | 446 | 446 | 446 | 446 |
| $SO_2$ | g/bbl | 220 | 220 | 220 | 220 | 220 |
| NOx | g/bbl | 11,530 | 11,530 | 11,530 | 11,530 | 11,530 |
| $N_2O$ | g/bbl | 8.6 | 8.6 | 8.6 | 8.6 | 8.6 |
| $CH_4$ | g/bbl | 13.3 | 13.3 | 13.3 | 13.3 | 13.3 |

* Refers to site fuel oil savings.

## 13.4 UPSTREAM FACTORS

The upstream emissions accounting uses the same approach as the upstream energy accounting described in appendix 10-B. See also Coughlin (2013)[3] and Coughlin (2014).[4] When demand for a particular fuel is reduced, there is a corresponding reduction in the emissions from combustion of that fuel at either the building site or the power plant. The associated reduction in energy use for upstream activities leads to further reductions in emissions. These upstream emissions are defined to include the combustion emissions from the fuel used upstream, the fugitive emissions associated with the fuel used upstream, and the fugitive emissions associated with the fuel used on site.

Fugitive emissions of $CO_2$ occur during oil and gas production, but are small relative to combustion emissions. They comprise about 2.5 percent of total $CO_2$ emissions for natural gas and 1.7 percent for petroleum fuels. Fugitive emissions of methane occur during oil, gas and coal production. Combustion emissions of $CH_4$ are very small, while fugitive emissions (particularly for gas production) may be relatively large. 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.

Upstream emissions factors account for both fugitive emissions and combustion emissions in extraction, processing, and transport of primary fuels. Fugitive emissions factors for 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] As more data are made available, DOE will continue to update these estimated emissions factors.

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 13.4.1 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.

**Table 13.4.1 Electricity Upstream Emissions Factors**

| | **Unit** | **2020** | **2025** | **2030** | **2035** | **2040** |
|---|---|---|---|---|---|---|
| $CO_2$ | kg/MWh | 29.1 | 29.4 | 29.7 | 29.9 | 29.8 |
| $SO_2$ | g/MWh | 5.0 | 5.1 | 4.9 | 4.7 | 4.6 |
| NOx | g/MWh | 368 | 375 | 382 | 387 | 387 |
| Hg | g/MWh | 0.00001 | 0.00001 | 0.00001 | 0.00001 | 0.00001 |
| $N_2O$ | g/MWh | 0.25 | 0.25 | 0.24 | 0.23 | 0.23 |
| $CH_4$ | g/MWh | 2,149 | 2,195 | 2,216 | 2,248 | 2,255 |

Table 13.4.2 illustrates the natural gas upstream emissions factors for selected years. These were used to estimate the emissions associated with the increased gas use at some of the considered efficiency levels.

**Table 13.4.2 Natural Gas Upstream Emissions Factors**

| | **Unit** | **2020** | **2025** | **2030** | **2035** | **2040** |
|---|---|---|---|---|---|---|
| $CO_2$ | kg/ mcf | 7.1 | 7.2 | 7.3 | 7.4 | 7.4 |
| $SO_2$ | g/ mcf | 0.030 | 0.031 | 0.031 | 0.032 | 0.032 |
| NOx | g/ mcf | 101 | 103 | 105 | 105 | 105 |
| $N_2O$ | g/ mcf | 0.011 | 0.011 | 0.012 | 0.012 | 0.012 |
| $CH_4$ | g/ mcf | 659 | 665 | 666 | 670 | 670 |

Table 13.4.3 presents the fuel oil upstream emissions factors for selected years.

**Table 13.4.3 Fuel Oil Upstream Emissions Factors**

| | **Unit** | **2020** | **2025** | **2030** | **2035** | **2040** |
|---|---|---|---|---|---|---|
| $CO_2$ | kg/bbl | 70.8 | 70.3 | 69.9 | 68.9 | 68.3 |
| $SO_2$ | g/bbl | 14.5 | 14.1 | 14.0 | 13.9 | 13.9 |
| NOx | g/bbl | 765 | 742 | 737 | 733 | 732 |
| Hg | g/bbl | 0.000007 | 0.000007 | 0.000007 | 0.000007 | 0.000007 |
| $N_2O$ | g/bbl | 0.598 | 0.579 | 0.574 | 0.569 | 0.568 |
| $CH_4$ | g/bbl | 897 | 905 | 902 | 888 | 877 |

## 13.5 EMISSIONS IMPACT RESULTS

Table 13.5.1 presents the estimated cumulative emissions reductions for the lifetime of products sold in 2019-2048 for each TSL. Negative values indicate that emissions increase.

**Table 13.5.1 Cumulative Emissions Reduction for Potential Standards for Dishwashers**

| | **TSL** | | |
|---|---|---|---|
| | **1** | **2** | **3** |
| **Power Sector and Site Emissions** | | | |
| $CO_2$ (million metric tons) | 0.225 | 57.9 | 138 |
| $SO_2$ (thousand tons) | -0.414 | 42.4 | 98.1 |
| $NO_X$ (thousand tons) | 2.28 | 68.9 | 171 |
| Hg (tons) | -0.001 | 0.130 | 0.299 |
| $N_2O$ (thousand tons) | -0.005 | 0.716 | 1.68 |
| $CH_4$ (thousand tons) | -0.034 | 4.97 | 11.7 |
| **Upstream Emissions** | | | |
| $CO_2$ (million metric tons) | 0.073 | 3.96 | 9.68 |
| $SO_2$ (thousand tons) | -0.003 | 0.521 | 1.23 |
| $NO_X$ (thousand tons) | 1.16 | 57.8 | 142 |
| Hg (tons) | 0.000 | 0.001 | 0.003 |
| $N_2O$ (thousand tons) | 0.000 | 0.027 | 0.064 |
| $CH_4$ (thousand tons) | 7.08 | 340 | 835 |
| **Total Emissions** | | | |
| $CO_2$ (million metric tons) | 0.298 | 61.9 | 147 |
| $SO_2$ (thousand tons) | -0.417 | 42.9 | 99.4 |
| $NO_X$ (thousand tons) | 3.44 | 127 | 313 |
| Hg (tons) | -0.001 | 0.131 | 0.302 |
| $N_2O$ (thousand tons) | -0.005 | 0.743 | 1.74 |
| $CH_4$ (thousand tons) | 7.05 | 345 | 846 |

Figure 13.5.1 through Figure 13.5.6 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 2019-2048.

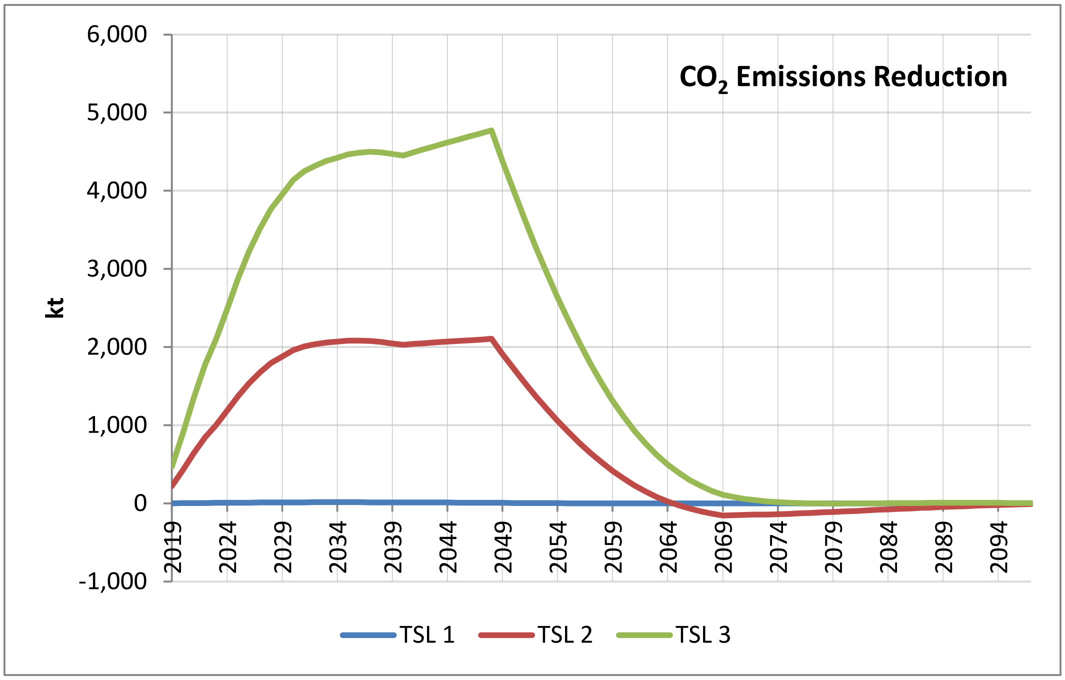


**Figure 13.5.1 Dishwashers: CO$_2$ Total Emissions Reduction**

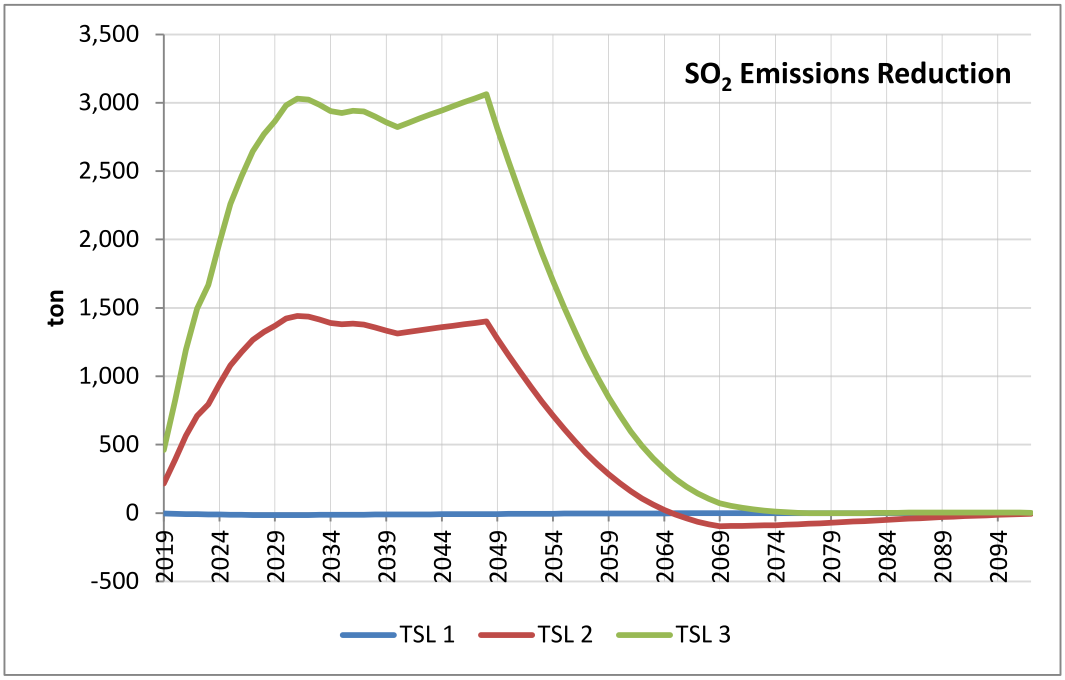


**Figure 13.5.2 Dishwashers: SO$_2$ Total Emissions Reduction**

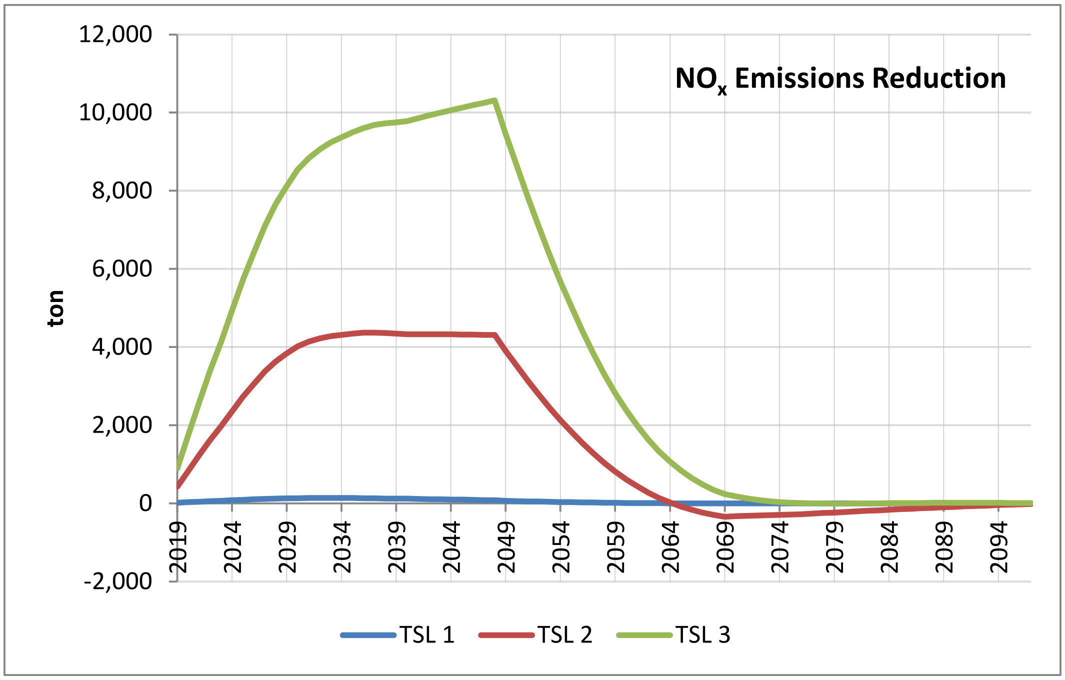


**Figure 13.5.3 Dishwashers: $NO_x$ Total Emissions Reduction**

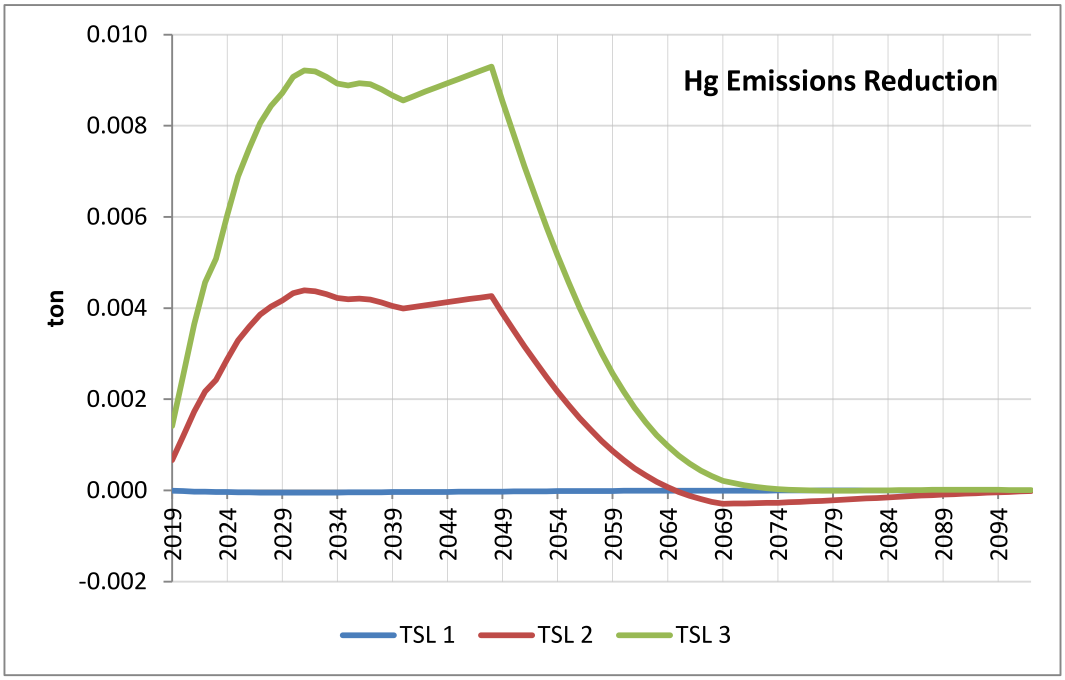


**Figure 13.5.4 Dishwashers: Hg Total Emissions Reduction**

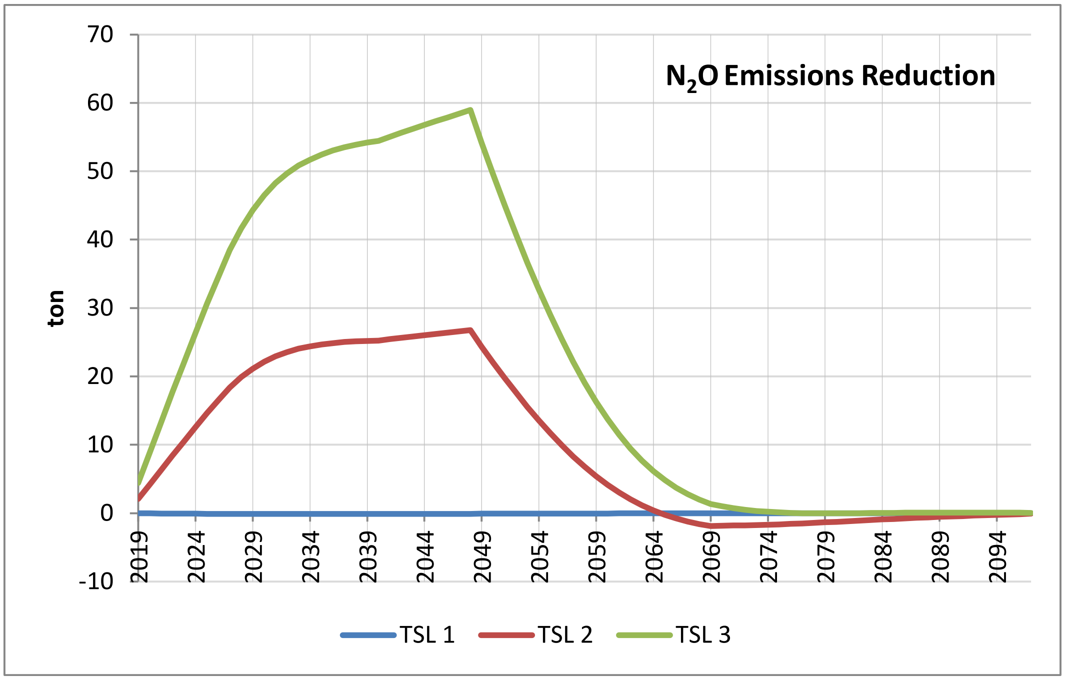


**Figure 13.5.5** **Dishwashers: $N_2O$ Total Emissions Reduction**

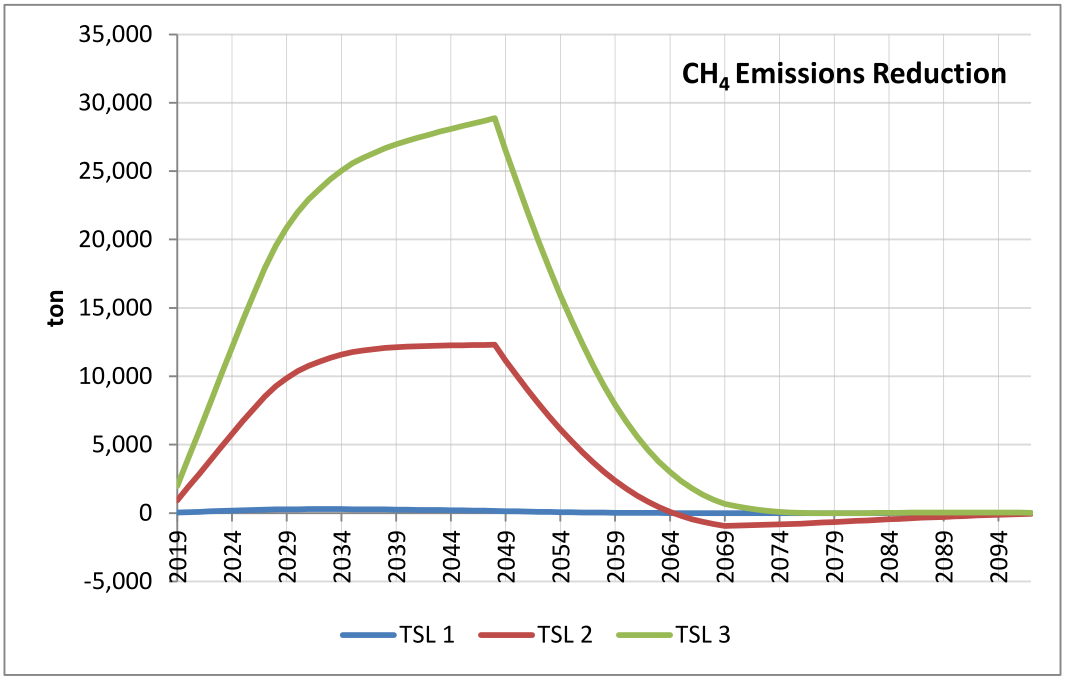


**Figure 13.5.6** **Dishwashers: $CH_4$ Total Emissions Reduction**

## REFERENCES

1. Energy Information Administration, *Annual Energy Outlook 2013 with Projections to 2040*, June 2013. Washington, DC. <http://www.eia.gov/forecasts/aeo/pdf/0383(2013).pdf>

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.

4. Coughlin, K., *Utility Sector Impacts of Reduced Electricity Demand*, 2014. Lawrence Berkeley National Laboratory. Report No. LBNL-xxxx.

5. Burnham, A., J. Han, C. E. Clark, M. Wang, J. B. Dunn, I. Palou-Rivera,, Life-Cycle Greenhouse Gas Emissions of Shale Gas, Natural Gas, Coal, and Petroleum. *Environmental Science & Technology*, 2011. 46(2): pp. 619-627

6. U.S. Environmental Protection Agency, *Fugitive Emissions Reporting from the Petroleum and Natural Gas Industry*, 2009. U.S. Environmental Protection Agency. Washington, DC.

7. U.S. Environmental Protection Agency, *Oil and Natural Gas Sector: Standards of Performance for Crude Oil and Natural Gas Production, Transmission, and Distribution, Background Supplemental Technical Support Document for the Final New Source Performance Standards*, 2012. U.S. Environmental Protection Agency. Washington, DC.

# CHAPTER 14. MONETIZATION OF EMISSION REDUCTIONS BENEFITS

## TABLE OF CONTENTS

## LIST OF TABLES

# CHAPTER 14. MONETIZATION OF EMISSION REDUCTIONS BENEFITS

## 14.1 INTRODUCTION

As part of its assessment of the effects of potential energy conservation standards for residential dishwashers, the U.S. Department of Energy (DOE) estimated the monetary benefits of the reduced emissions of carbon dioxide ($CO_2$) and nitrogen oxides ($NO_X$) that would be expected to result from each trial standard level (TSL) considered for dishwashers. This chapter summarizes the basis for the monetary values assigned to emissions and presents the modeled benefits of estimated reductions.

## 14.2 MONETIZING CARBON DIOXIDE EMISSIONS

One challenge for anyone attempting to calculate the monetary benefits of reduced emissions of $CO_2$ is what value to assign to each unit eliminated. The value must encompass a broad range of physical, economic, social, and political effects. Analysts developed the concept of the social cost of carbon (SCC) to represent the broad cost or value associated with producing—or reducing—a quantifiable amount of $CO_2$ emissions.

### 14.2.1 Social Cost of Carbon

The SCC is an estimate of the monetized damages associated with an incremental increase in carbon emissions in a given year. The SCC 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. SCC estimates are provided in dollars per metric ton of carbon dioxide. A value for the domestic SCC is meant to represent the damages in the United States resulting from a unit change in carbon dioxide emissions, whereas a global SCC is meant to reflect the value of damages worldwide.

Under section 1(b)(6) of Executive Order 12866,[1] 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 required by the Executive Order is to enable agencies to incorporate the monetized social benefits of reducing $CO_2$ emissions into cost-benefit analyses of regulatory actions. The estimates are presented with an acknowledgement of the many uncertainties involved and with a clear understanding that they will need updating in response to increasing knowledge of the science and economics of climate impacts.

As part of the interagency process that developed the SCC estimates, technical experts from numerous agencies met regularly to explore the technical literature in relevant fields, discuss key model inputs and assumptions, and consider public comments. The primary objective of the process was to develop a range of SCC values using a defensible set of assumptions regarding model inputs that was grounded in the scientific and economic literature. In this way, key uncertainties and model differences transparently and consistently inform the range of SCC estimates developed for use 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 several serious challenges. A report from the National Research Council[2] 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 effects of changes in climate on the physical and biological environment, and (4) the translation of those environmental impacts into economic damages. As a result, any effort to quantify and monetize the harms associated with climate change raises 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 $CO_2$ emissions. An 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 values appropriate for that year. Then the net present value of the benefits can be calculated by multiplying each of the 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.

## 14.3 DEVELOPMENT OF SOCIAL COST OF CARBON VALUES

In 2009, an interagency process was initiated to develop a preliminary assessment of how best to quantify the benefits from reducing carbon dioxide emissions. To provide consistency in how benefits are evaluated across Federal 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 literature to use as interim values until a more comprehensive analysis could be conducted. The outcome of the preliminary assessment was a set of five interim values: global SCC estimates for 2007 (in 2006$) of $55, $33, $19, $10, and $5 per ton of $CO_2$.[3] Those 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 that preliminary effort were presented in several proposed and final rules.

### 14.3.1 Current Approach and Key Assumptions

After the release of the interim values, the interagency group reconvened regularly to improve the 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 commonly used to estimate the SCC. The models are known by their acronyms of FUND, DICE, and PAGE. Those three models frequently are cited in the peer-reviewed literature and were used in the most recent assessment of the Intergovernmental Panel on Climate Change. Each model was given equal weight in developing SCC values.

Each model takes a slightly different approach to calculating how increases in emissions produce economic damages. A key objective of the interagency process was to enable a consistent exploration of the three models while respecting the different approaches taken by the key modelers in the field. An extensive review of the literature identified three sets of input parameters for the models: climate sensitivity; socioeconomic and emissions trajectories; and discount rates. A probability distribution for climate sensitivity was specified as an input to 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.

The interagency group selected four SCC values for use in regulatory analyses. Three values are based on the average SCC from the three integrated assessment models, at discount rates of 2.5 percent, 3 percent, and 5 percent. The fourth value, which represents the 95th percentile of the SCC estimate across all three models at a 3-percent discount rate, is included to represent larger-than-expected effects from temperature changes farther out in the tails of the SCC distribution. The values increase 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, although preference is given to consideration of the global benefits of reducing $CO_2$ emissions. Table 14.2.1 presents the values in the 2010 interagency group report.[4]

**Table 14.2.1 Annual SCC Values for 2010-2050 from 2010 Interagency Report (in 2007$ per Metric Ton)**

| **Year** | **Discount Rate (%)** | | | |
|---|---|---|---|---|
| | 5 | 3 | 2.5 | 3 |
| | Average | Average | Average | 95th Percentile |
| 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 values used for the analysis of the effects of potential standards for dishwashers were generated using the most recent versions of the three integrated assessment models that have been published in the peer-reviewed literature, as described in the 2013 update from the interagency working group (revised November 2013).[4] Table 14.2.2 shows the updated sets of SCC estimates in 5-year increments from 2010 to 2050. The full set of annual SCC estimates for 2010–2050 is presented in appendix 14-B of this TSD. The central value that emerges is the average SCC across models at a 3-percent discount rate. To capture the uncertainties involved in regulatory impact analysis, however, the interagency group emphasizes the importance of including all four sets of SCC values.

**Table 14.2.2 Annual SCC Values for 2010–2050 from 2013 Interagency Update (in 2007$ per Metric Ton of $CO_2$)**

| **Year** | **Discount Rate (%)** | | | |
|---|---|---|---|---|
| | 5 | 3 | 2.5 | 3 |
| | Average | Average | Average | 95th Percentile |
| 2010 | 11 | 32 | 51 | 89 |
| 2015 | 11 | 37 | 57 | 109 |
| 2020 | 12 | 43 | 64 | 128 |
| 2025 | 14 | 47 | 69 | 143 |
| 2030 | 16 | 52 | 75 | 159 |
| 2035 | 19 | 56 | 80 | 175 |
| 2040 | 21 | 61 | 86 | 191 |
| 2045 | 24 | 66 | 92 | 206 |
| 2050 | 26 | 71 | 97 | 220 |

### 14.3.2 Limitations of Current Estimates

The interagency group recognizes that current models are imperfect and incomplete. Because key uncertainties remain, current SCC estimates should be treated as provisional and revisable. Estimates doubtless will evolve in response to improved scientific and economic understanding. The 2009 National Research Council report[2] points out the tension between producing quantified estimates of the economic damages from an incremental ton of carbon and the limits of current modeling efforts. Several analytic challenges are being addressed by the research community, some by research programs housed in many of the Federal agencies participating in the interagency process. The interagency group intends to review and reconsider SCC estimates periodically to incorporate expanding knowledge of the science and economics of climate impacts, as well as improvements in modeling.

In summary, in considering the potential global benefits resulting from reduced $CO_2$ emissions, DOE used the values from the 2013 interagency report, applying the GDP price deflator to adjust the values to 2013$. For the four SCC values, the values of emissions in 2015 were $12.0, $40.5, $62.4, and $119 per metric ton avoided (values expressed in 2013$). DOE derived values after 2050 using the relevant growth rates for 2040–2050 in the interagency update.

DOE multiplied the $CO_2$ emissions reduction estimated for each year by the SCC value for that year under each discount rate. To calculate a present value of the stream of monetary values, DOE discounted the values in each of the four cases using the same discount rate that had been used to obtain the SCC values in each case.

## 14.4 VALUATION OF OTHER EMISSIONS REDUCTIONS

DOE considered the potential monetary benefits of reduced $NO_X$ emissions attributable to the TSLs considered for residential dishwashers. As noted in chapter 13, new or amended energy conservation standards would reduce $NO_X$ emissions in those States that are not affected by emissions caps. DOE estimated the monetized value of $NO_X$ emissions reductions resulting from each TSL based on estimates of environmental damage found in the scientific literature. Estimates suggest a wide range of monetary values, from \$476 to \$4,893 per ton (in 2013\$).[5] DOE calculated monetary benefits using a median value for $NO_X$ emissions of \$2,684 per short ton (in 2013\$), at real discount rates of 3 percent and 7 percent.

DOE continues to evaluate appropriate values for monetizing avoided $SO_2$ and Hg emissions. DOE did not monetize those emissions for this analysis.

## 14.5 RESULTS

Table 14.4.1 presents the global values of $CO_2$ emissions reductions for each considered TSL.

**Table 14.4.1 Estimates of Global Present Value of $CO_2$ Emissions Reduction under TSLs for Residential Dishwashers**

| TSL | SCC Case* | | | |
|---|---|---|---|---|
| | 5% discount rate, average* | 3% discount rate, average* | 2.5% discount rate, average* | 3% discount rate, 95th percentile* |
| | Million 2013$ | | | |
| **Primary Energy Emissions** | | | | |
| 1 | 1.74 | 7.70 | 12.1 | 23.9 |
| 2 | 400 | 1,849 | 2,937 | 5,725 |
| 3 | 901 | 4,246 | 6,773 | 13,138 |
| **Upstream Emissions** | | | | |
| 1 | 0.529 | 2.39 | 3.79 | 7.40 |
| 2 | 27.1 | 126 | 200 | 390 |
| 3 | 62.4 | 296 | 473 | 917 |
| **Full-Fuel-Cycle Emissions** | | | | |
| 1 | 2.27 | 10.1 | 15.9 | 31.3 |
| 2 | 427 | 1,975 | 3,137 | 6,114 |
| 3 | 964 | 4,542 | 7,246 | 14,056 |

* For each of the four cases, the corresponding global SCC value for emissions in 2015 is $12.0, $40.5, $62.4, and $119 per metric ton (2013$).

After calculating global values of $CO_2$ emissions reductions for each considered TSL, DOE calculated domestic values as a range of from 7 percent to 23 percent of the global values. Results for domestic values are presented in Table 14.4.2.

### Table 14.4.2 Estimates of Domestic Present Value of $CO_2$ Emissions Reduction under TSLs for Residential Dishwashers

| TSL | SCC Case* | | | |
|---|---|---|---|---|
| | 5% discount rate, average* | 3% discount rate, average* | 2.5% discount rate, average* | 3% discount rate, 95th percentile* |
| | Million 2013$ | | | |
| **Primary Energy Emissions** | | | | |
| 1 | 0.1 to 0.4 | 0.5 to 1.8 | 0.8 to 2.8 | 1.7 to 5.5 |
| 2 | 28.0 to 92.1 | 129.4 to 425.3 | 205.6 to 675.5 | 400.7 to 1,316.7 |
| 3 | 63.1 to 207.3 | 297.2 to 976.5 | 474.1 to 1,557.7 | 919.7 to 3,021.8 |
| **Upstream Emissions** | | | | |
| 1 | 0.0 to 0.1 | 0.2 to 0.6 | 0.3 to 0.9 | 0.5 to 1.7 |
| 2 | 1.9 to 6.2 | 8.8 to 28.9 | 14.0 to 46.0 | 27.3 to 89.6 |
| 3 | 4.4 to 14.3 | 20.7 to 68.1 | 33.1 to 108.8 | 64.2 to 210.9 |
| **Full-Fuel-Cycle Emissions** | | | | |
| 1 | 0.2 to 0.5 | 0.7 to 2.3 | 1.1 to 3.7 | 2.2 to 7.2 |
| 2 | 29.9 to 98.3 | 138.2 to 454.2 | 219.6 to 721.5 | 428.0 to 1,406.3 |
| 3 | 67.5 to 221.7 | 317.9 to 1,044.6 | 507.2 to 1,666.5 | 983.9 to 3,232.8 |

* For each of the four cases, the corresponding SCC value for emissions in 2015 is $12.0, $40.5, $62.4, and $119 per metric ton (2013$).

Table 14.4.3 presents the present value of cumulative $NO_X$ emissions reductions for each TSL. Monetary values are calculated using the average dollar-per-ton values assigned to $NO_X$ emissions at 7-percent and 3-percent discount rates.

**Table 14.4.3 Estimates of Present Value of $NO_X$ Emissions Reduction under TSLs for Residential Dishwashers**

| TSL | 3% discount rate | 7% discount rate |
|---|---|---|
| | Million 2013$ | |
| **Primary Energy Emissions** | | |
| 1 | 3.23 | 1.56 |
| 2 | 95.5 | 44.4 |
| 3 | 221 | 98.5 |
| **Upstream Emissions** | | |
| 1 | 1.68 | 0.820 |
| 2 | 77.9 | 34.8 |
| 3 | 179 | 76.9 |
| **Full-Fuel-Cycle Emissions** | | |
| 1 | 4.91 | 2.38 |
| 2 | 173 | 79.2 |
| 3 | 400 | 175 |

## REFERENCES

---

1 Presidential Documents–Executive Order 12866–Regulatory Planning and Review. 58 FR, 51735 (October 4, 1993). (Last accessed June 28, 2014.) <http://www.archives.gov/federal-register/executive-orders/pdf/12866.pdf>

2 National Research Council. *Hidden Costs of Energy: Unpriced Consequences of Energy Production and Use*. 2010. National Academies Press. Washington, D.C. (Last accessed June 28, 2014.) <http://www.nap.edu/catalog.php?record_id=12794>

3 Interagency Working Group on Social Cost of Carbon. *Technical Support Document: Social Cost of Carbon for Regulatory Impact Analysis under Executive Order 12866.* February 2010. United States Government. Washington, D.C. (Last accessed June 28, 2014.) <http://www.whitehouse.gov/sites/default/files/omb/inforeg/for-agencies/Social-Cost-of-Carbon-for-RIA.pdf>

4 Interagency Working Group on Social Cost of Carbon. *Technical Support Document: Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis under Executive Order 12866.* May 2013. United States Government. Washington, D.C. (Last accessed June 28, 2014.) <http://www.whitehouse.gov/sites/default/files/omb/inforeg/social_cost_of_carbon_for_ria_2013_update.pdf>

5 U.S. Office of Management and Budget (OMB). *2006 Report to Congress on the Costs and Benefits of Federal Regulations and Unfunded Mandates on State, Local, and Tribal Entities*. 2006. Washington, D.C. (Last accessed June 28, 2014.) <http://www.whitehouse.gov/sites/default/files/omb/assets/omb/inforeg/2006_cb/2006_cb_final_report.pdf>

# CHAPTER 15. UTILITY IMPACT ANALYSIS

## TABLE OF CONTENTS

## LIST OF TABLES

## LIST OF FIGURES

# 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. As of 2014, DOE is using a new methodology based on results published for the *Annual Energy Outlook 2014 (AEO 2014)* Reference case and a set of side cases that implement a variety of efficiency-related policies.[2]

The new approach retains key aspects of DOE's previous methodology, and provides some improvements:

- 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 side cases to estimate the utility impacts enhances the transparency of DOE's analysis.
- The variability in impacts estimates from one edition of AEO to the next will be reduced under the new approach.

On the average, however, over the full analysis period, the results from the new approach are comparable to results from the old approach.

---

[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]

## 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.

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 by fuel type may change. 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's new approach examines a series of AEO side cases to estimate the relationship between demand reductions and the marginal energy, emissions and capacity changes. The assumptions for each side case are documented in Appendix E of the AEO. The side cases, or scenarios, that incorporate significant changes to equipment efficiencies relative to the Reference case are:

- 2013 Technology (leaves all technologies at 2013 efficiencies);
- Best Available Technology (highest efficiency irrespective of cost);
- High Technology (higher penetration rates for efficiency and demand management);
- Extended Policies (includes efficiency standards that are not in the reference).

Scenarios that incorporate policies that directly affect the power sector without changes in energy demand (for example, subsidies for renewables, or high fuel price assumptions) are not appropriate for this analysis. The methodology proceeds in seven steps:

1. Supply-side data on generation, capacity and emissions, and demand-side data on electricity use by sector and end-use, are extracted from each side case. The data are converted to differences relative to the AEO Reference case.

2. The changes in electricity use on the demand-side data are allocated to one of three categories: on-peak, shoulder, and off-peak. These categories are used in the utility sector to correlate end-use consumption with supply types. For each of the end-uses that are modeled explicitly in NEMS, load shape information is used to identify the fraction of annual electricity use assigned to each category. On-peak hours are defined as noon-5pm, June through September. Off-peak hours are nights and Sundays. All other hours are assigned to the shoulder period.

3. For each year and each side case, the demand-side reductions to on-peak, off-peak and shoulder-period electricity use are matched on the supply-side to reductions in generation by fuel type. The fuel types are petroleum fuels, natural gas, renewables, nuclear and coal. The allocation is based on the following rules:
    3.1. All petroleum-based generation is allocated to peak periods;
    3.2. Natural gas generation is allocated to any remaining peak reduction; this is consistent with the fact that oil and gas steam units are used in NEMS to meet peak demand;
    3.3. Base-load generation (nuclear and coal) is allocated proportionally to all periods;
    3.4. The remaining generation of all types is allocated to the remaining off-peak and shoulder reductions proportionally.
4. The output of step 3 defines fuel-share weights giving the fraction of energy demand in each load category that is met by each fuel type as a function of time. These are combined with the weights that define the load category shares by end-use to produce coefficients that allocate a marginal reduction in end-use electricity demand to each of the five fuel types.
5. A regression model is used to relate reductions in generation by fuel type to reductions in emissions of power sector pollutants. The model produces coefficients that define the change in total annual emissions of a given pollutant resulting from a unit change in total annual generation for each fuel type, as a function of time. These coefficients are combined with the weights calculated in step 4 to produce coefficients that relate emissions changes to changes in end-use demand.
6. A regression model is used to relate reductions in generation by fuel type to reductions in installed capacity. The categories used for installed capacity are the same as for generation except for peak: NEMS uses two peak capacity types (combustion turbine/diesel and oil and gas steam) which are combined here into a single “peak” category. The model produces coefficients that define the change in total installed capacity of a given type resulting from a unit change in total annual generation for the corresponding fuel type. These coefficients are combined with the weights calculated in step 4 to produce coefficients that relate installed capacity changes to changes in end-use demand, as a function of time.
7. The coefficient time-series for fuel share, pollutant emissions and capacity for the appropriate end use are multiplied by the stream of energy savings calculated in the NIA to produce estimates of the utility impacts.

This analysis ignores pumped storage, fuel cells and distributed generation, as these generation types are not affected by the policy changes modeled in the EIA side cases. The methodology is described in more detail in K. Coughlin, “Utility Sector Impacts of Electricity Demand Reductions” (Coughlin, 2014).[4]

## 15.3 UTILITY IMPACT RESULTS

This section presents results of the analysis for all of the capacity types.

### 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 factors (megawatts (MW) of capacity reduction per gigawatt hours (GWh) of generation reduction) calculated using the methodology described in Section 15.2. Note that a negative number means an increase in capacity under a TSL

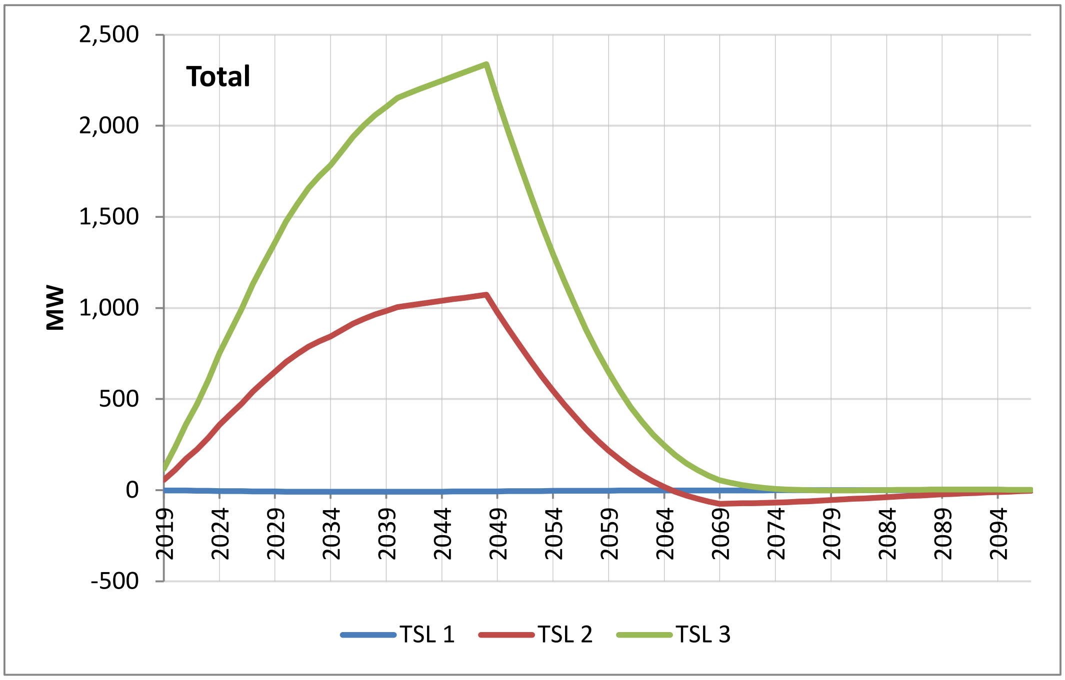


**Figure 15.3.1 Dishwashers: Total Electric Capacity Reduction**

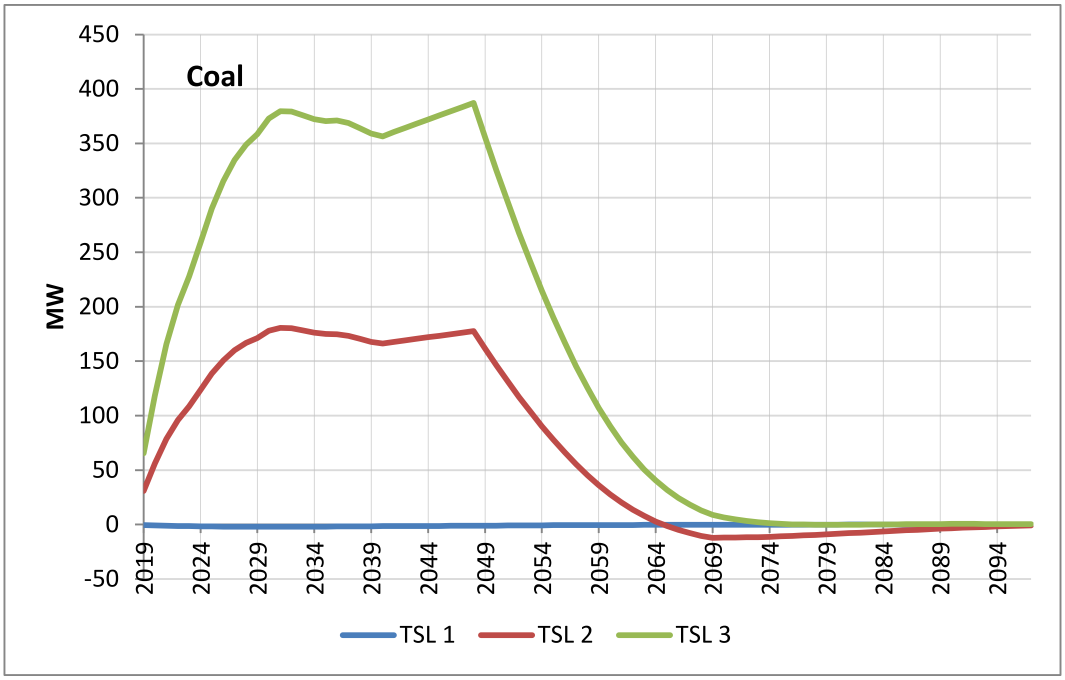


Figure 15.3.2 Dishwashers: Coal Capacity Reduction

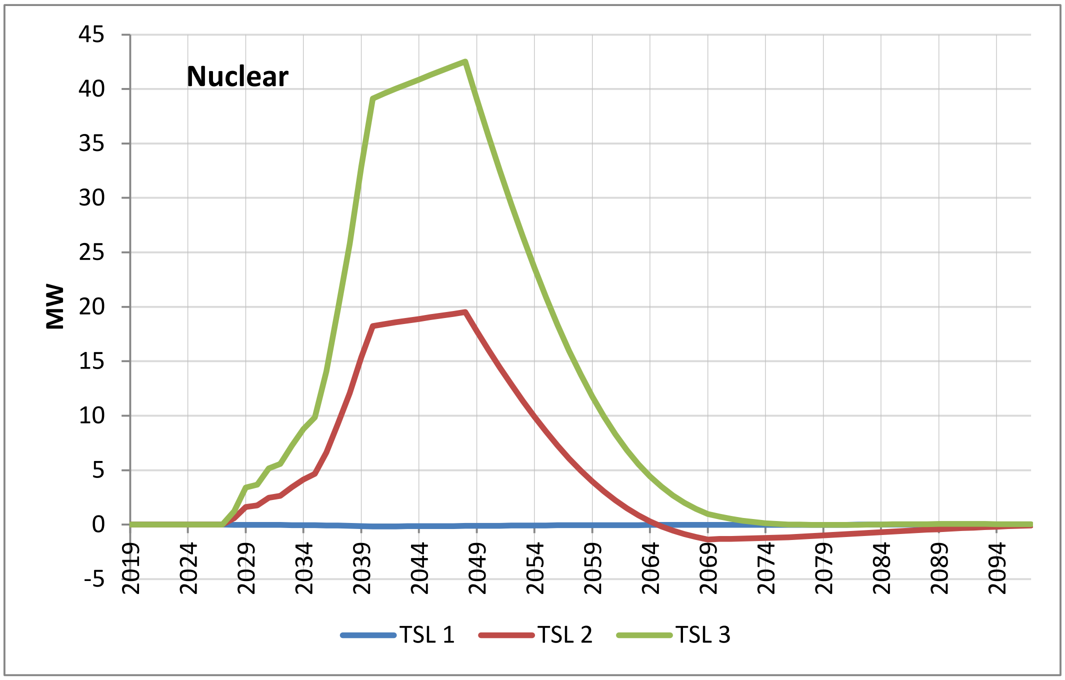


Figure 15.3.3 Dishwashers: Nuclear Capacity Reduction

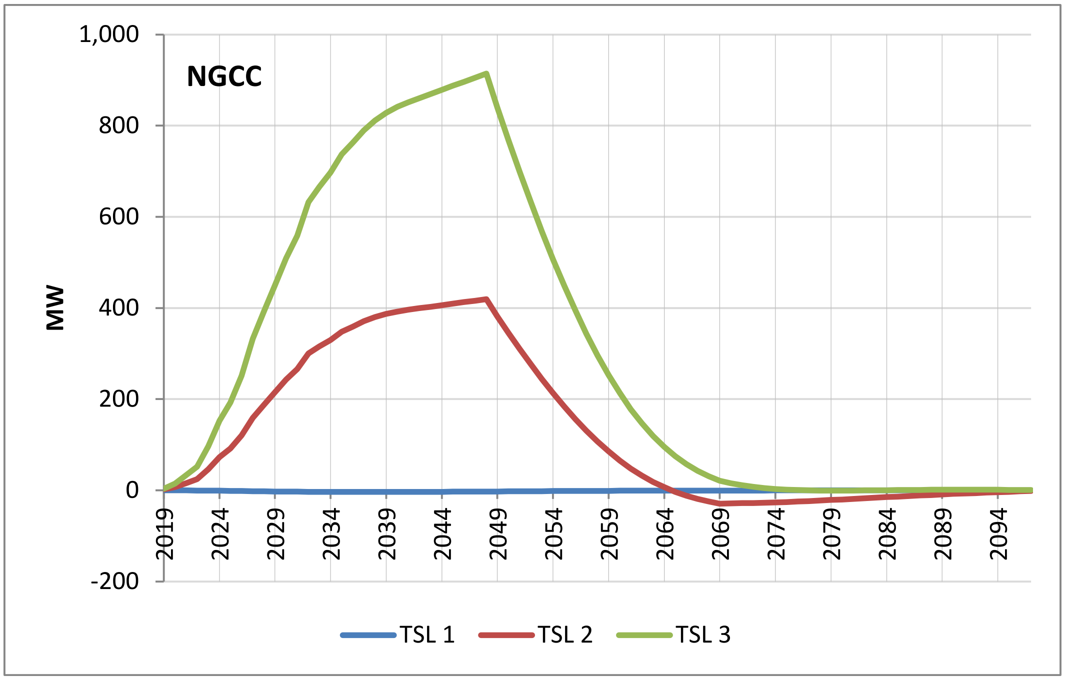


Figure 15.3.4 Dishwashers: Gas Combined Cycle Capacity Reduction

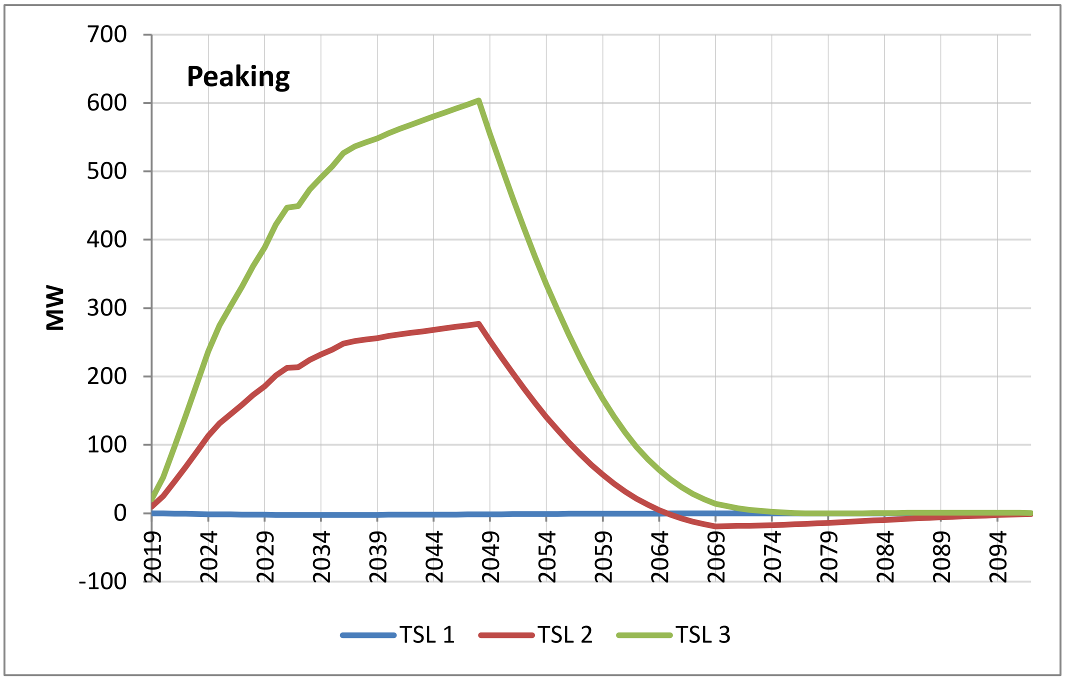


Figure 15.3.5 Dishwashers: Peaking Capacity Reduction

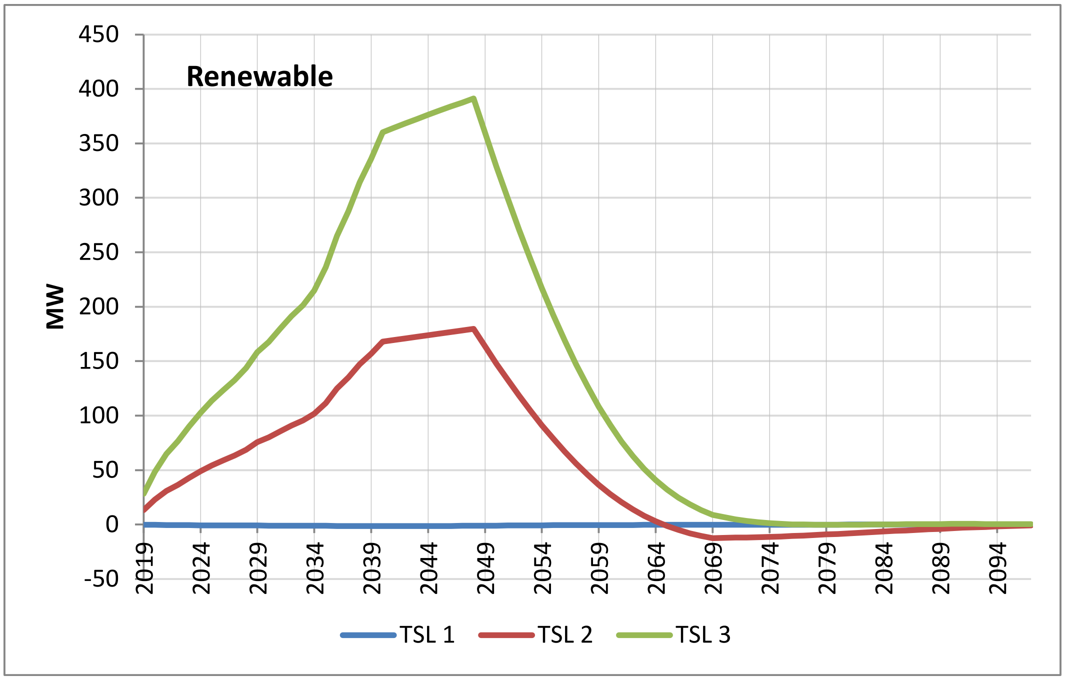


**Figure 15.3.6 Dishwashers: Renewables Capacity Reduction**

### 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 Section 15.2.

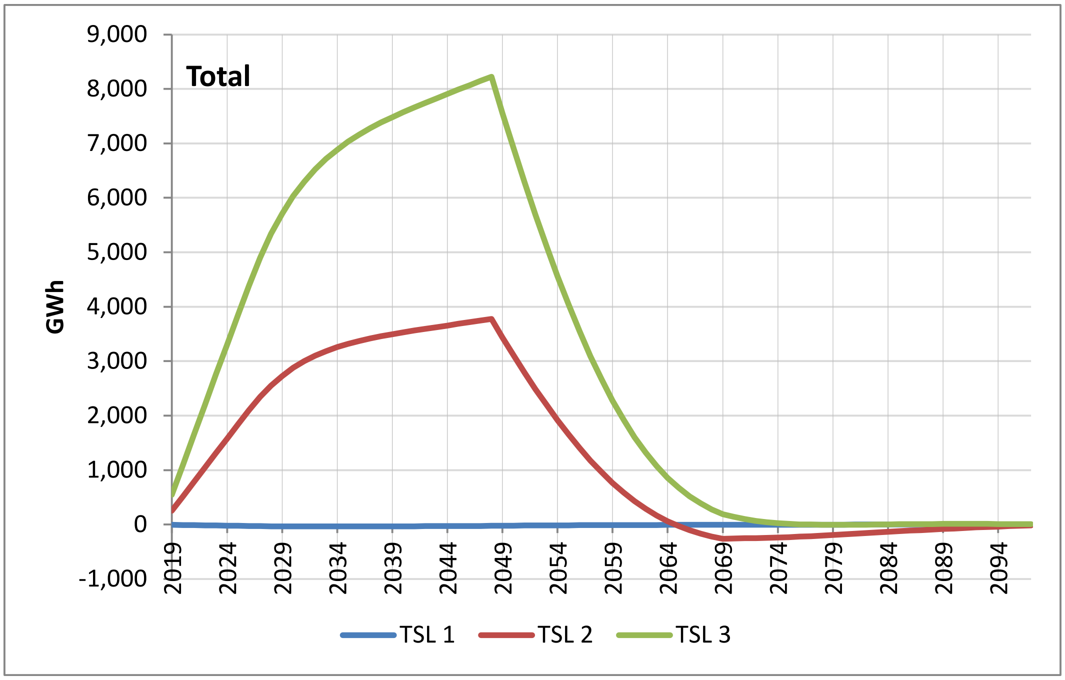


Figure 15.3.7 Dishwashers: Total Generation Reduction

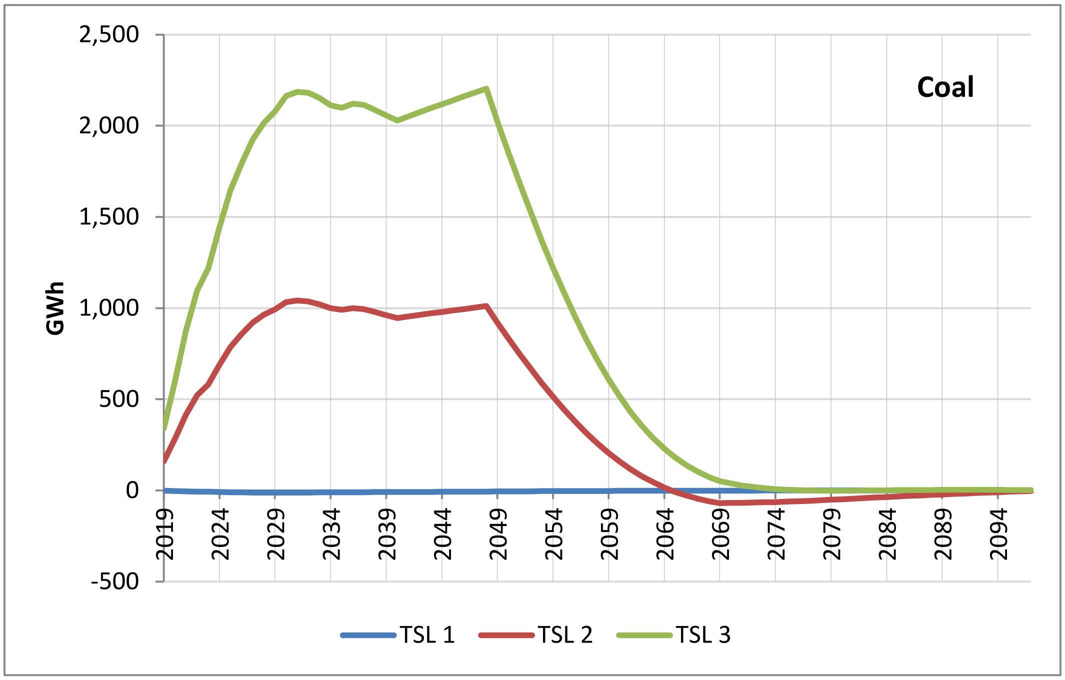


Figure 15.3.8 Dishwashers: Coal Generation Reduction

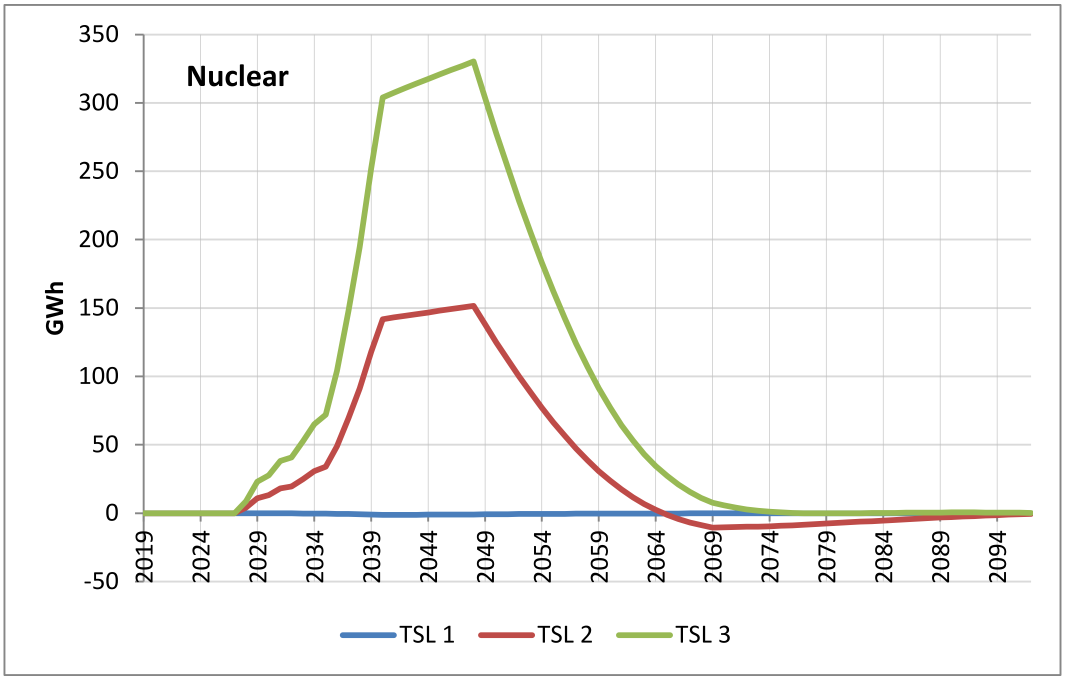


Figure 15.3.9 Dishwashers: Nuclear Generation Reduction

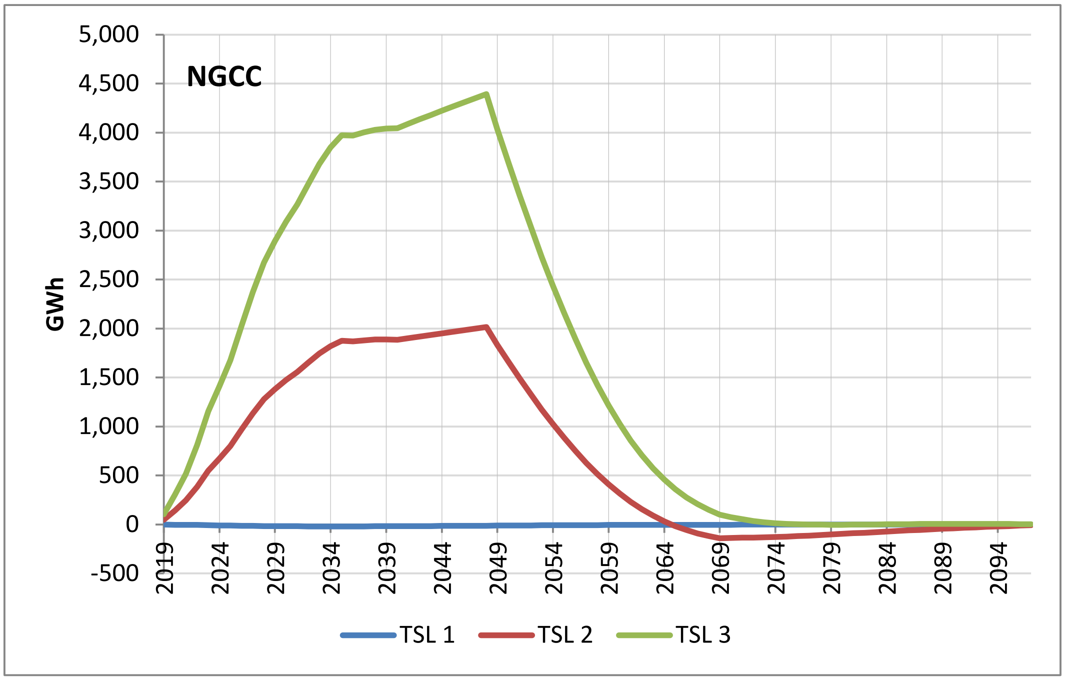


Figure 15.3.10 Dishwashers: Gas Combined Cycle Generation Reduction

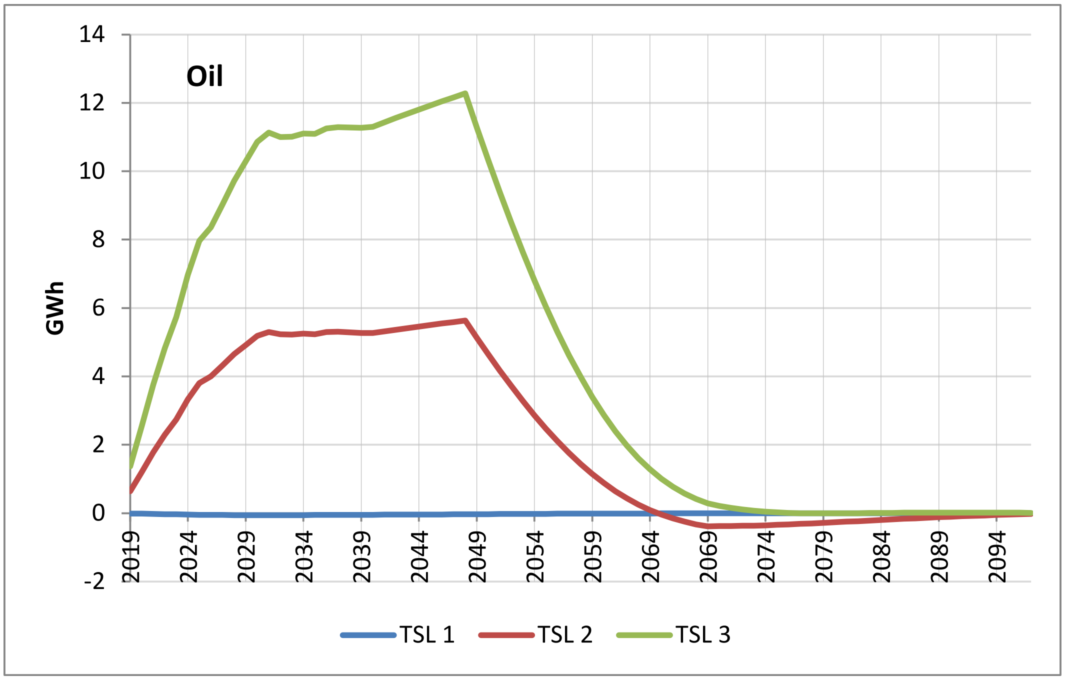


**Figure 15.3.11 Dishwashers: Oil Generation Reduction**

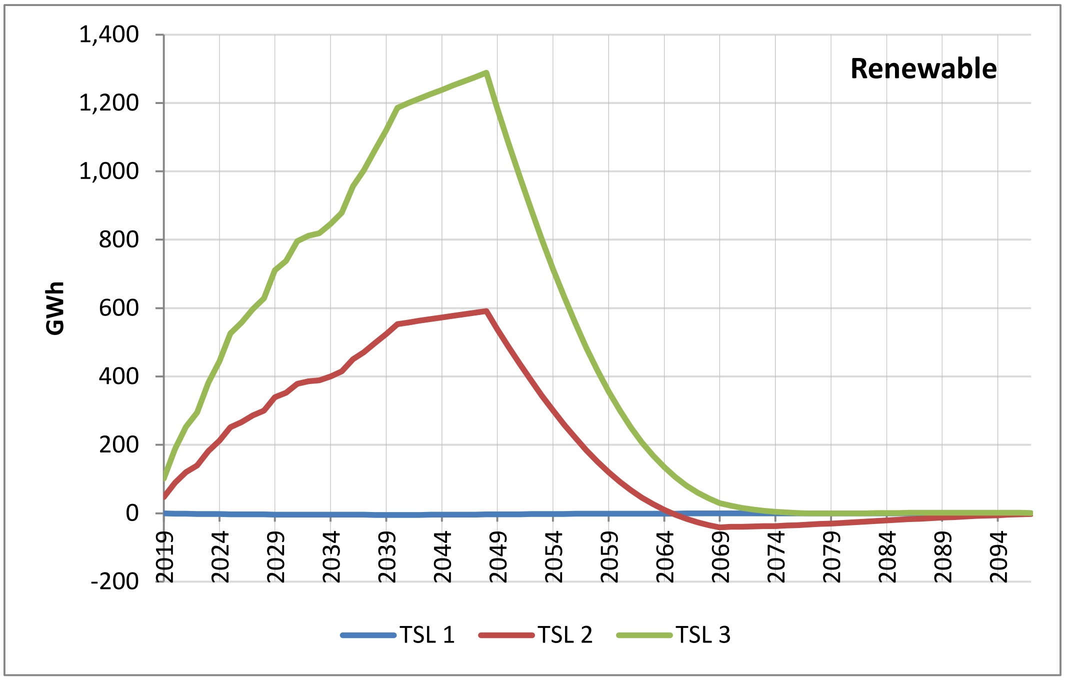


**Figure 15.3.12 Dishwashers: Renewables Generation Reduction**

### 15.3.3 Results Summary

Table 15.3.1 presents a summary of the utility impact results for dishwashers.

**Table 15.3.1 Dishwashers: Summary of Utility Impact Results**

| | **TSL** | | |
|---|---|---|---|
| | **1** | **2** | **3** |
| **Installed Capacity Reduction (MW)** | | | |
| 2020 | -1.57 | 110 | 234 |
| 2025 | -5.30 | 416 | 871 |
| 2030 | -8.18 | 704 | 1,475 |
| 2035 | -9.16 | 878 | 1,861 |
| 2040 | -9.03 | 1,004 | 2,153 |
| **Electricity Generation Reduction (GWh)** | | | |
| 2020 | -7.37 | 518 | 1,097 |
| 2025 | -23.5 | 1,842 | 3,854 |
| 2030 | -33.4 | 2,877 | 6,030 |
| 2035 | -34.6 | 3,319 | 7,032 |
| 2040 | -31.7 | 3,531 | 7,572 |

## REFERENCES

1. U.S. Department of Energy-Energy Information Administration, *National Energy Modeling System: An Overview*, 2009. Report No. DOE/EIA-0581(2009). <http://www.eia.gov/oiaf/aeo/overview/>

2. Energy Information Administration, *Annual Energy Outlook 2014 with Projections to 2040*, 2014. Washington, DC. <http://www.eia.gov/forecasts/aeo/pdf/0383(2014).pdf>

3. Coughlin, K., H. Shen, P. Chan, B. McDevitt, and A. Sturges, *Marginal Utility Sector Impacts of Reduced Electricity Demand*, 2012.

4. Coughlin, K., *Utility Sector Impacts of Reduced Electricity Demand*, 2014. Lawrence Berkeley National Laboratory. Report No. LBNL-xxxx.

# CHAPTER 16. EMPLOYMENT IMPACT ANALYSIS

## TABLE OF CONTENTS

## LIST OF TABLES

# CHAPTER 16. EMPLOYMENT IMPACT ANALYSIS

## 16.1 INTRODUCTION

The U.S. Department of Energy's (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 dishwashers. Job increases or decreases reported in this chapter are separate from the direct manufacturing sector employment impacts reported in chapter 12 and reflect the employment impact of efficiency standards on all other 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 appliances, including the retail price plus sales tax, and increase installation costs.

Using an input/output econometric model of the U.S. economy, ImSET, this analysis estimated the short-term effect of these expenditure impacts on net economic output and employment. The Pacific Northwest National Laboratory developed the model, ImSET 3.1.1[1] (Impact of Sector Energy Technologies), as a successor to ImBuild[2], a special-purpose version of the IMPLAN[3] national input/output model. DOE intends 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 there are uncertainties involved in projecting employment impacts, especially the changes in the later years of the analysis.[4] ImSET is not a general equilibrium forecasting model and therefore has its limitations. 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. As input/output models do not allow prices to bring markets into equilibrium, they are best used for short-run analyses. DOE, therefore, includes 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, ImSET, that estimates the effects of standards on major sectors of the economy related to buildings and the net impact of standards on jobs. ImSET estimates the employment and income effects of building energy technologies. In comparison with simple economic multiplier approaches, ImSET allows for a 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 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 affect the overall level of employment.

ImSET uses a 187-sector model of the national economy to predict the economic effects of residential and commercial building 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 appliances. The increased cost of appliances leads to higher employment in the appliance manufacturing sectors and lower employment in other economic sectors. Second, commercial firm and residential spending are redirected from utilities toward firms that supply production inputs. Third, electric utility sector investment funds are released for use in other sectors of the economy. When consumers use less energy, electric 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 dishwasher 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 indirect employment impacts of dishwasher 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 does not predict variation in non-energy operation and maintenance costs by dishwasher efficiency level. DOE presents the summary impacts in this section.

Conceptually, one can consider the impact of the rule in its first year on three aggregate sectors: the dishwasher production sector, the energy generation sector, and the general consumer good sector. (As mentioned previously, ImSET's calculations are made at a much more disaggregated level.) By raising energy efficiency, the rule increases the purchase price of dishwashers; 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 electricity. The reduction in electricity demand causes a reduction in employment in that sector. Finally, based on the net impact of increased expenditures on dishwashers and reduced expenditures on electricity, 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, generating more employment; the converse is true for workers who are laid off.)

Table 16.4.1 presents the modeled net employment impact from the rule in 2019, rounded to the nearest ten jobs. Approximately 93% of dishwashers are domestically produced and 7% are imported. The net employment impact estimate is sensitive to assumptions regarding the return to the U.S. economy of money spent on imported dishwashers. The two scenarios bounding the ranges presented in Table 16.4.1 represent situations in which none of the money spent on imported dishwashers returns to the U.S. economy and all of the money spent on imported dishwashers 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 dishwashers is likely to return, with employment impacts falling within the ranges presented below.

**Table 16.4.1 Net National Short-Term Change in Employment (Number of Jobs)**

| Trial Standard Level | 2019 | 2024 |
|---|---|---|
| 1 | -60 to -50 | -50 to -40 |
| 2 | -2,180 to -1,860 | -1,860 to -1,000 |
| 3 | -2,220 to -1,870 | -80 to 280 |

For context, the Office of Management and Budget (OMB) currently projects that the official unemployment rate may decline to 6.8% during 2014 and drop further to 5.4% in 2017.[5] The unemployment rate in 2019 is projected to be 5.4%, which is close to "full employment." When an economy is at full employment, any effects of a dishwasher standard on net employment are likely to be transitory as workers change jobs, rather than enter or exit longer-term employment.

## 16.5 LONG-TERM IMPACTS

Due to the short payback period of energy efficiency improvements mandated by this rule, over the long term DOE expects the energy savings to consumers to increasingly dominate the increase in appliance costs, resulting in increased aggregate savings to consumers. As a result, DOE expects demand for electricity to decline over time and demand for other goods to increase. As the electricity generation sector is relatively capital intensive compared to the consumer goods sector, the net effect will be an increase in labor demand. In equilibrium, this should lead to upward pressure on wages and a shift in employment away from electricity generation towards consumer goods. Note that, in a 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 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 2024, are included in the second column of Table 16.4.1.

## REFERENCES

1. Roop, J. M., M. J. Scott, and R. W. Schultz, *ImSET: Impact of Sector Energy Technologies*, 2005. Pacific Northwest National Laboratory. Richland, WA. Report No. PNNL- 15273.

2. Scott, M. J., D. J. Hostick, and D. B. Belzer, *ImBuild: Impact of Building Energy Efficiency Programs*, April, 1998. Pacific Northwest National Laboratory. Richland, WA. Report No. PNNL-11884.

3. Minnesota IMPLAN Group Inc., *IMPLAN Professional: User's Guide, Analysis Guide, Data Guide*, 1997. Stillwater, MN.

4. Scott, M., JM Roop, RW Schultz, DM Anderson, KA Cort, The Impact of DOE Building Technology Energy Efficiency Programs on U.S. Employment, Income, and Investment. *Energy Economics*, 2008. 30(5): pp. 2283-2301

5. Office of Management and Budget, *Fiscal Year 2014 Mid-Session Review: Budget of the U.S. Government*, <http://www.whitehouse.gov/sites/default/files/omb/budget/fy2014/assets/14msr.pdf>

# CHAPTER 17. REGULATORY IMPACT ANALYSIS

## TABLE OF CONTENTS

## LIST OF TABLES

## LIST OF FIGURES

# CHAPTER 17. REGULATORY IMPACT ANALYSIS

## 17.1 INTRODUCTION

Under 10 CFR part 430, subpart C, appendix A, section III.12, the U.S. Department of Energy (DOE) committed to evaluating non-regulatory alternatives to adopted standards. 61 FR 36981, Volume 61, No. 136, page 36978. (November 15, 1996). (October 4, 1993). This regulatory impact analysis (RIA), evaluates potential non-regulatory alternatives, comparing the costs and benefits of each to those of the proposed standards.

For this RIA, DOE used an integrated National Impact Analysis (NIA)-RIA model built on the NIA model discussed in chapter 10 for its analysis. DOE studied the impacts of the non-regulatory policies on the standard-sized product class.

DOE identified five non-regulatory policy alternatives that possibly could provide incentives for the same energy efficiency levels as the proposed standards for the products 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 proposed standard.

**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 the five policies listed above. Section 17.4 presents the results of the policy alternatives.

## 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 standard-sized residential dishwashers. 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 17-A discusses the NIA-RIA integrated model approach.

DOE quantified the effect of each alternative on the purchase of products that meet target levels, which are defined as the efficiency levels in the proposed standards. 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 products meeting target efficiency levels in the proposed standard. The shipments of products for any given year reflect a distribution of efficiency levels. DOE assumed that the proposed standards would affect 100 percent of the shipments of products that did not meet target levels in the base case,[a] 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 residential dishwashers 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 proposed standards. In some 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 primary energy saved over the lifetime of equipment purchased during the 30-year analysis period starting in the effective date of the policy (2019-2048).

- Net Present Value (NPV), represents the value of net monetary savings in 2014, expressed in 2013$, from equipment purchased during the 30-year analysis period starting in the effective date of the policy (2019-2048). DOE calculated the NPV as the difference between the present values of the total installed equipment cost and operating expenditures in the base case and the present values of those costs in each policy case. DOE calculated operating expenses (including energy costs) for the life of equipment.

---

[a] The base case for the NIA is a market-weighted average of units at several efficiency levels.

### 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' responses 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 residential dishwashers relative to their base 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 levels as required by the proposed standards (the target levels). As opposed to the standards case, however, the policy cases may not lead to 100 percent market penetration of units that meet target levels.

Table 17.2.1 shows the efficiency levels stipulated in the proposed standards for residential dishwashers.

**Table 17.2.1 Efficiency Levels in Proposed Standard Level for Standard-Sized Residential Dishwashers (TSL 2)**

| **Level** | **Annual Energy Use** (kWh/year) | **Annual Water Use** (1,000 gal/year) |
|---|---|---|
| Baseline | 307 | 1.08 |
| 3 | 234 | 0.67 |

DOE assumed that the effects of non-regulatory policies would last from the effective date of standards—2019—through the end of the analysis period, which is 2048.

### 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 energy efficiency standards with consumer rebates. However, DOE attempted to make conservative assumptions to avoid double-counting policy impacts. The resulting policy impacts are not additive; 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 standard-sized residential dishwashers.

## 17.3 NON-REGULATORY POLICY ASSUMPTIONS

The following subsections describe DOE's analysis of the impacts of the six non-regulatory policy alternatives to proposed standards for residential dishwashers. (Because the alternative of No New Regulatory Action has no energy or NPV impacts, essentially representing the NIA base case, DOE did not perform any additional analysis for that alternative.) DOE developed estimates of the market penetration of high-efficiency 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 residential dishwashers constitutes the base case, as described in chapter 10, National Impact Analysis. The base 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 appliances. This policy provides a consumer rebate for purchasing residential dishwashers that operate at the same efficiencies as stipulated in proposed standards (target levels).

#### 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. This study, performed by XENERGY, Inc.,[b] 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

---

[b] XENERGY is now owned by KEMA, Inc. (www.kema.com)

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 analysis 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. *Internal sources* of information encourage consumers to purchase new products 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 17-A 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 products driven by consumer response to changes in B/C ratio induced by rebate programs. The penetration curves depict various diffusion patterns based on perceived barriers (from no barriers to extremely high barriers) to consumer purchase of high-efficiency products. DOE adjusted the XENERGY penetration curves based on expert advice founded on more recent utility program experience.[5, 8] DOE also devised an interpolation method to create penetration curves based on relationships between the actual base case market penetrations and actual B/C ratios. Appendix 17-A, sections 17-A.4.2 and 17-A.4.3, contain discussion on DOE's methodology for adjusting and interpolating the curves.

DOE modeled the effects of a consumer rebate policy for residential dishwashers by determining the increase in market penetration of products meeting the target level relative to their market penetration in the base case. It used the interpolation method presented in Blum et al (2011)[9] to create customized penetration curves based on relationships between actual base 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 residential dishwashers. It gathered data on utility or agency rebates throughout the nation for this product, and used this data to calibrate the customized penetration curves it developed for residential dishwashers so they can best reflect the market barrier level faced by this product class. Section 17.3.2.2 shows the interpolated curve used in the analysis.

#### 17.3.2.2 Analysis

For the standard-sized residential dishwasher product class, DOE estimated the effect of increasing its B/C ratio via a rebate that would pay all (or part) of the increased installed cost of a unit that met the target efficiency level compared to one meeting the baseline efficiency level.[c] To inform its estimate of an appropriate rebate amount, DOE performed a thorough nationwide search for existing rebate programs that includes 63 rebates for standard-sized residential dishwashers initiated by 57 utilities or agencies in various States. (Appendix 17-A identifies the rebate programs.) To represent the rebate level, DOE used the simple average of the rebate amounts for units meeting the target level in these programs. DOE assumed that these average rebates amounts would apply to models at all efficiency levels at or above the target level for this product class. DOE assumed that rebates would remain in effect at the same levels throughout the forecast period (2019-2048).

For standard-sized residential dishwashers, DOE first calculated the B/C ratio without a rebate using the difference in total installed costs (C) and lifetime operating cost savings (B) between the unit meeting the target level and the 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 receiving the rebate had a larger B/C ratio. Table 17.3.1 shows the effect of consumer rebates on the B/C ratio.

**Table 17.3.1 Benefit/Cost Ratios Without and With Rebates for Standard-Sized Residential Dishwashers (2013$)**

| Standard-sized Residential Dishwashers | Proposed Standard (TSL 2) |
|---|---|
| **B/C Ratio Without Rebate** | 1.1 |
| **Rebate Amount (2013$)** | 34.03 |
| **B/C Ratio With Rebate** | 1.6 |
| **Calculated Market Barrier Curve** | Low - Moderate |

DOE used these B/C ratios along with the penetration curve shown in Figure 17.3.1 to estimate the percentage of consumers who would purchase standard-sized residential dishwashers that meet the target levels both with and without a rebate incentive. The penetration curve calculated by DOE to represent the market behavior for standard-sized residential dishwashers is indicated in Table 17.3.1.

---

[c] The baseline technology for each product class is defined in the engineering analysis, chapter 5, as the technology that represents the basic characteristics of products in that class. A baseline unit typically is one that just meets current Federal energy conservation standards and provides basic consumer utility.

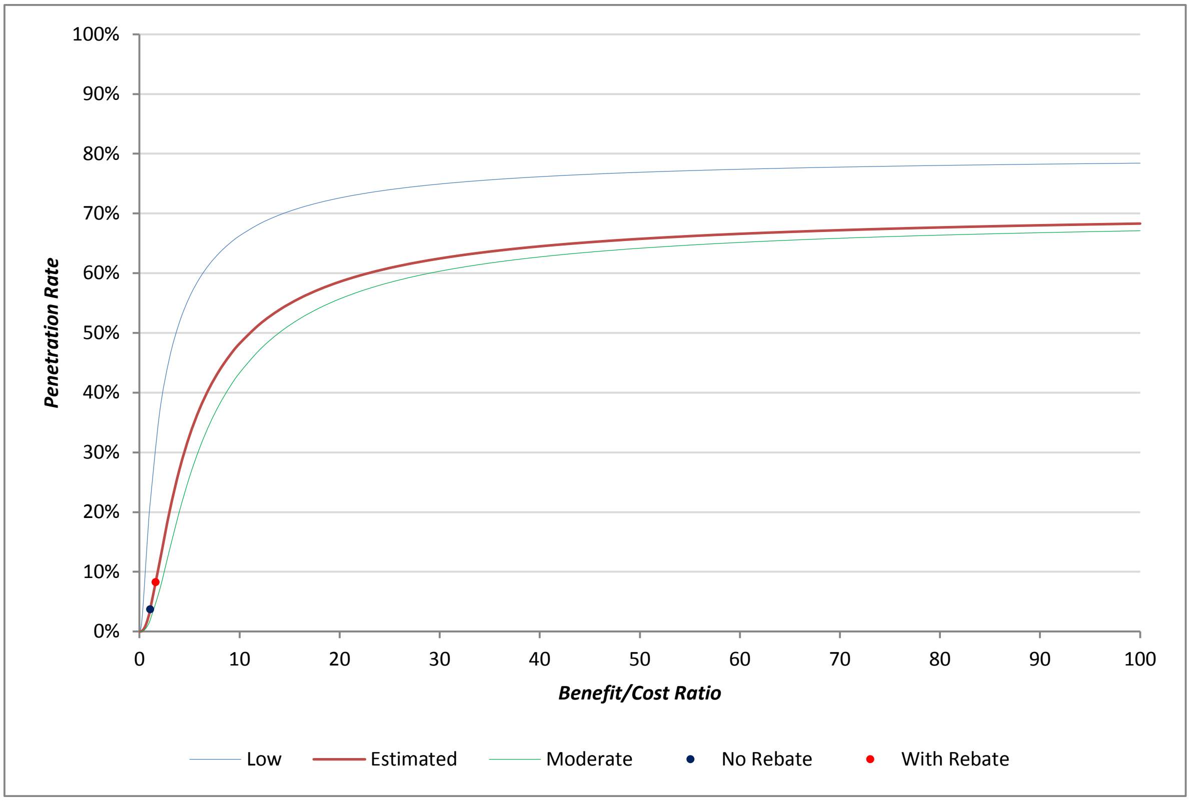


**Figure 17.3.1 Market Penetration Curve for Standard-Sized Residential Dishwashers**

DOE next estimated the percent increase represented by the change in penetration rate shown on the penetration curve. It then added that percent increase to the market share of units that meet the target level in the base 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 standard-sized residential dishwashers in 2019 that meet the target efficiency level for the proposed standard given a consumer rebate.

**Table 17.3.2 Market Penetrations in 2019 Attributable to Consumer Rebates for Standard-Sized Residential Dishwashers**

| Standard-sized Residential Dishwashers | Proposed Standard (TSL 2) |
|---|---|
| **Base-Case Market Share** | 3.7% |
| **Policy Case Market Share** | 8.2% |
| **Increased Market Share** | 4.5% |

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. Section 17.4 presents the resulting market penetration trends for the policy case of consumer rebates for standard-sized residential dishwashers.

### 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 standard-sized residential dishwashers, 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. 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.[13, 14] The American Taxpayer Relief Act of 2012 extended, with some modification, residential tax credits for air conditioners, heat pumps, furnaces, and water heaters placed in service between January 1, 2012 and December 21, 2013[15]. 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 dishwashers to warrant adjusting its analysis method for the Consumer Tax Credits policy case. Appendix 17-A contains more information on Federal consumer tax credits.

DOE also reviewed its previous analysis on Oregon's tax credits for clothes washers to provide support for its assumptions.[16] In the 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 17-A.

DOE applied the assumed 60 percent participation described above to the 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 penetration curve estimated for standard-sized residential dishwashers.

Table 17.3.3 summarizes DOE's assumptions for standard-sized residential dishwashers regarding the market penetration of units in 2019 that meet the target efficiency level for the proposed standard given a consumer tax credit.

**Table 17.3.3 Market Penetrations in 2019 Attributable to Consumer Tax Credits for Standard-Sized Residential Dishwashers**

| **Standard-sized Residential Dishwashers** | **Proposed Standard (TSL 2)** |
|---|---|
| **Base-Case Market Share** | 3.7% |
| **Policy Case Market Share** | 6.4% |
| **Increased Market Share** | 2.7% |

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 17-A shows the annual market share increases due to this policy. Section 17.4 presents the resulting efficiency trends for the policy case of consumer tax credits for standard-sized residential dishwashers that meet target efficiency levels.

### 17.3.4 Manufacturer Tax Credits

To analyze the potential effects of a policy that offers tax credits to manufacturers that produce standard-sized residential dishwashers that meet target efficiency levels, 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.[d] Because the direct price effect is approximately equivalent

---

[d] 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.

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. This 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.[17] Those manufacturer tax credits were in effect for dishwasher models produced in 2006 and 2007, reinstated for 2009 and 2010, and extended to 2011 with modifications in the eligibility requirements. DOE was unable to locate data from the Internal Revenue Service or other sources on manufacturer response to the Federal credits. Appendix 17-A, section 17-A.6.2, presents details on Federal manufacturer tax credits.

DOE applied the assumption of 30 percent participation to the penetration rates predicted for the rebate policy to estimate the effects of a manufacturer tax credit policy. In doing so, the Department incorporated the assumptions for consumer response to financial incentives from the penetration curve selected for standard-sized residential dishwashers.

Table 17.3.4 summarizes DOE’s assumptions for standard-sized residential dishwashers regarding the market penetration of units in 2019 meeting the target efficiency level given a manufacturer tax credit.

**Table 17.3.4 Market Penetrations in 2019 Attributable to Manufacturer Tax Credits for Standard-Sized Residential Dishwashers**

| Standard-sized Residential Dishwashers | Proposed Standard (TSL 2) |
|---|---|
| **Base-Case Market Share** | 3.7% |
| **Policy Case Market Share** | 5.0% |
| **Increased Market Share** | 1.4% |

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 17-A shows the annual market share increases due to this policy. Section 17.4 presents the resulting market penetration trends for the policy case of manufacturer tax credits for standard-sized residential dishwashers.

### 17.3.5 Voluntary Energy Efficiency Targets

DOE assumed that voluntary energy efficiency targets for standard-sized residential dishwashers would be achieved as manufacturers gradually stopped producing units that operated below the target efficiency levels. 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.[18, 19,20]

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 equipment over time. During the rebate analysis, when assessing the B/C ratio and market penetration in the base case for standard-sized residential dishwashers, DOE observed that the market barrier for standard-sized residential dishwashers is low-to-moderate. DOE estimates that voluntary energy efficiency targets could reduce these barriers to a low level over 10 years, and followed the methodology presented by Blum et al (2011)[9] to evaluate the effects that such a reduction in market barriers have on the market penetration of the product class of standard-sized residential dishwashers. 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.

Table 17.3.5 summarizes DOE's assumptions for standard-sized residential dishwashers regarding the market penetration of units in 2019 that meet the target efficiency level for the proposed standard given voluntary energy efficiency targets.

**Table 17.3.5 Market Penetrations in 2019 Attributable to Voluntary Energy Efficiency Targets for Standard-Sized Residential Dishwashers**

| Standard-sized Residential Dishwashers | Proposed Standard (TSL 2) |
|---|---|
| **Base-Case Market Share** | 3.7% |
| **Policy Case Market Share** | 5.7% |
| **Increased Market Share** | 2.0% |

The increased market shares attributable to voluntary energy efficiency targets shown in Table 17.3.5 were used as inputs in the NIA-RIA model. Appendix 17-A shows the annual market share increases due to this policy. Section 17.4 presents the resulting market penetration trends for the policy case of voluntary energy efficiency targets for standard-size residential dishwashers that meet target efficiency levels.

### 17.3.6 Bulk Government Purchases

Bulk government purchases can lead to Federal, State, and local governments purchasing large quantities of products that meet the target efficiency level. Combining the market demands of multiple public sectors also 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 calling for bulk government purchases 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, number of vendors, etc. 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.[21, 22]

DOE assumed that government agencies would administer a bulk purchasing program for residential dishwashers. At the federal level, this type of program could modify the current FEMP procurement guidelines for residential dishwashers, which refer to the ENERGY STAR requirements for residential dishwashers.[23] 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 the year 2000 already incorporated energy efficiency requirements based on FEMP guidelines. One scenario in the DOE report showed energy-efficient Federal 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 residential dishwashers meeting target efficiency levels.

DOE assumed that bulk government purchases would affect a subset of housing units for which government agencies purchased or influenced the purchase of dishwashers. This subset would consist primarily of public housing and housing on military bases. According to the 2009 Residential Energy Consumption Survey (RECS 2009), about 4.3 percent of all U.S. households are housing units in public housing authority, and 16.4 percent of those households had dishwashers.[26] DOE therefore estimated that 0.7 percent of U.S. housing units represent publicly owned households using dishwashers; this constitutes the population to which this policy would apply.

DOE estimated that starting in 2019, each year of a bulk government purchase policy would result in an increasing percent of shipments of government-purchased units beyond the base case that would meet target efficiency levels. DOE estimated that within 10 years (by 2028) bulk government purchasing programs would result in 80 percent of the dishwasher market for publicly owned housing meeting target levels. DOE modeled the bulk government purchase program assuming that the market share for dishwashers achieved in 2028 would be at least maintained throughout the rest of the forecast period. Appendix 17-A, Table 17-A.2.2, shows the annual market share increases due to this policy used as inputs to the NIA-RIA model. Section 17.4 presents the resulting efficiency trends for the policy case of bulk government purchase of residential dishwashers.

Table 17.3.6 summarizes DOE's assumptions for standard-sized residential dishwashers regarding the market penetration of units in 2019 that meet the target efficiency level for the proposed standards given bulk government purchasing.

**Table 17.3.6 Market Penetrations in 2019 Attributable to Bulk Government Purchasing for Standard-Sized Residential Dishwashers**

| Standard-sized Residential Dishwashers | Proposed Standard (TSL 2) |
|---|---|
| **Base-Case Market Share** | 3.68% |
| **Policy Case Market Share** | 3.73% |
| **Increased Market Share** | 0.05% |

The increased market shares attributable to bulk government purchasing shown in Table 17.3.6 were used as inputs in the NIA-RIA model. Appendix 17-A shows the annual market share increases due to this policy that DOE used as inputs to the NIA-RIA model. Section 17.4 below presents the resulting market penetration trends for the policy case of bulk government purchase of standard-sized residential dishwashers.

## 17.4 IMPACTS OF NON-REGULATORY ALTERNATIVES

Figure 17.4.1 shows the effects of each non-regulatory policy on market penetration for standard-sized residential dishwashers. Relative to the base case, the policy cases increase the market shares that meet the target level. Note that the proposed standards (not shown in the figures) would result in a 100-percent market penetration of products that meet the target efficiency level.

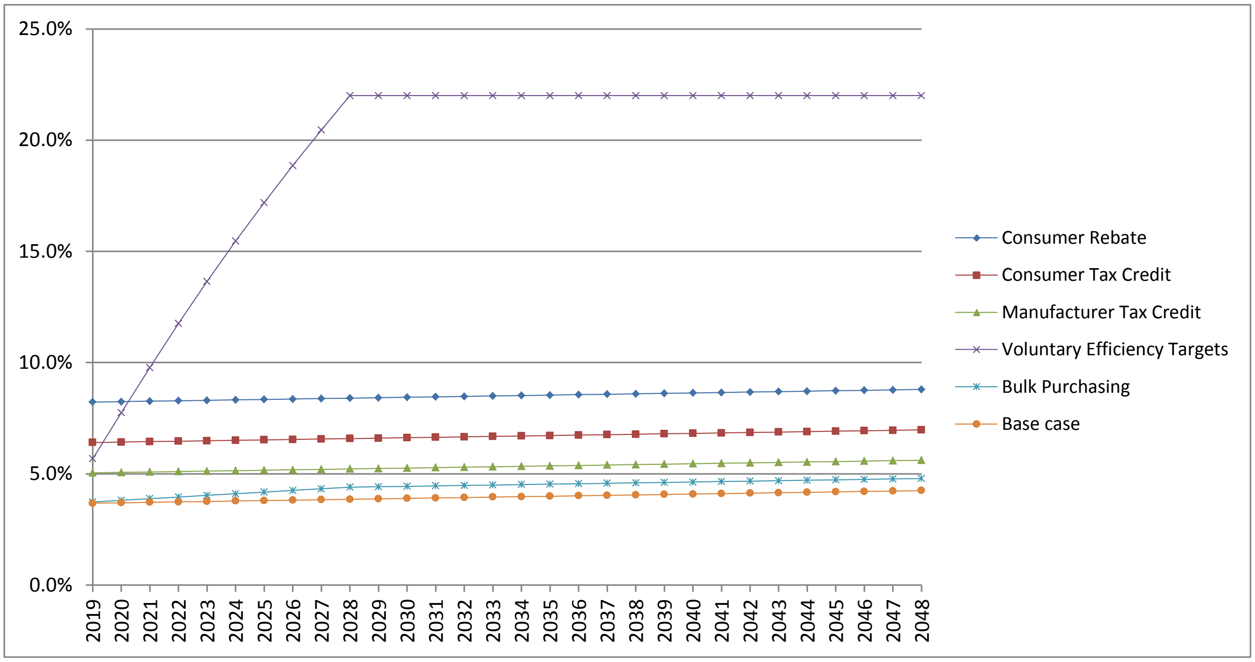


**Figure 17.4.1 Market Penetration of Standard-Sized Residential Dishwashers Meeting the Target Level in Policy Cases**

Table 17.4.1 shows the national energy savings and net present value (NPV) for five non-regulatory policies analyzed in detail for standard-sized residential dishwashers. The target level for each policy equals the efficiency level in the corresponding proposed standard.

The case in which no regulatory action is taken with regard to standard-sized residential dishwashers constitutes the base case (or "No New Regulatory Action" scenarios), in which energy savings and NPV are zero by definition. For comparison, the tables include the impacts of the proposed standards. Energy savings are given in quadrillion British thermal units (quads). The NPVs shown in Table 17.4.1 are based on two discount rates, 7 percent and 3 percent.

Cumulative NES provided by the five non-regulatory policies evaluated in this RIA range from 0.5 percent (bulk government purchases) to 16.5 percent (voluntary energy efficiency targets) of the NES provided by standards at the proposed TSL. Consumer rebates and tax credits would provide intermediate energy saving benefits, ranging from 1.4 percent (manufacturer tax credits) to 4.7 percent (consumer rebates) of those provided by standards at the proposed TSL. NPV is positive for all non-regulatory policies at both 7 percent and 3 percent discount rates.

**Table 17.4.1 Impacts of Non-Regulatory Alternatives for Residential Dishwashers, Standard-Sized (TSL 2)**

| **Policy Alternative** | **Primary Energy Savings** (quads) | **Net Present Value*** (billion 2013$) 7% Discount Rate | 3% Discount Rate |
|---|---|---|---|
| Consumer Rebates | 0.055 | 0.024 | 0.177 |
| Consumer Tax Credits | 0.033 | 0.014 | 0.106 |
| Manufacturer Tax Credits | 0.017 | 0.007 | 0.053 |
| Voluntary Energy Efficiency Targets | 0.193 | 0.113 | 0.658 |
| Bulk Government Purchases | 0.006 | 0.003 | 0.020 |
| Proposed Standards | 1.170 | 0.496 | 3.744 |

* For products shipped in 2019─2048

## REFERENCES

1. Rufo, M. and F. Coito, *California's Secret Energy Surplus: The Potential for Energy Efficiency*, 2002. XENERGY Inc. (Last accessed March, 2014.) <http://www.issuelab.org/resource/californias_secret_energy_surplus_the_potential_for_energy_efficiency>

2. ICF International, *Arizona Public Service Energy Efficient Market Potential Study*, 2007. Fairfax, VA.

3. Mosenthal, P., Telephone Conversation with Barbara Atkinson of LBNL, *personal communication.* Optimal Energy. January, 2008.

4. Lee, A., Telephone Conversation with Barbara Atkinson of LBNL, *personal communication.* Quantec, LLC. January, 2008.

5. Rufo, M., Telephone Conversation with Barbara Atkinson of LBNL, *personal communication.* Itron, Inc. January 2008 and March 2009.

6. Itron Inc. and KEMA Inc., *California Energy Efficiency Potential Study*, 2008. (Last accessed March, 2014.) <http://calmac.org/publications/PGE0264_Final_Report.pdf>

7. Global Energy Partners LLC, *AmerenUE Demand Side Management (DSM) Market Potential Study*, 2010. (Last accessed March, 2014.) <https://www.ameren.com/-/media/missouri-site/Files/Environment/Renewables/AmerenUEVolume2MarketResearchReport2.pdf>

8. Coito, F., E-mail to Barbara Atkinson of LBNL, *personal communication.* KEMA, Inc. June, 2010.

9. Blum, H., B. Atkinson, and A. Lekov, *A Framework for Comparative Assessments of Energy Efficiency Policy Measures*, May, 2011. Report No. LBNL-4749E. <http://eetd.lbl.gov/publications/framework-comparative-assessments-energy-efficiency-policy-measures>

10. Lawrence Berkeley National Laboratory, *Energy End-Use Forecasting: Analysis of Tax Credits for Efficient Equipment*, 1998. LBNL Technology Evaluation Modeling and Assessment Group (Last accessed March, 2014.) <http://enduse.lbl.gov/Projects/TaxCredits.html>

11. Train, K., *Customer Decision Study: Analysis of Residential Customer Equipment Purchase Decisions*, 1994. Prepared for Southern California Edison by Cambridge Systematics, Pacific Consulting Services, The Technology Applications Group, and California Survey Research Services.

12. U.S. Department of Energy: Office of Codes and Standards, *Technical Support Document: Energy Efficiency Standards for Consumer Products: Refrigerators, Refrigerator-Freezers, and Freezers, Including Environmental Assessment and Regulatory Impact Analysis,* November, 1995. Washington, DC. Report No. DOE/EE-0064.

13. *American Recovery and Reinvestment Act of 2009,* 2009. Government Printing Office. (Last accessed March, 2014.) <http://frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=111_cong_bills&docid=f:h1enr.pdf>

14. Tax Incentives Assistance Project, *Consumer Tax Incentives: Home Heating & Cooling Equipment.,* 2011. (Last accessed March, 2014.) <www.energytaxincentives.org/consumers/heating-cooling.php>

15. Tax Incentives Assistance Project, *The Tax Incentives Assistance Project (TIAP),* 2013. (Last accessed March, 2014.) <http://energytaxincentives.org/>

16. U.S. Department of Energy - Energy Efficiency & Renewable Energy, *Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment, Residential Dishwashers, Dehumidifiers, and Cooking Products, and Commercial Clothes Washers,* 2008. Washington, DC.

17. Tax Incentives Assistance Project, *Manufacturers Incentives,* (Last accessed March, 2014.) <http://energytaxincentives.org/builders/appliances.php>

18. Feldman, S., L. Hoegfen, L.Wilson-Wright, and A. Li, *Modeling the Effects of U.S. ENERGY STAR® Appliance Programs. In Energy Savings: What Works and Who Delivers?,* May 30-June 4, 2005. ECEEE Summer Study Proceedings. Mandelieu La Napoule, France. <http://www.eceee.org/conference_proceedings/eceee/2005c/Panel_4/4228feldman/paper>

19. Rosenberg, M., *The Impact of Regional Programs on the Market Share of Energy Star® Appliances,* August 20-22, 2003. Seattle, WA. Published in the 2003 International Energy Program Evaluation Conference Proceedings.

20. Titus, E. and S. Feldman, *Tracking the Effectiveness of Energy-Efficient Appliance Programs in the U.S.,* August 20-22, 2003. In 2003 International Energy Program Evaluation Conference Proceedings. Seattle, WA.

21. Smith, N., Telephone conversation with Barbara Atkinson of LBNL, *personal communication.* National Association of State Procurement Officials. April, 2008.

22. Responsible Purchasing Network, (Last accessed March, 2014.) <www.responsiblepurchasing.org/>

23. Federal Energy Management Program (FEMP), *Covered Products Category: Light Commercial Heating and Cooling*, <http://energy.gov/eere/femp/covered-product-category-residential-dishwashers>

24. Harris, J. and F. Johnson, Potential Energy, Cost, and CO2 Savings from Energy-Efficient Government Purchase. *ACEEE: Summer Study on Energy Efficiency in Buildings*, 2000: pp. 147-166 <http://www.census.gov/programs-surveys/ahs/>

25. U.S. Department of Housing and Urban Development, *A Picture of Subsidized Households–2008*, (Last accessed September, 2011.) <www.huduser.org/picture2008/index.html>

26. U.S. Department of Energy: Energy Information Administration, *Residential Energy Consumption Survey (RECS)*, 2009. (Last accessed December, 2013.) Public use data files. <http://www.eia.gov/consumption/residential/data/2009/index.cfm?view=microdata>

# APPENDIX 8-A. USER INSTRUCTIONS FOR LIFE-CYCLE COST AND PAYBACK PERIOD SPREADSHEETS

## TABLE OF CONTENTS

# APPENDIX 8-A. USER INSTRUCTIONS FOR LIFE-CYCLE COST AND PAYBACK PERIOD SPREADSHEETS

## 8-A.1 DEFINITIONS

The interested reader can examine and reproduce detailed results of the U.S. Department of Energy's (DOE's) life-cycle cost (LCC) and payback period (PBP) analysis for residential dishwashers by using Microsoft Excel spreadsheets available on DOE's website: http://www1.eere.energy.gov/buildings/appliance_standards/residential/dishwashers.html. To fully execute the spreadsheets requires both Microsoft Excel and Crystal Ball software. Both applications are commercially available. Crystal Ball is available at http://www.oracle.com/us/products/applications/crystalball/overview/index.html.

The latest version of the spreadsheet workbook was tested using Microsoft Excel 2010. The LCC and PBP workbook for residential dishwashers comprises the following worksheets.

| | |
|---|---|
| **Statistics** | Presents a statistical summary of the simulation runs performed: the range in LCC savings and PBPs; retail purchase price; total installed cost; total operating costs over the product lifetime (discounted); annual electricity, gas, and oil use; annual water use; and household characteristics. The worksheet provides minimum, maximum, and average values, along with 5th, 25th, 50th, 75th, and 95th percentile values. |
| **Summary** | Presents the results of an analysis in terms of average LCC; LCC savings; and median, average, and undefined PBP for both standard-sized and compact dishwashers. For each efficiency level considered, a table is generated that provides installed price; lifetime operating cost; LCC; average savings; and the percentage of households that would incur a net cost, no impact, or net savings from the efficiency level. The user can stipulate three parameters for a simulation run: whether the *Annual Energy Outlook* (*AEO*) energy price trend reflects an economic case that is reference, low-growth, or high-growth (reference is default); the year, starting at 2019, at which to begin the calculation of LCC and PBP (2019 is default); and the number of simulation runs to be performed (from 100 to 50,000; 10,000 is default). |
| **LCC & Payback** | Lists the input values used to calculate LCC and PBP. Many values were derived from data collected from Residential Energy Consumption Survey (RECS) households. Parameters include fuel type for heating water; annual numbers of dishwasher loads; product lifetime; the discount rate applied to costs and savings; energy and water prices; the base-case efficiency distribution; |

| | |
|---|---|
| | product price and total installed cost; and energy and water use. The result includes annual and cumulative cash flow for both standard-sized and compact dishwashers operating at each efficiency level. |
| **Rebuttable PB** | Presents results of the rebuttable payback analysis. |
| **RECS Samples** | Presents the data collected from the 7,382 RECS households that reported having dishwashers. Identifies the parameters exported to (1) the LCC and PBP analysis (water-heating fuel and price, numbers of dishwashing cycles per year); (2) product price; (3) energy and water prices; and (4) discount rate. |
| **Energy & Water Use** | Contains per-cycle energy and water use data at each efficiency level broken down into machine energy use; standby power; water-heating energy use (electric, gas, or oil); and hot water use. Identifies the parameters exported to the LCC and PBP analysis. |
| **Base-Case Efficiency Distribution** | Gives the market shares of efficiency levels in the base case. |
| **Equipment Prices** | Develops total installed costs for dishwashers in 2013$. Gives baseline and incremental manufacturer costs, retail price, sales tax, and installation cost for both product classes and every efficiency level. Includes the assumptions used for applying mark-ups and sales tax. |
| **Energy & Water Prices** | Contains the regional prices in 2013$ for electricity, gas, oil, and water as used in the LCC and PBP analysis. |
| **Energy Price Trends** | Displays the trends in energy prices for electricity, gas, and oil for 2019–2048 under the reference, high, and low economic growth scenarios from *AEO2014*. |
| **Water Price Trend** | Contains the trend for water prices for 2019–2048 based on the consumer price index for 1970–2012. |
| **Discount Rate** | Presents data used to develop average real discount rates and a distribution of discount rates. Rates are for the various types of household debt and equity used to purchase products installed in new homes and replacement products. Appendix 8-E gives a detailed description of DOE's development of discount rates. |
| **Lifetime** | Presents the average lifetime, in years, of standard-sized and compact dishwashers (15.4 years for both). Includes the Weibull |

| | |
|---|---|
| | parameters used for the survival function, and a graph of the Weibull retirement function for residential dishwashers. |
| **Forecast Cells** | Gives details regarding base-case efficiency distributions for both product classes of dishwashers. Median, minimum, maximum, and average values are given, along with 5th, 25th, 50th, 75th, and 95th percentile values. Included are product prices and details of the LCC and PBP analysis. LCC savings are given in terms of money, energy, and water. Also given are the percentages of households that would experience a net cost, no impact, or net savings from each efficiency level. |

## 8-A.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 *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 spreadsheet to choose parameters or enter data. You can change the default choices for the three inputs listed under "User Input" (energy price trend, start year, and number of simulation runs). To change a default input, select the desired value from the drop-down choices by the input box.

4. After selecting the desired parameters, click the "Run" button. The spreadsheet will minimize until the simulation is complete, then re-open with the updated results.

# APPENDIX 8-B. UNCERTAINTY AND VARIABILITY

## TABLE OF CONTENTS

## LIST OF FIGURES

# APPENDIX 8-B. UNCERTAINTY AND VARIABILITY

## 8-B.1 INTRODUCTION

Analyzing a potential energy efficiency standard involves calculating its various effects, such as its effect on consumer life-cycle cost (LCC) for products that have higher prices because of the new energy standard. 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 or model, and
3. provide numerical values for each quantity.

In the simplest case, the equation is unambiguous—it contains all relevant quantities and no others; each quantity has a single numerical value; and the calculation produces a single value. Unambiguousness and precision are rarely the case, however. Usually 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 on other conditions (*i.e.*, there is variability). Even given a single numerical value for each quantity in a calculation, arguments can arise about the appropriateness of each value.

Thorough analysis involves accounting for uncertainty and variability. Explicit analysis of uncertainty and variability provides more complete information to the decision-making process.

## 8-B.2 UNCERTAINTY

When drawing conclusions about past events or speculating about the future, imperfect knowledge is the rule rather than the exception. For example, the energy consumed by a particular type of appliance (such as the average residential dishwasher) is not recorded directly, but rather estimated based on available information. Even direct laboratory measurements have a margin of error. When estimating numerical values for quantities at some future date, the exact outcome is rarely known.

## 8-B.3 VARIABILITY

Specifying an exact value for a quantity is difficult if the value depends on other factors. Variability in the calculation of a quantity means that different applications or situations produce different numerical values. For example, the number of hours a household operates a dishwasher depends on the circumstances and behaviors of the occupants (their number and habits). Variability makes it difficult to specify an appropriate value for an entire population, because no single value is likely to represent that entire population. Surveys can be helpful in such situations, and analysis of surveys can relate the variable of interest (such as hours of use) to other variables that are better known or easier to forecast (such as number of occupants per household).

## 8-B.4 APPROACHES TO UNCERTAINTY AND VARIABILITY

Two approaches to uncertainty and variability are:

- scenario analysis, and
- probability analysis.

Scenario analysis uses a single numerical value for every quantity in a calculation, then changes one (or more) of those values and repeats the calculation. Numerous calculations are performed, providing some indication of the extent to which the result depends on each input. The LCC of an appliance, for example, can be calculated based on electricity costs of 2, 8, or 14 cents per kilowatt-hour.

The advantages of scenario analysis are that each calculation is simple; a range of estimates is considered; and crossover points can be identified. An example of a crossover point is the energy rate above which the LCC declines, holding all other inputs constant. In other words, the crossover point is the energy rate above which the consumer achieves savings in operating costs that more than compensate for the increased purchase price. The disadvantage of scenario analysis is that there is no information about the likelihood of any particular scenario.

Probability analysis considers the probability of each value within a range of values. To estimate the probability of each value for quantities characterized by variability (*e.g.*, electricity rates), survey data can be used to generate a frequency distribution of, for instance, the number of households subject to specific electricity rates. For quantities characterized by uncertainty, statistical or subjective measures can provide probabilities (*e.g.*, the manufacturing cost to improve an appliance’s energy efficiency to a given level may be estimated to be $10 ± $3).

The major disadvantage of probability analysis is that it requires additional information about the shape and magnitude of the variability and the uncertainty of each quantity. The advantage of probability analysis is that it gives more information about the results of calculations by providing the probability that the result will be within a particular range.

Scenario and probability analyses provide some indication of the robustness of a policy given the identified uncertainties and variability. A policy is robust when the impacts are acceptable over a wide range of likely conditions and outcomes.

## 8-B.5 USING CRYSTAL BALL TO PERFORM PROBABILITY ANALYSES

To quantify the uncertainty and variability in inputs to the engineering, LCC, and PBP analyses, DOE conducted probability analyses using Microsoft Excel spreadsheets combined with Crystal Ball, a commercially available add-in software. The analyses used probability distributions and Monte Carlo simulation. Simulation refers to any analytical method intended to duplicate a real-life system, especially when mathematical analyses are too complex or difficult to apply. Without the aid of simulation, a spreadsheet model will reveal only a single outcome, generally the most likely or average outcome.

Spreadsheet analysis incorporates simulation to analyze how varying inputs affects the outputs of the modeled system. Monte Carlo simulation randomly generates values for uncertain variables and does so numerous times. 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. 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 number for any particular roll. This condition applies to other variables that have a known range of values but an uncertain value for any particular time or event (such as product lifetime, discount rate, or installation cost). As with games of chance, Monte Carlo simulation selects variable values at random.

For each uncertain variable (each variable that has a range of possible values), a probability distribution is used to define the range of possible values. The type of distribution selected is based on the conditions surrounding that variable. Types of probability distributions include those in Figure 8-B.5.1 through Figure 8-B.5.3.

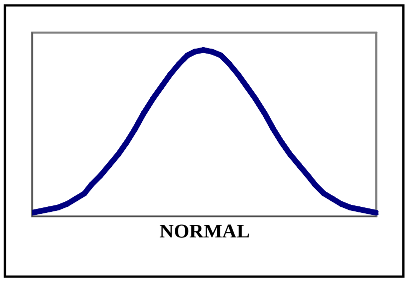


**Figure 8-B.5.1 Normal Probability Distribution**

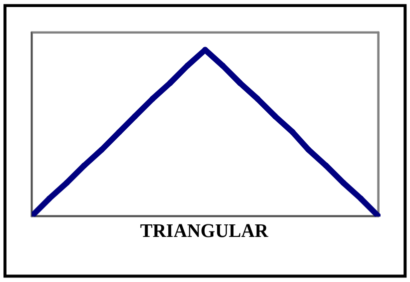


**Figure 8-B.5.2 Triangular Probability Distribution**

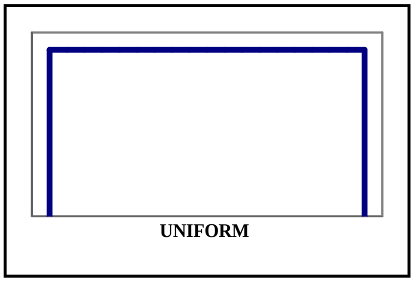


**Figure 8-B.5.3 Uniform Probability Distribution**

During a simulation, multiple scenarios are examined by repeatedly sampling values from the probability distributions for the uncertain variables. Crystal Ball simulations can consist of as many trials (or scenarios) as desired—hundreds or even thousands. For calculating the LLC for residential dishwashers, DOE performed 10,000 Monte Carlo simulations for each variable. During a single trial, Crystal Ball randomly selected a value from the defined possibilities (the range and shape of the probability distribution) for each uncertain variable and then recalculated the spreadsheet.

# APPENDIX 8-C. ESTIMATING PRODUCT PRICE TRENDS FOR RESIDENTIAL DISHWASHERS

## TABLE OF CONTENTS

## LIST OF FIGURES

# APPENDIX 8-C. ESTIMATING PRODUCT PRICE TRENDS FOR RESIDENTIAL DISHWASHERS

## 8-C.1 INTRODUCTION

In its Notice of Data Availability (NODA) published February 22, 2011 (76 FR 9696), DOE stated that it may consider addressing product price trends in order to improve regulatory analyses for appliances and equipment subject to energy conservation standards. In the NODA, DOE stated that historical price data for certain appliances and equipment indicate that the assumption of constant real prices and costs may, in many cases, overestimate long-term trends in product price. Economic literature and historical data suggest that the real costs of such products may in fact trend downward over time based on "experience" or "experience curves." Desroches *et al.* (2013) summarize the current data and literature relevant to forecasting prices for selected appliances and equipment.[1]

The literature on the "experience" or "experience curve" phenomenon typically refers to observations made in the manufacturing sector.[1, 2] According to the experience curve approach, the real cost of production is related to a manufacturer's cumulative production of, or experience with, manufacturing a specific product. A common functional relationship used to model the evolution of production costs in such cases is:

$$Y = aX^{-b}$$

Where:

$a$ = the initial price (or cost),
$b$ = a positive constant known as the experience rate parameter,
$X$ = cumulative production, and
$Y$ = the price as a function of cumulative production.

The above equation indicates that as experience (production) accumulates, the cost of producing the next unit decreases. The percentage reduction in cost that occurs with each doubling of cumulative production is known as the experience rate (ER), given by:

$$ER = 1 - 2^{-b}$$

In typical experience curve formulations, the experience rate parameter is derived using two types of historical data: cumulative production and price (or cost). Consistent with the NODA, DOE used the experience curve method to develop experience rates for forecasting future prices of dishwashers at each trial standard level. This appendix describes the method used to develop experience rates and to project future product prices used in the life-cycle cost (LCC) and payback period (PBP) analysis.

## 8-C.2 ESTIMATING THE EXPERIENCE RATE

To derive parameters related to the experience rate for dishwashers, DOE obtained from the Bureau of Labor Statistics Producer Price Index (PPI) data for "other miscellaneous household appliances" spanning 1988–2013.[a] DOE used PPI data for other miscellaneous household appliances to represent residential dishwashers, because there were no PPI data specific to residential dishwashers. The PPI data reflect nominal prices, adjusted for changes in product quality. An inflation-adjusted price index for other miscellaneous household appliances was calculated by dividing the PPI series by the Gross Domestic Product Chained Price Index (see Figure 8-C.1).

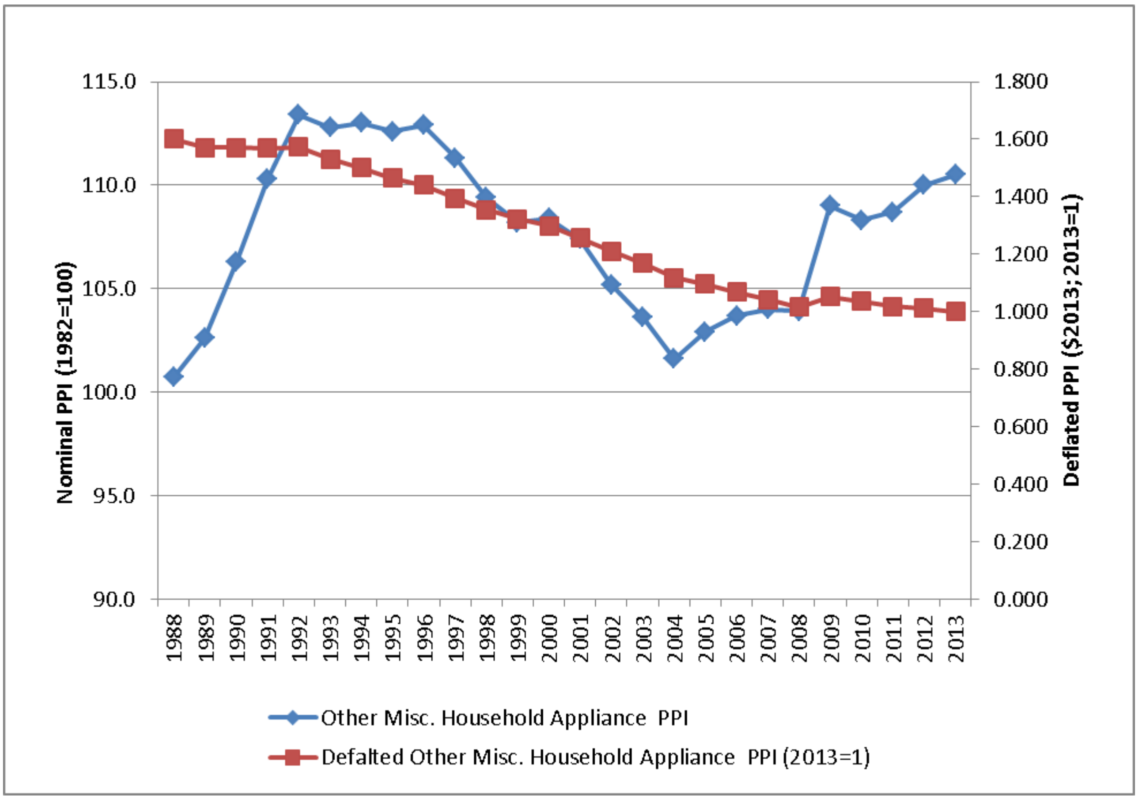


**Figure 8-C.1 Historical Nominal and Defalted Producer Price Indexes for Other Miscellaneous Household Appliances**

DOE assembled a time series of historical annual shipments of dishwashers for 1972–2012. The data for historical annual shipments were used to project future shipments and to estimate cumulative shipments (production). Figure 8-C.2 shows the shipments time series used in the LCC and PBP analysis.

---

[a] Series ID PCU3352283352285; http://www.bls.gov/ppi/.

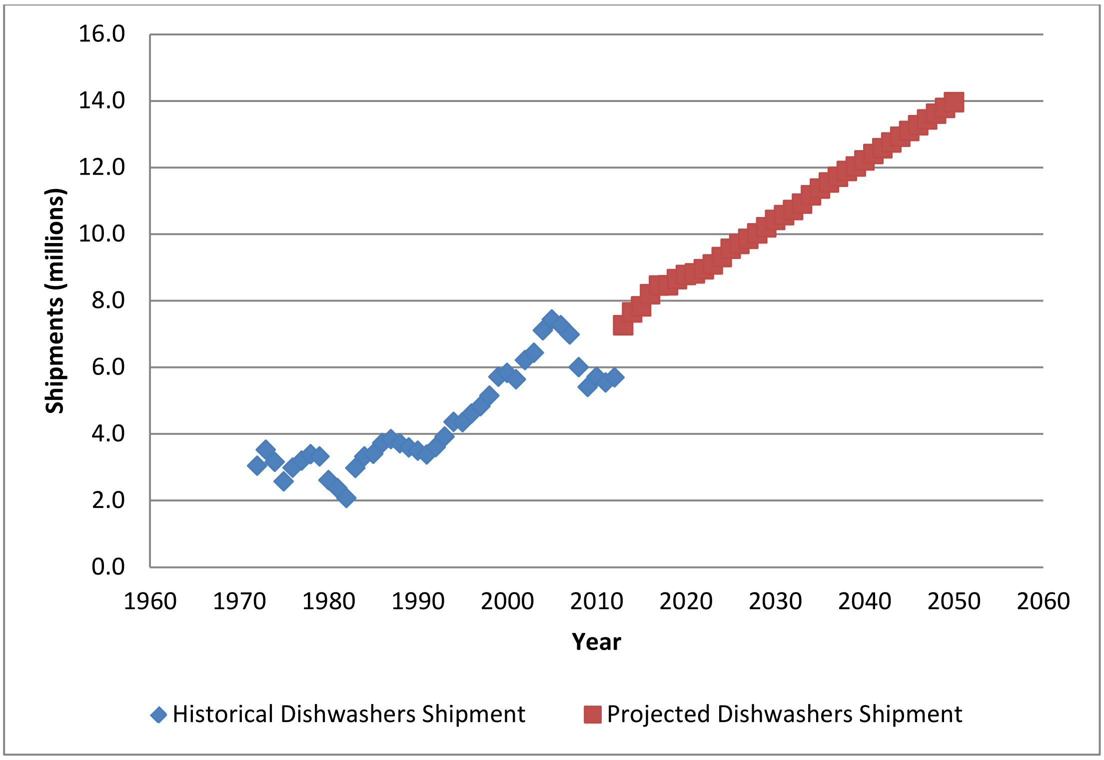


**Figure 8-C.2** **Historical and Projected Total Shipments of Dishwashers**

To estimate parameters related to the experience rate, a least-squares power-law fit was performed on the unified price index versus cumulative shipments. See Figure 8-C.3.

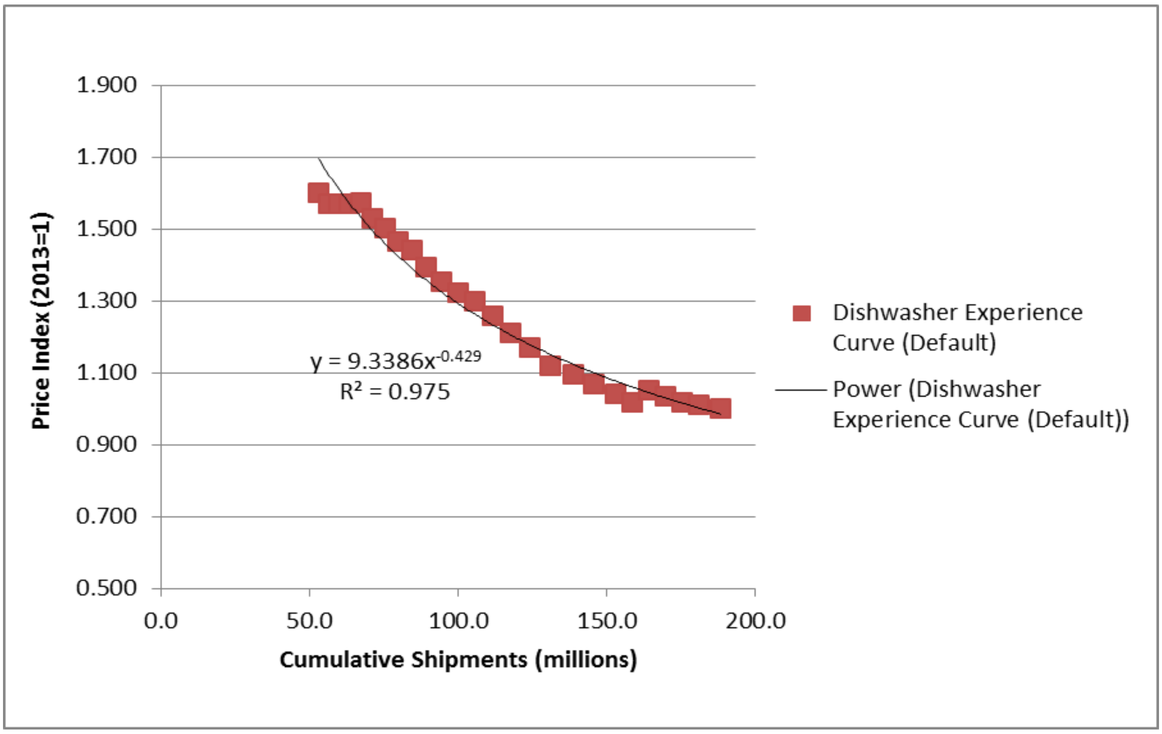


**Figure 8-C.3** **Relative Price versus Cumulative Shipments of Other Miscellaneous Household Appliances, with Power-Law Fit**

The form of the fitting equation is:

$$P(X) = P_o X^{-b},$$

where the two parameters, $b$ (the experience rate parameter) and $P_o$ (the price or cost of the first unit of production), are obtained by fitting the model to the data. DOE notes that the cumulative shipments on the right-hand side of the equation may depend on price, creating an issue with simultaneity whereby the independent variable is not truly independent. DOE's use of a simple least-squares fit is equivalent to assuming that there are no significant first-price elasticity effects in the cumulative shipments variable.

The parameter values obtained are:

$P_o = 9.339^{+1.355}_{-1.183}$ (95% confidence) for other miscellaneous household appliances, and
b = 0.429±0.029 (95% confidence) for other miscellaneous household appliances.

The estimated experience rate (defined as the percent reduction in price expected from each doubling of cumulative production) is 25.7 ±1.5 percent (95% confidence). That is, each doubling of cumulative production should reduce the production cost by 25.7 ±1.5 percent.

DOE derived a price factor index, with 2013 equal to 1, to estimate prices in each future year of the analysis period. The index value in a given year is a function of the experience parameter and the cumulative production forecast for that year, which is based on the shipments forecast described in chapter 9. Figure 8-C.4 shows the price factor index out to 2048 (the last year in the analysis period) derived from the experience curve model. The average annual rate of price deline is 1.33 percent. The value for 2019, which is used in the LCC and PBP analysis, is 0.905. Thus, the 2019 prices forecast for the LCC and PBP analysis are equal to 0.905 times the 2013 values for each efficiency level in each product class.

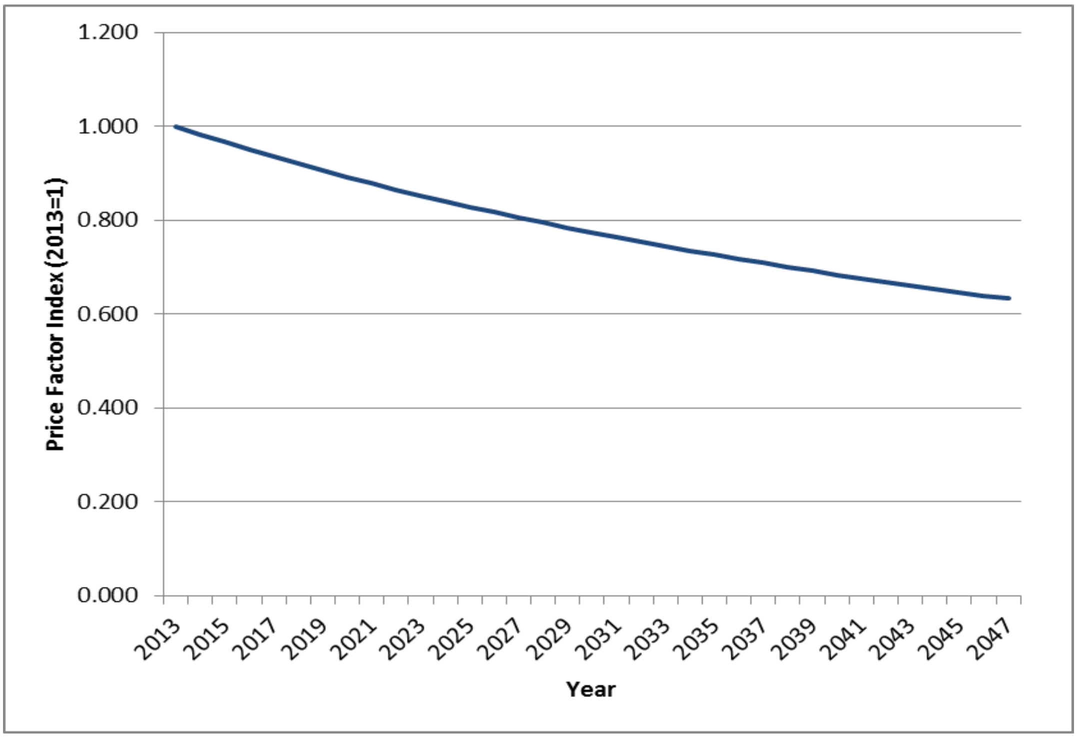


**Figure 8-C.4** **Price Factor Index for the Default Case, Other Miscellaneous Household Appliances**

## 8-C.3 ANALYTICAL ISSUES

DOE uses a cost-based analysis to estimate product prices in both the standards and base (no-standards) cases. DOE develops engineering cost estimates to estimate manufacturer selling prices. The manufacturer selling price includes direct manufacturing production costs (labor, material, and overhead estimated for DOE's manufacturer production costs) and all non-production costs (selling, general, and administration; research and development; and interest), along with profit. The cost-based method for developing manufacturer selling prices is described in Chapter 5, Engineering Analysis. To convert the manufacturer selling price to a product price for the consumer, DOE analyzes markups taken throughout the distribution chain and estimates markups on both the baseline and incremental manufacturer selling prices.

In analyzing experience curves to forecast price trends, DOE uses PPI as a key data input to estimate the experience curve exponent. This approach uses only one model parameter to describe the price trend and assumes a simple relationship between producer price and retail product price. Specifically, the approach assumes that producer prices, distribution chain markups, and product prices for the same product all scale proportionally through time.

DOE could have developed a more complex model for forecasting price trends by using additional parameters that could explain various trends in some product prices and cost components over time. But the relatively few available data points mean that using multiple parameters could "overfit" the data. Overfitting occurs when a statistical model has too many degrees of freedom compared to the data, and the fits are sensitive to random noise unrelated to long-term trends. Because of the risk of overfitting the available data, DOE decided not to develop a more complex multi-parameter model to estimate price trends at this time.

DOE's simple model for estimating price trends will not capture several well-known economic and market phenomena. Unaccounted-for parameters could lead to an over- or underestimate of the long-term price trend. For example, if there has been increasing market concentration on the part of manufacturers, manufacturer and wholesale markups may have increased over time. This situation could produce an observed historical producer price trend that does not decrease as quickly as the underlying industrial experience rate would indicate. Depending on whether market concentration accelerated or decelerated into the future, this effect could lead to over- or underestimating future price trends.

Similarly, some cost components may have relatively slow long-term price trends that have an increasing impact on price over time. In this case the decreasing share of costs that are declining rapidly can change the empirically estimated experience curve exponent.

## REFERENCES

---

1 Desroches, L.-B., K. Garbesi, C. Kantner, R.D. Van Buskirk, and H.-C. Yang. 2013. Incorporating Experience Curves in Appliance Standards Analysis. *Energy Policy*, Vol. 52, pp. 402–416. DOI: 10.1016/j.enpol.2012.09.066 (Last accessed June 20, 2014.) < http://www.sciencedirect.com/science/article/pii/S0301421512008488 >

2 Weiss, M., H.M. Junginger, M.K. Patel, and K. Blok. 2010a. A Review of Experience Curve Analyses for Energy Demand Technologies. *Technological Forecasting & Social Change*. 77:411–428.

# APPENDIX 8-D. LIFETIME DISTRIBUTIONS

## TABLE OF CONTENTS

## LIST OF TABLES

## LIST OF FIGURES

# APPENDIX 8-D. LIFETIME DISTRIBUTIONS

## 8-D.1 INTRODUCTION

The U.S. Department of Energy (DOE) characterized the lifetimes of both product classes of dishwashers (standard and compact) being considered for new energy efficiency standards. DOE characterized dishwasher lifetimes using a Weibull probability distribution that encompassed lifetime estimates from minimum to maximum, as described in chapter 8, section 8.2.3. The Weibull distribution is recommended for evaluating lifetime data, because it can be shaped to match low, most likely (or average), and high values. The probability of exceeding the high value is contained in the long tail of the Weibull distribution.[1, 2]

## 8-D.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 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,
$\alpha$ = scale, and
$\beta$ = shape.

The cumulative distribution is therefore:

$$F(x) = 1-\exp^{-\left(\frac{x-L}{\alpha}\right)^{\beta}}$$

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.

## 8-D.3 LIFETIME DISTRIBUTION FOR DISHWASHERS

Table 8-D.3.1 shows the average, minimum, and maximum lifetimes plus maximum percentile values used to determine the Weibull distribution parameters $\alpha$ and $\beta$ for residential dishwashers. DOE estimated that the maximum lifetime percentile for both standard and compact dishwashers was 99 percent.

**Table 8-D.3.1 Distribution Parameters for Dishwashers**

| Value | | | | Weibull Parameters | |
|---|---|---|---|---|---|
| Minimum (years) | Average (years) | Maximum (years) | Maximum Percentile (%) | Alpha (scale) | Beta (shape) |
| 5 | 15.4 | 50 | 99 | 16.25 | 2.18 |

Figure 8-D.1 shows the Weibull distribution for the lifetime of both standard and compact dishwashers. DOE used an average lifetime of 15.4 years in its analyses.

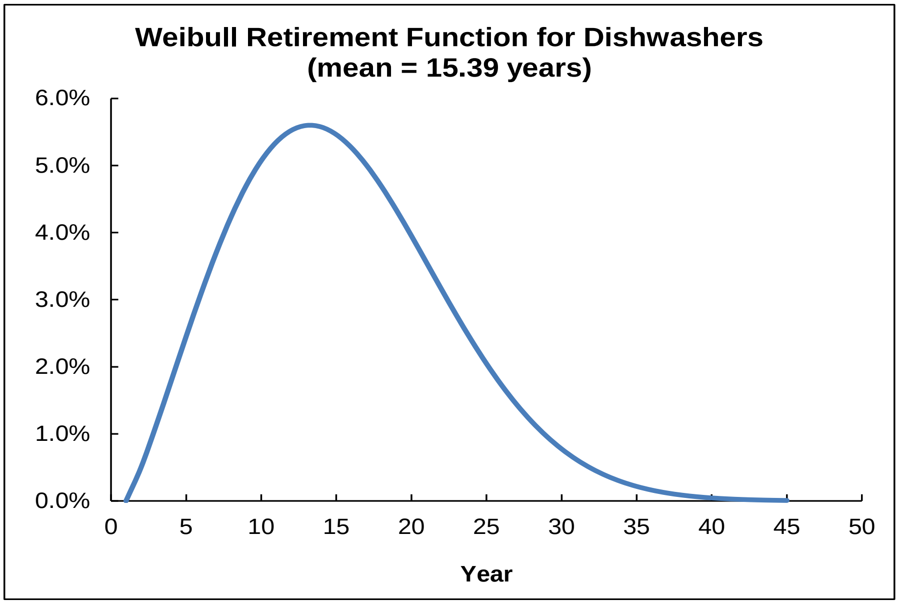


Figure 8-D.1 Percent of Dishwashers Failing each Year

## REFERENCES

---

[1] Barnes, P.R., J.W. Van Dyke, B.W. McConnell, S.M. Cohn, and S.L. Purucker. *The Feasibility of Replacing or Upgrading Utility Distribution Transformers During Routine Maintenance*. 1995. Oak Ridge National Laboratory: Oak Ridge, TN.

2 Karr, T. Making the Most of Life Test Data. *Appliance Magazine*. October 2003. (Last accessed June 20, 2014.) <www.appliancemagazine.com/ae/editorial.php?article=197&zone=215&first=1 >

3 Crystal Ball. *Technote: Derivation of Weibull Distribution Parameters When the Minimum, Most Likely Value, and a Percentile are Known*. 2007. (Last accessed December 4, 2008.) Available from: www.crystalball.com/support/simulation/cbl_gen_021A.html.

# APPENDIX 8-E. DISTRIBUTIONS USED FOR DISCOUNT RATES

## TABLE OF CONTENTS

## LIST OF TABLES

## LIST OF FIGURES

# APPENDIX 8-E. DISTRIBUTIONS USED FOR DISCOUNT RATES

## 8-E.1 INTRODUCTION

The U.S. Department of Energy (DOE) derived 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, and 2010.[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.

## 8-E.2 DISTRIBUTION OF RATES FOR DEBT CLASSES

Figure 8-E.2.1 through Figure 8-E.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, and 2010.[1] 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.

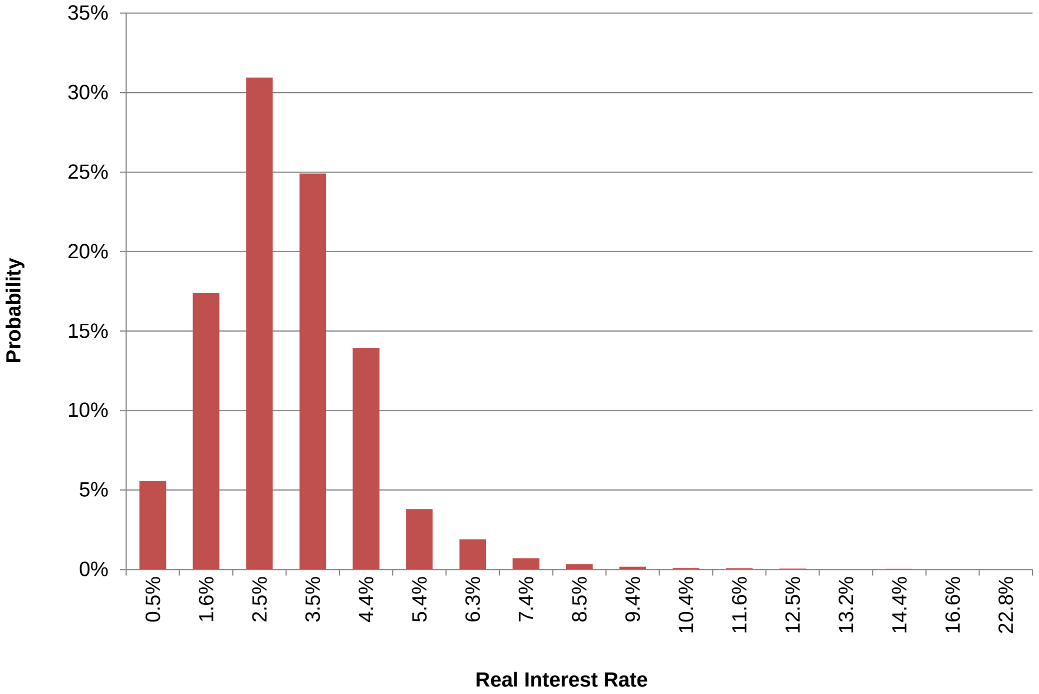


**Figure 8-E.2.1 Distribution of Mortgage Interest Rates**

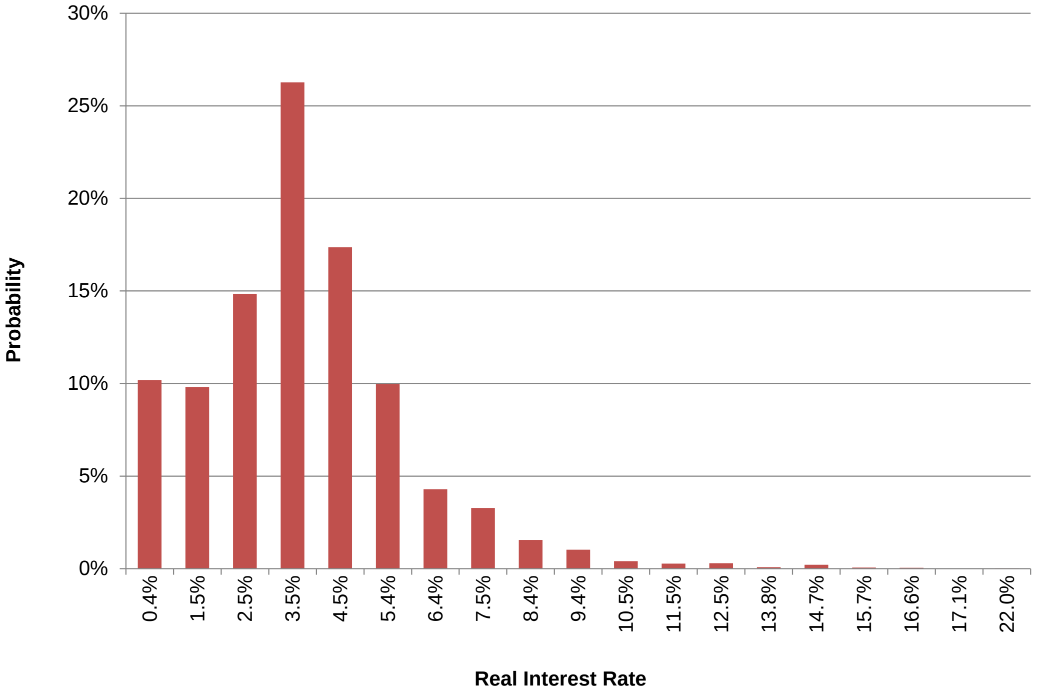


**Figure 8-E.2.2 Distribution of Home Equity Loan Interest Rates**

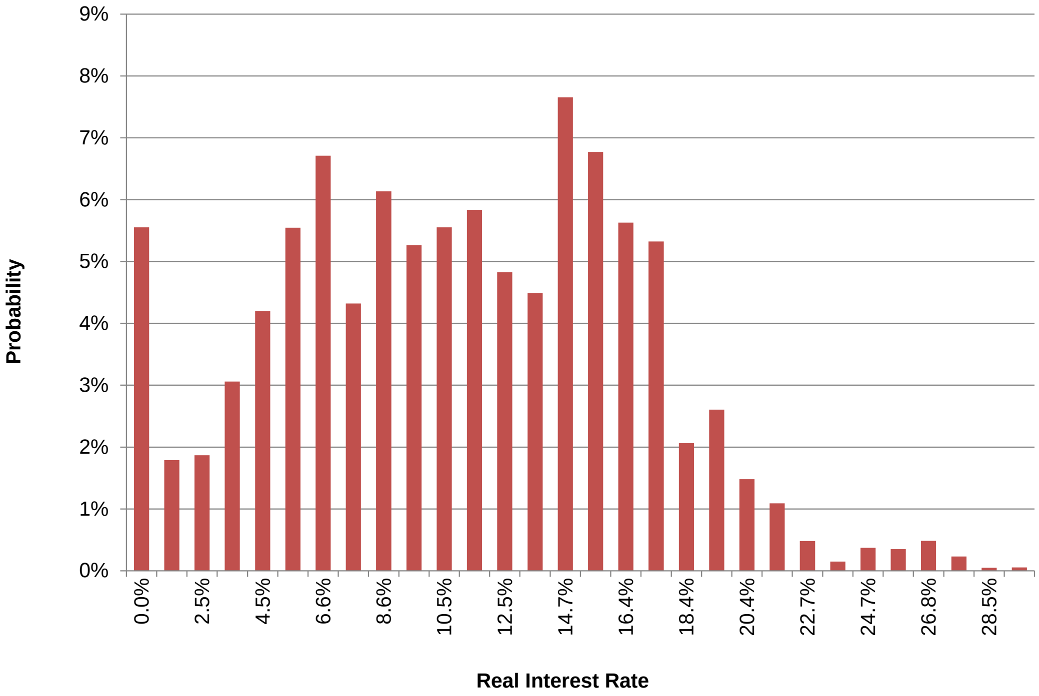


**Figure 8-E.2.3 Distribution of Credit Card Interest Rates**

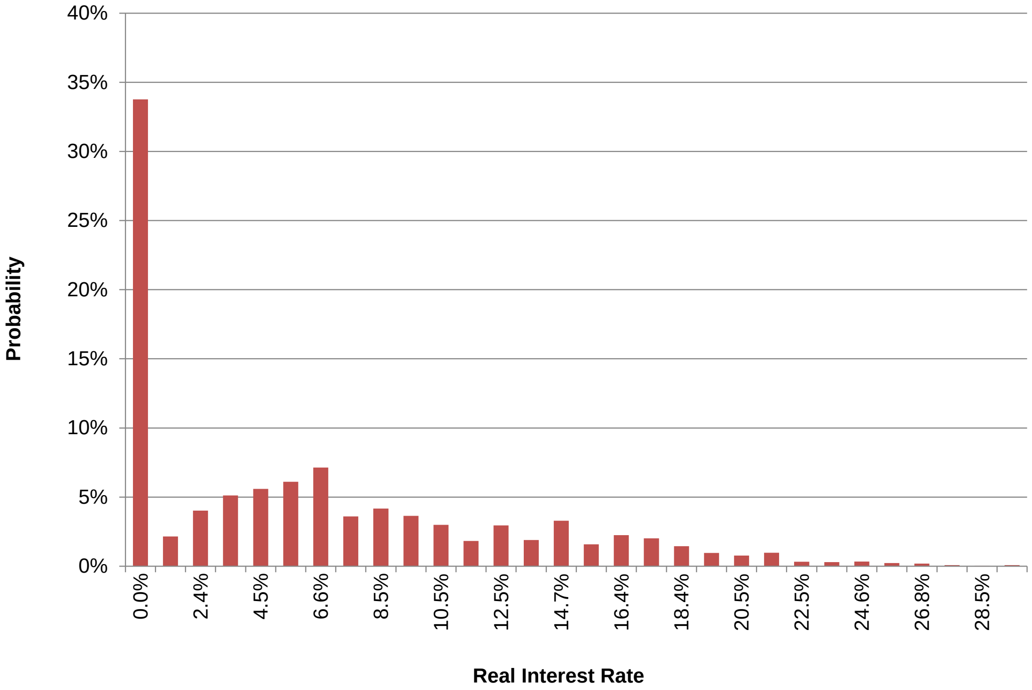


**Figure 8-E.2.4 Distribution of Installment Loan Interest Rates**

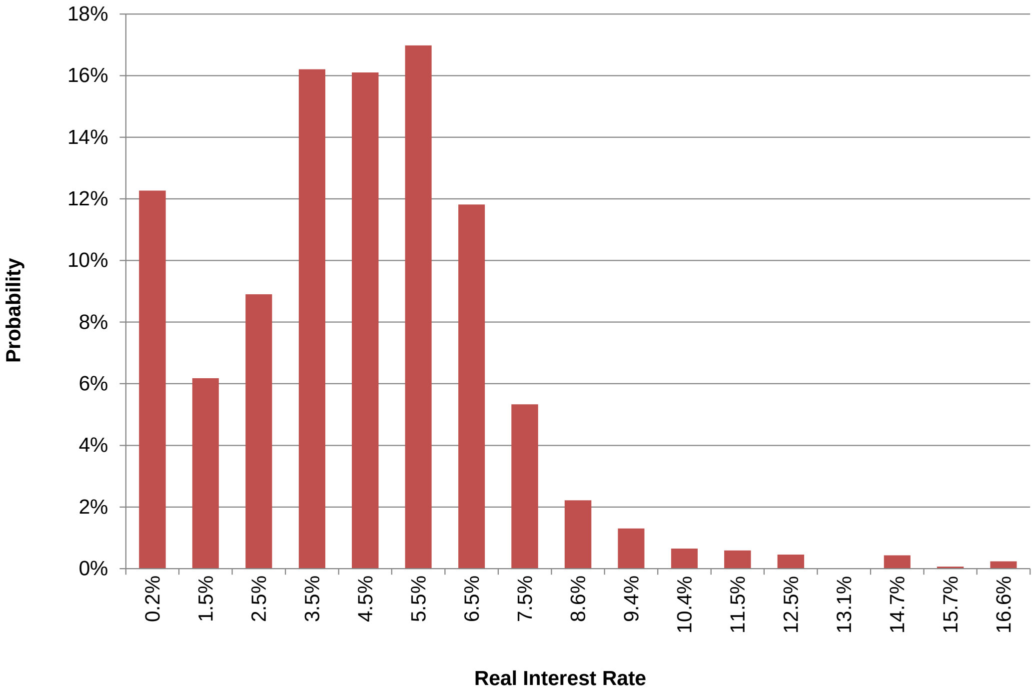


**Figure 8-E.2.5 Distribution of Other Residence Loan Interest Rates**

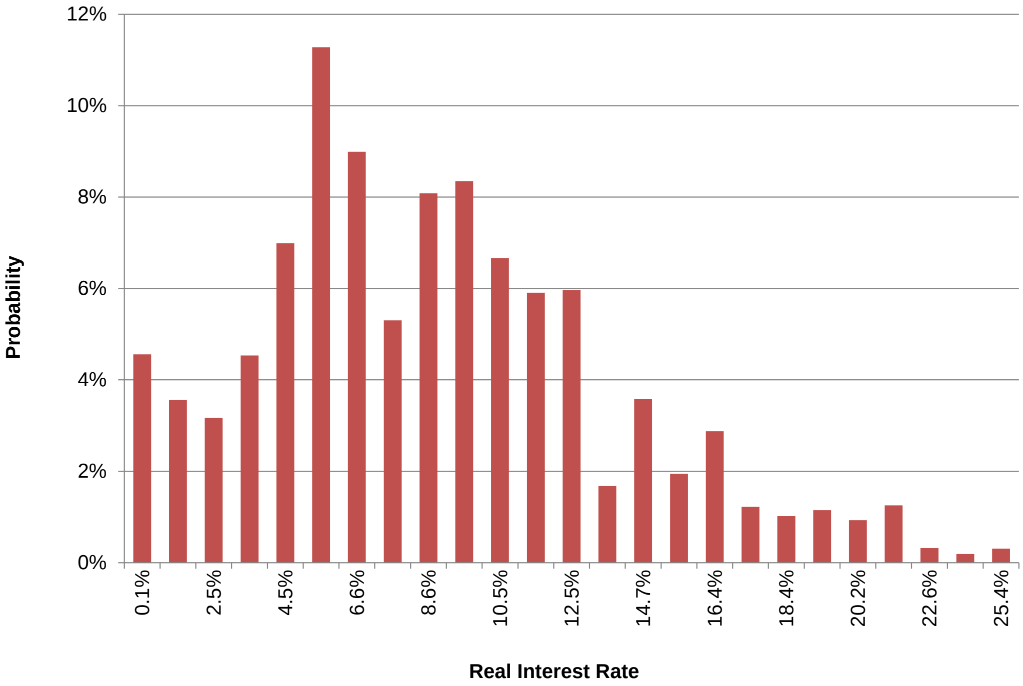


**Figure 8-E.2.6 Distribution of Other Lines of Credit Loan Interest Rates**

## 8-E.3 DISTRIBUTION OF RATES FOR EQUITY CLASSES

Figure 8-E.3.1 through Figure 8-E.3.7 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 (1984-2013). 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.

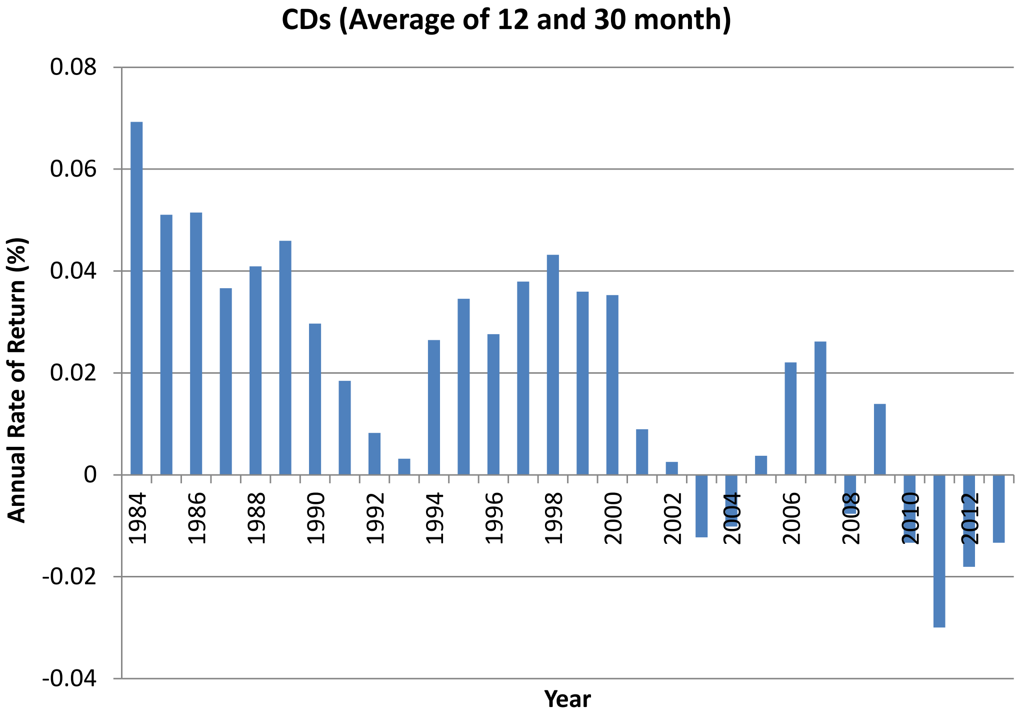


**Figure 8-E.3.1 Distribution of Annual Rate of Return on CDs**

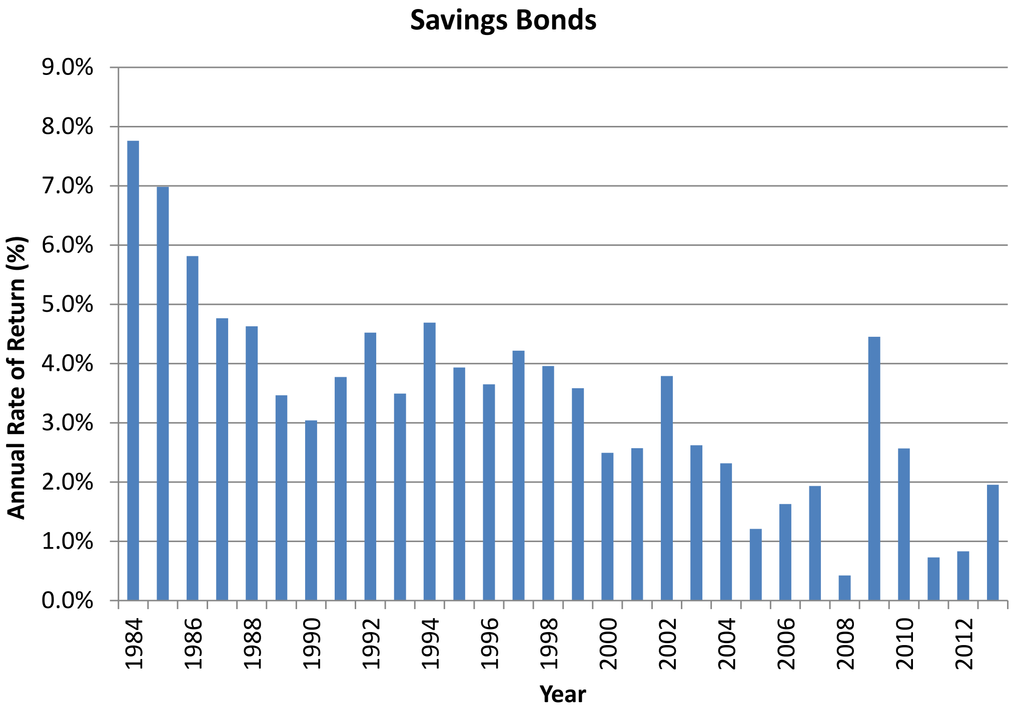


**Figure 8-E.3.2 Distribution of Annual Rate of Return on Savings Bonds**

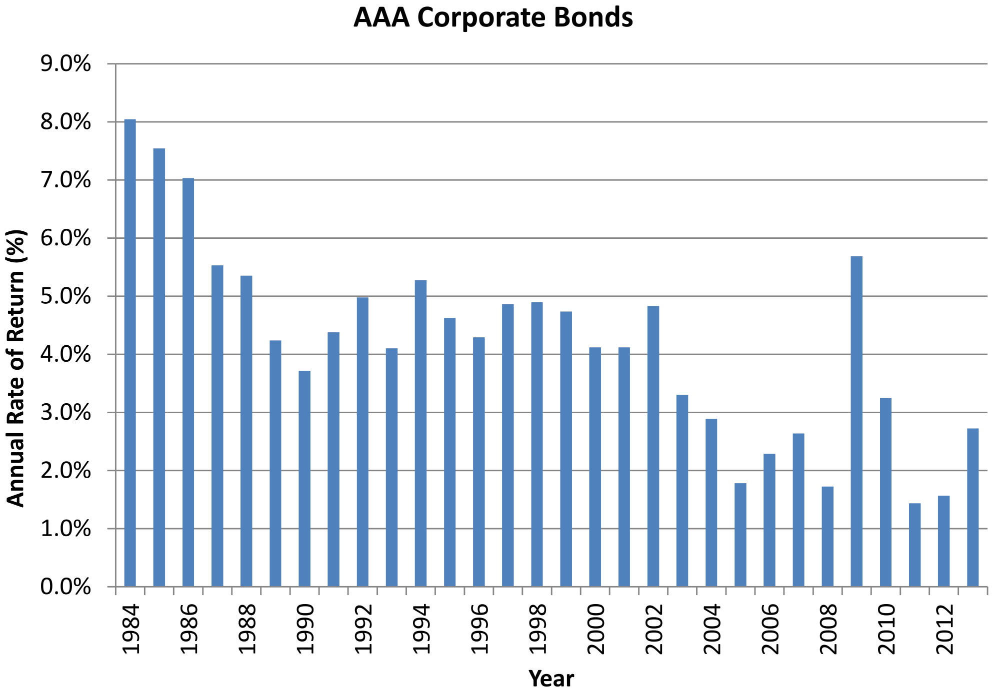


**Figure 8-E.3.3 Distribution of Annual Rate of Return on Corporate AAA Bonds**

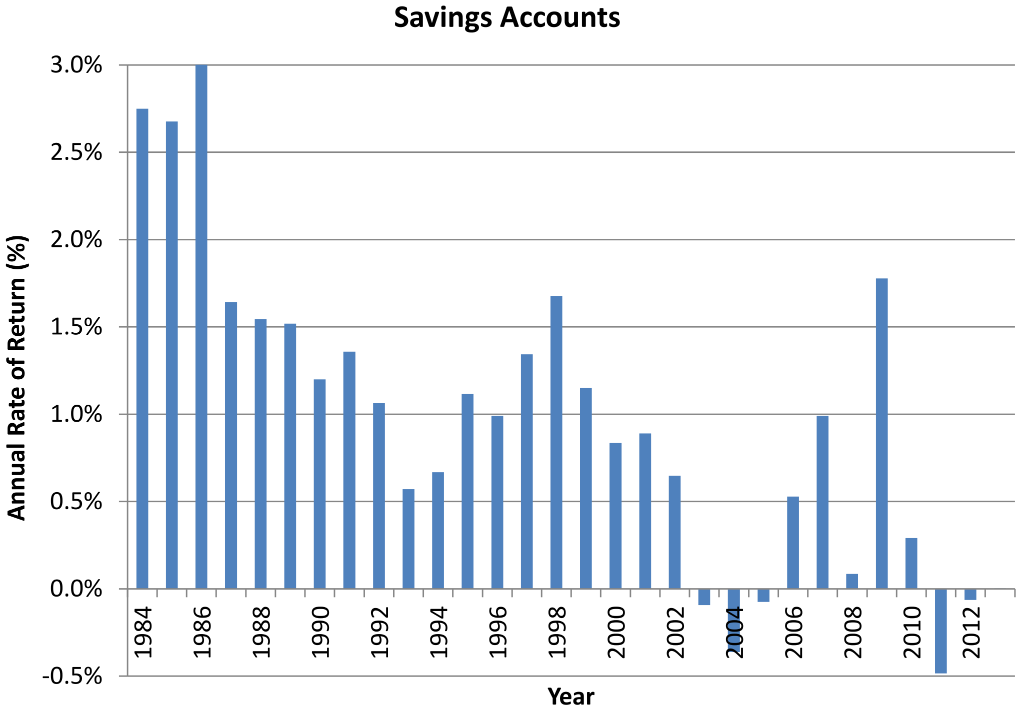


Figure 8-E.3.4 Distribution of Annual Rate of Savings Accounts

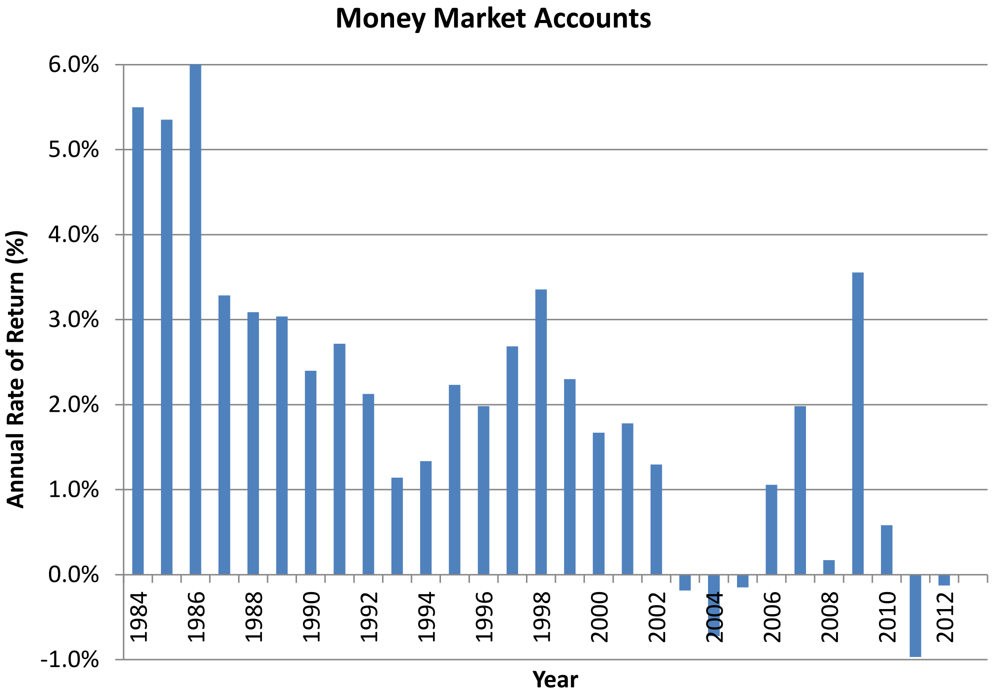


Figure 8-E.3.5 Distribution of Annual Rate of Money Market Accounts

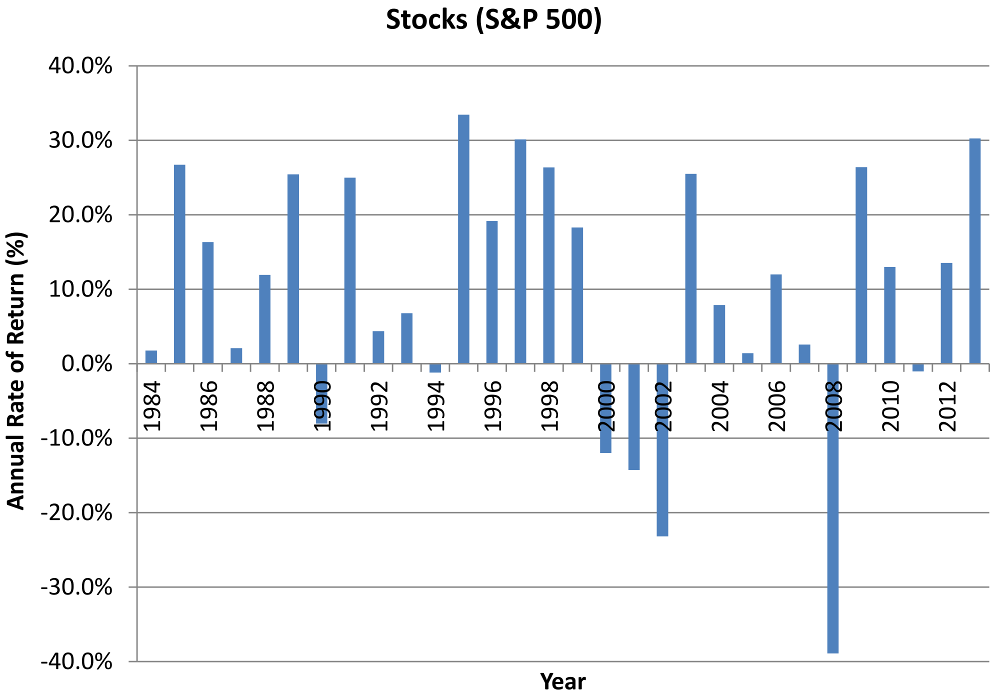


**Figure 8-E.3.6** Distribution of Annual Rate of Return on S&P 500

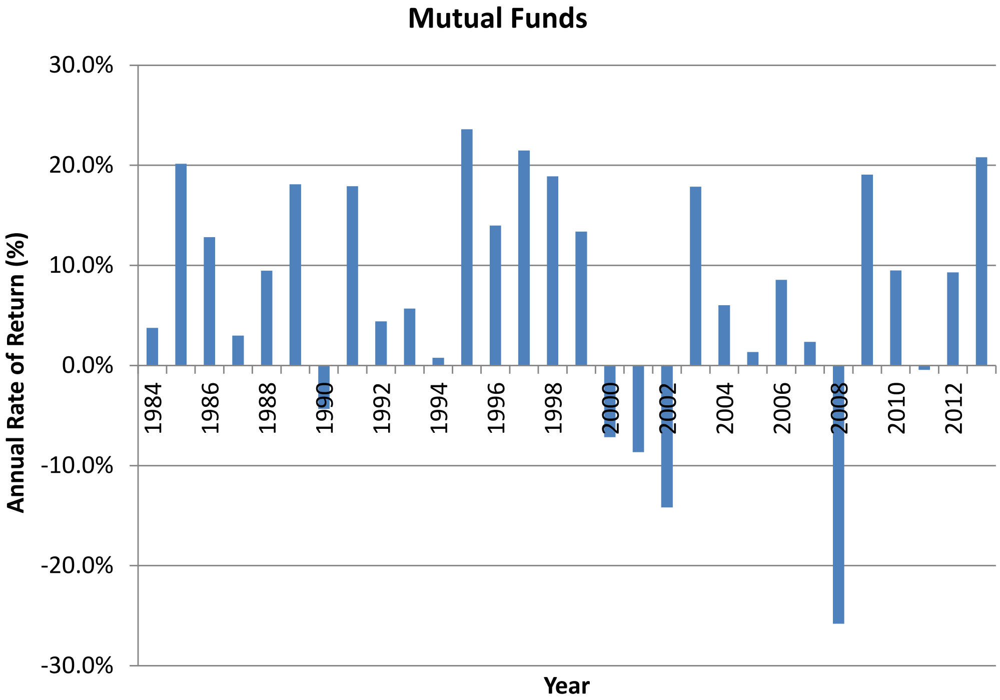


**Figure 8-E.3.7** Distribution of Annual Rate of Return on Mutual Funds

## 8-E.4 DISTRIBUTION OF REAL EFFECTIVE DISCOUNT RATES BY INCOME GROUP

Figure 8-E.4.1 and Table 8-E.4.1 present the distributions of real discount rates for each income group.

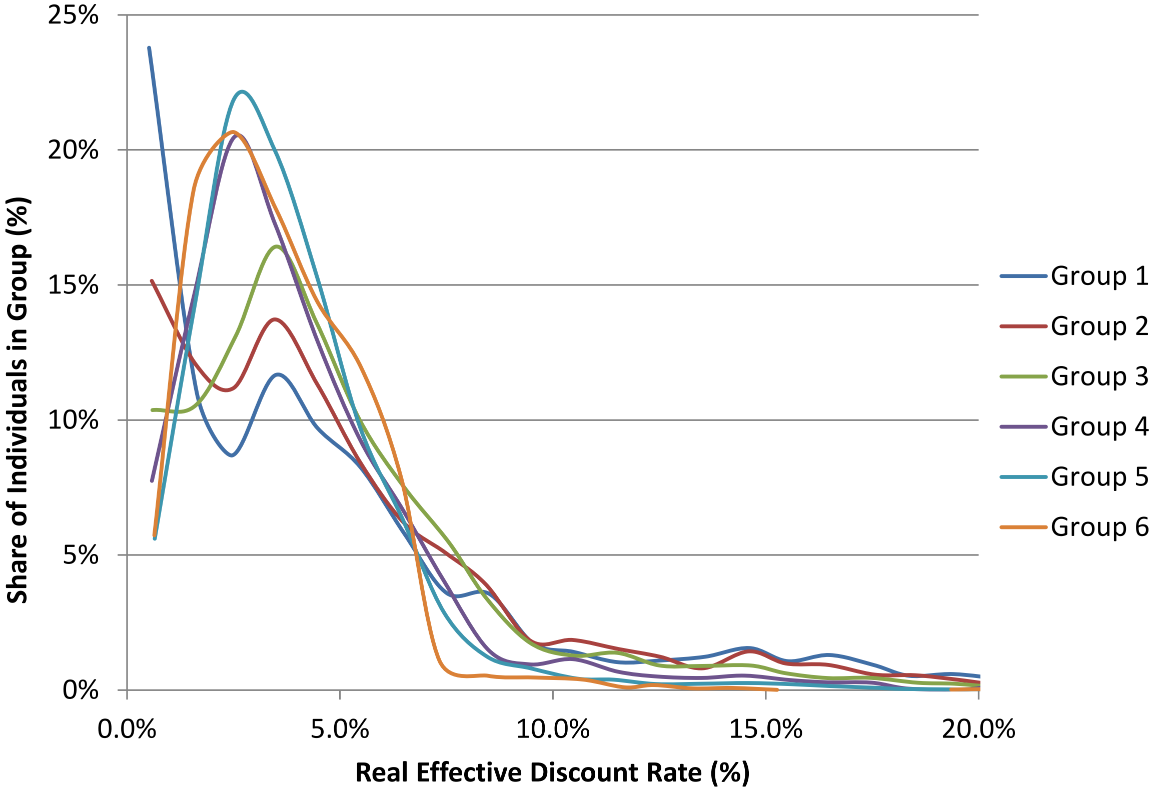


**Figure 8-E.4.1 Distribution of Real Discount Rates by Income Group**

## Table 8-E.4.1 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 | 0.5% | 0.238 | 0.6% | 0.152 | 0.6% | 0.104 | 0.6% | 0.077 | 0.6% | 0.056 | 0.6% | 0.057 |
| 1-2 | 1.6% | 0.110 | 1.6% | 0.120 | 1.6% | 0.105 | 1.6% | 0.146 | 1.6% | 0.142 | 1.6% | 0.185 |
| 2-3 | 2.5% | 0.087 | 2.5% | 0.112 | 2.6% | 0.131 | 2.5% | 0.205 | 2.5% | 0.219 | 2.5% | 0.207 |
| 3-4 | 3.5% | 0.117 | 3.5% | 0.137 | 3.5% | 0.164 | 3.5% | 0.173 | 3.5% | 0.200 | 3.5% | 0.178 |
| 4-5 | 4.5% | 0.097 | 4.5% | 0.113 | 4.5% | 0.136 | 4.5% | 0.129 | 4.5% | 0.153 | 4.5% | 0.144 |
| 5-6 | 5.5% | 0.083 | 5.5% | 0.084 | 5.5% | 0.100 | 5.5% | 0.093 | 5.5% | 0.098 | 5.5% | 0.120 |
| 6-7 | 6.5% | 0.058 | 6.5% | 0.062 | 6.5% | 0.075 | 6.5% | 0.067 | 6.5% | 0.063 | 6.4% | 0.079 |
| 7-8 | 7.5% | 0.036 | 7.5% | 0.051 | 7.6% | 0.054 | 7.4% | 0.041 | 7.4% | 0.029 | 7.3% | 0.011 |
| 8-9 | 8.5% | 0.036 | 8.4% | 0.039 | 8.4% | 0.034 | 8.5% | 0.015 | 8.4% | 0.012 | 8.5% | 0.005 |
| 9-10 | 9.5% | 0.017 | 9.5% | 0.018 | 9.5% | 0.017 | 9.5% | 0.010 | 9.5% | 0.008 | 9.6% | 0.005 |
| 10-11 | 10.5% | 0.014 | 10.5% | 0.019 | 10.5% | 0.013 | 10.5% | 0.011 | 10.6% | 0.004 | 10.7% | 0.004 |
| 11-12 | 11.5% | 0.010 | 11.5% | 0.015 | 11.5% | 0.014 | 11.5% | 0.007 | 11.4% | 0.004 | 11.7% | 0.001 |
| 12-13 | 12.5% | 0.011 | 12.5% | 0.012 | 12.5% | 0.009 | 12.4% | 0.005 | 12.4% | 0.002 | 12.4% | 0.002 |
| 13-14 | 13.6% | 0.012 | 13.5% | 0.008 | 13.5% | 0.009 | 13.5% | 0.004 | 13.5% | 0.002 | 13.3% | 0.001 |
| 14-15 | 14.6% | 0.016 | 14.6% | 0.014 | 14.6% | 0.009 | 14.5% | 0.005 | 14.6% | 0.003 | 14.2% | 0.001 |
| 15-16 | 15.5% | 0.011 | 15.5% | 0.010 | 15.5% | 0.006 | 15.6% | 0.004 | 15.6% | 0.002 | 15.3% | 0.000 |
| 16-17 | 16.5% | 0.013 | 16.5% | 0.009 | 16.5% | 0.004 | 16.5% | 0.003 | 16.5% | 0.001 | 0.0% | 0.000 |
| 17-18 | 17.5% | 0.009 | 17.6% | 0.006 | 17.5% | 0.005 | 17.5% | 0.003 | 17.6% | 0.001 | 17.7% | 0.001 |
| 18-19 | 18.4% | 0.005 | 18.5% | 0.005 | 18.6% | 0.003 | 18.4% | 0.001 | 18.2% | 0.000 | 0.0% | 0.000 |
| 19-20 | 19.4% | 0.006 | 19.4% | 0.004 | 19.4% | 0.002 | 19.7% | 0.000 | 19.7% | 0.000 | 19.4% | 0.000 |
| 20-21 | 20.6% | 0.004 | 20.4% | 0.002 | 20.5% | 0.001 | 20.3% | 0.001 | 20.5% | 0.000 | 20.3% | 0.000 |
| 21-22 | 21.4% | 0.003 | 21.4% | 0.002 | 21.4% | 0.001 | 21.5% | 0.001 | 0.0% | 0.000 | 21.4% | 0.000 |
| 22-23 | 22.5% | 0.002 | 22.4% | 0.001 | 22.6% | 0.001 | 22.9% | 0.000 | 22.8% | 0.000 | 22.3% | 0.000 |
| 23-24 | 23.6% | 0.001 | 23.4% | 0.001 | 23.6% | 0.001 | 0.0% | 0.000 | 0.0% | 0.000 | 24.0% | 0.000 |
| 24-25 | 24.6% | 0.001 | 24.5% | 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 | 25.5% | 0.000 | 0.0% | 0.000 | 0.0% | 0.000 | 0.0% | 0.000 |
| 26-27 | 26.5% | 0.001 | 26.5% | 0.000 | 26.4% | 0.000 | 0.0% | 0.000 | 0.0% | 0.000 | 0.0% | 0.000 |
| 27-28 | 27.8% | 0.000 | 27.6% | 0.000 | 27.8% | 0.000 | 0.0% | 0.000 | 0.0% | 0.000 | 0.0% | 0.000 |
| 28-29 | 28.2% | 0.000 | 0.0% | 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 | 59.1% | 0.001 | 142.7% | 0.002 | 0.0% | 0.000 | 53.3% | 0.000 | 0.0% | 0.000 | 0.0% | 0.000 |

## REFERENCES

1. The Federal Reserve Board, Survey of Consumer Finances 1995, 1998, 2001, 2004, 2007, 2010. <http://www.federalreserve.gov/pubs/oss/oss2/scfindex.html>

2. The Federal Reserve Board, *Federal Reserve Statistical Release, Selected Interest Rates, Historical Data, Instrument: CDs (secondary market), Maturity: 6-month, Frequency: Annual, Description: Average rate on 6-month negotiable certificates of deposit (secondary market), quoted on an investment basis*, 2013. <www.federalreserve.gov/releases/H15/data.htm>

3. The Federal Reserve Board, *Federal Reserve Statistical Release, Selected Interest Rates, Historical Data, Instrument: State and local bonds, Maturity: 20-year, Frequency: Monthly, Description: Bond buyer go 20-bond municipal bond index*, 2013. <www.federalreserve.gov/releases/H15/data.htm>

4. The Federal Reserve Board, *Federal Reserve Statistical Release, Selected Interest Rates, Historical Data, Instrument: Corporate bonds/Moody's Seasoned AAA, Frequency: Annual, Description: Moody's yield on seasoned corporate bonds—all industries, AAA*, 2013. <www.federalreserve.gov/releases/H15/data.htm>

5. Mortgage-X - Mortgage Information Service, *Cost of Savings Index (COSI) Index History*, 2013. <http://mortgage-x.com/general/indexes/default.asp>

6. Damodaran Online Data Page, *The Data Page: Historical Returns on Stocks, Bonds and Bills - United States*, 2013. Damodaran. <http://pages.stern.nyu.edu/~adamodar/>

# APPENDIX 9-A. RELATIVE PRICE ELASTICITY OF DEMAND FOR APPLIANCES

## TABLE OF CONTENTS

## LIST OF TABLES

## LIST OF FIGURES

# APPENDIX 9-A. RELATIVE PRICE ELASTICITY OF DEMAND FOR APPLIANCES

## 9-A.1 INTRODUCTION

This appendix summarizes the U.S. Department of Energy's (DOE's) study of the price elasticity of demand for home appliances, including refrigerators, clothes washers, and dishwashers. DOE chose this particular set of appliances because of the availability of data to determine a price elasticity. Section 9-A.2 reviews the existing economics literature describing the impact of economic variables on the sale of durable goods. Section 9-A.3 describes the market for home appliances and the changes that have occurred over the past 20 years. In section 9-A.4, DOE summarizes the results of its regression analysis and presents estimates of the price elasticity of demand for the three appliances. In section 9-A.5, DOE presents the development of an 'effective' purchase price elasticity. DOE's interpretation of its results is presented in section 9-A.6. Finally, section 9-A.7 describes the data used in DOE's analysis.

## 9-A.2 LITERATURE REVIEW

Relatively few studies measure the impact of price, income, and efficiency on the sale of household appliances. This section briefly reviews the literature that describes the likely importance of these variables on the purchase of household appliances.

### 9-A.2.1 Price

DOE reviewed many studies that sought to measure the impact of price on sales in a dynamic market. One study of the automobile market prior to 1970 finds the price elasticity of demand tends to decline over time. The author explains this as the result of buyers delaying purchases after a price increase but eventually making the purchase (Table 9-A.2.1).[1] A contrasting study of household white goods, also prior to 1970, finds the elasticity of demand to increase over time as more price-conscious buyers enter the market.[2] An analysis of refrigerator market survey data finds that consumer purchase probability decreases with survey asking price.[3] Estimates of the price elasticity of demand for different brands of the same product tend to vary. A review of 41 studies of the impact of price on market share found the average price elasticity to be -1.75.[4] The average estimate of price elasticity of demand reported in these studies is -0.33 in the appliance market and -0.47 in the combined automobile and appliance markets.

### 9-A.2.2 Income

Higher income households are more likely to own household appliances.[5] The impact of income on appliance shipments is explored in two econometric studies of the automobile and appliance markets.[1,2] The average income elasticity of demand is 0.50 in the appliance study cited in the literature review and is much larger in the automobile study (Table 9-A.2.1).

### 9-A.2.3 Appliance Efficiency and Discount Rates

Many studies estimate the impact of appliance efficiency on consumers' choice of appliance. Typically, this impact is summarized by the implicit discount rate; that is, the rate consumers use to compare future savings in appliance operating costs against a higher initial purchase price of an appliance. One early and much cited study concludes that consumers use a 20-percent implicit discount rate when purchasing room air conditioners (Table 9-A.2.1).[6] A survey of several studies of different appliances suggests that the consumer implicit discount rate has a broad range and averages about 37 percent.[7]

**Table 9-A.2.1 Estimates of the Impact of Price, Income, and Efficiency on Automobile and Appliance Sales**

| Durable Good | Price Elasticity | Income Elasticity | Brand Price Elasticity | Implicit Discount Rate | Model | Data Years | Time Period |
|---|---|---|---|---|---|---|---|
| Automobiles[1] | -1.07 | 3.08 | - | - | Linear Regression, stock adjustment | - | Short run |
| Automobiles[1] | -0.36 | 1.02 | - | - | Linear Regression, stock adjustment | - | Long run |
| Clothes Dryers[2] | -0.14 | 0.26 | - | - | Cobb-Douglas, diffusion | 1947-1961 | Mixed |
| Room Air Conditioners[2] | -0.37[8] | 0.45 | - | - | Cobb-Douglas, diffusion | 1946-1962 | Mixed |
| Dishwashers[2] | -0.42 | 0.79 | - | - | Cobb-Douglas, diffusion | 1947-1968 | Mixed |
| Refrigerators[3] | -0.37 | - | - | 39% | Logit probability, survey data | 1997 | Short run |
| Various[4] | - | - | -1.76[9] | - | Multiplicative regression | - | Mixed |
| Room Air Conditioners[5] | - | - | -1.72 | - | Non-linear diffusion | 1949-1961 | Short run |
| Clothes Dryers[5] | - | - | -1.32 | - | Non-linear diffusion | 1963-1970 | Short run |
| Room Air Conditioners[6] | - | - | - | 20% | Qualitative choice, survey data | - | - |
| Household Appliances[7] | - | - | - | 37%[10] | Assorted | - | - |

**Sources:** [1] S. Hymens. 1971; [2] P. Golder and G. Tellis, 1998; [3] D. Revelt and K. Train, 1997; [4] G. Tellis, 1988; [5] D. Jain and R. Rao; [6] J. Hausman; [7] K. Train, 1985.

**Notes:** [8] Logit probability results are not directly comparable to other elasticity estimates in this table.
[9] Average brand price elasticity across 41 studies.
[10] Averaged across several household appliance studies referenced in this work.

## 9-A.3 VARIABLES DESCRIBING THE MARKET FOR REFRIGERATORS, CLOTHES WASHERS, AND DISHWASHERS

In this section DOE evaluates variables that appear to account for refrigerator, clothes washer, and dishwasher shipments, including physical household/appliance variables and economic variables.

### 9-A.3.1 Physical Household/Appliance Variables

Several variables influence the sale of refrigerators, clothes washers, and dishwashers. The most important for explaining appliance sales trends are the annual number of new households formed (housing starts) and the number of appliances reaching the end of their operating life (replacements). Housing starts influence sales because new homes are often provided with, or soon receive, new appliances, including dishwashers and refrigerators. Replacements are correlated with sales, because new appliances are typically purchased when old ones wear out. In principle, if households maintain a fixed number of appliances, shipments should equal housing starts plus appliance replacements.

### 9-A.3.2 Economic Variables

Appliance price, appliance operating cost, and household income are important economic variables affecting shipments. Low prices and costs encourage household appliance purchases, and a rise in income increases householder ability to purchase appliances. In principle, changes in economic variables should explain changes in the number of appliances per household.

During a 1980–2002 study period, annual shipments grew 69 percent for clothes washers, 81 percent for refrigerators, and 105 percent for dishwashers (Table 9A.3.1). This rising shipments trend is explained in part by housing starts, which increased 6 percent and by appliance replacements, which rose between 49 percent and 90 percent, depending on the appliance, over the period (Table 9-A.3.1).[a] For mature markets such as these, replacements exceed appliance sales associated with new housing construction.

**Table 9-A.3.1 Physical Household/Appliance Variables**

| | Shipments[1] (millions) | | | Housing Starts[2] (millions) | | | Replacements[3] (millions) | | |
|---|---|---|---|---|---|---|---|---|---|
| **Appliance** | **1980** | **2002** | **Change** | **1980** | **2002** | **Change** | **1980** | **2002** | **Change** |
| Refrigerators | 5.124 | 9.264 | 81% | 1.723 | 1.822 | 6% | 3.93 | 5.84 | 49% |
| Clothes Washers | 4.426 | 7.492 | 69% | 1.723 | 1.822 | 6% | 3.66 | 5.50 | 50% |
| Dishwashers | 2.738 | 5.605 | 105% | 1.723 | 1.822 | 6% | 1.99 | 3.79 | 90% |

[1] Shipments: Number of units sold. Sources: AHAM Fact Book and Appliance Magazine.

[2] Housing Starts: Annual number of new homes constructed. Source: U.S. Census.

[3] Replacements: Average of annual lagged shipments, with lag equal to expected appliance operating life, ± 5 years.

Shipments increased somewhat more rapidly than housing starts and replacements. This is shown by comparing the beginning and end points of lines that represent “starts plus replacements” (uppermost solid line in Figure 9-A.3.1) and “shipments” (diamond linked line in Figure 9-A.3.1). In 1980 the “shipment” line begins below the “starts plus replacements” line. In 2002, the “shipments” line ends above the “starts plus replacements” line. This more rapid

---

[a] Appliance replacements are determined from the expected operating life of refrigerators (19 years), clothes washers (14 years), and dishwashers (12 years), and from past shipments. Replacements are further discussed in section 9A.3. The dishwasher lifetime used in this analysis does not match the dishwasher used in the primary analysis.

increase in shipments, compared to housing starts plus replacements, suggests that the appliance per household ratio increased over the study period.

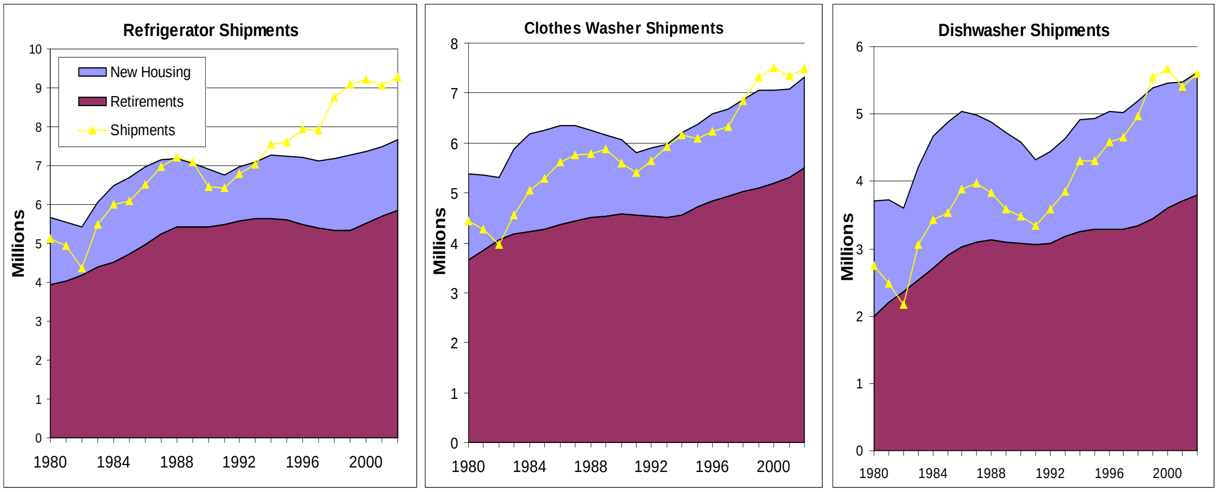


**Figure 9-A.3.1 Trends in Appliance Shipment, Housing Starts and Replacements**

Economic variables, including price, cost, and income, may explain this increase in appliances per household. Over the period, appliance prices decreased 40 percent to 50 percent, operating costs fell between 33 percent and 72 percent, and median household income rose 16 percent (Table 9-A.3.2).

**Table 9-A.3.2 Economic Variables**

| | **Price[1] (1999\$)** | | | **Operating Cost[2] (1999\$)** | | | **Household Income[3] (1999\$)** | | |
|---|---|---|---|---|---|---|---|---|---|
| **Appliance** | **1980** | **2002** | **Change** | **1980** | **2002** | **Change** | **1980** | **2002** | **Change** |
| Refrigerators | 1208 | 726 | -40% | 333 | 94 | -72% | 37,447 | 43,381 | 16% |
| Clothes Washers | 779 | 392 | -50% | 262 | 175 | -33% | 37,447 | 43,381 | 16% |
| Dishwashers | 713 | 369 | -48% | 183 | 95 | -48% | 37,447 | 43,381 | 16% |

[1] Price: Shipment weighted retail sales price. Sources: AHAM Fact Book and Appliance Magazine.

[2] Operating Cost: Annual electricity price times electricity consumption. Source: AHAM Fact Book.

[3] Income: Mean household income. Source: U.S. Census.

## 9-A.4 REGRESSION ANALYSIS OF VARIABLES AFFECTING APPLIANCE SHIPMENTS

Few data are available to estimate the impact of economic variables on the demand for appliances. Industry operating cost data is incomplete; appliance energy use data are available for only 12 years of the 1980-2002 study period. Industry price data are also incomplete—available for only 8 years of the study period for each of the appliances.

The lack of data suggests that regression analysis can at best evaluate broad data trends, utilizing relatively few explanatory variables. This section begins by describing broad trends apparent in the economic and physical household data sets and then specifies a simple regression model to measure these trends, making assumptions to minimize the number of explanatory variables. Finally, results of the regression analysis are presented along with an estimate of the price elasticity of demand for appliances. In section 9-A.4.5, DOE presents the results of a regression analysis performed with more complex models, which are used to test assumptions underlying the simple model. These results support the specification of the simple model and the price elasticity of appliance demand estimated with that model.

### 9-A.4.1 Broad Trends

In this section DOE reviews trends in the physical household and economic data sets and posits a simple approach for estimating the price elasticity of appliance demand. As noted previously, the physical household variables (housing starts and appliance replacements) explain most of the variability in appliance shipments during the study period (1980-2002).[b] DOE assumes the rest of the variability in shipments (referred to as “residual shipments”) is explained by economic variables. Here, DOE presents a tabular method for measuring price elasticities.

To illustrate this tabular approach, DOE defines two new variables—residual shipments and total price. Residual shipments are defined as the difference between shipments and physical household demand (starts plus replacements). Total price, represented by the following equation, is defined as appliance price plus the present value of lifetime appliance operating cost:[c]

$$TP = PP + PVOC$$

Where:

$TP$ = total price,
$PP$ = appliance purchase price, and
$PVOC$ = present value of operating cost.

Over the study period, residual shipments increased in proportion to total shipments by 30 percent for refrigerators, 19 percent for clothes washers, and 23 percent for dishwashers. At the same time, total prices declined 47 percent, 45 percent, and 48 percent for refrigerators, clothes washers, and dishwashers, respectively. Assuming that total price explains the entire change in per household appliance usage, a rough estimate was calculated of the total price elasticity of demand, which was found to equal -0.48 for refrigerators, -0.32 for clothes washers, and -0.37 for dishwashers (Table 9-A.4.1).

---

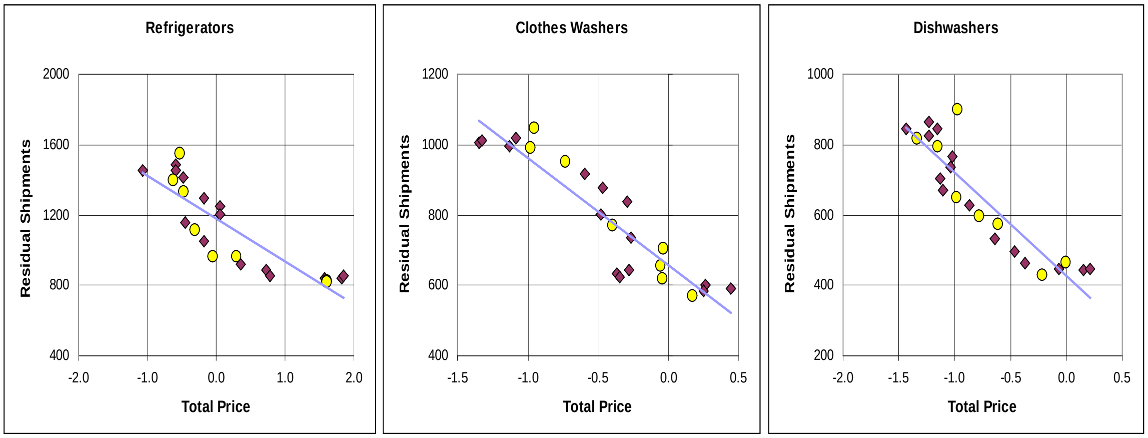
[b] A log regression of the form: Shipments = a + b • Housing Starts + c • Retirements, indicates that these two variables explain 89 percent of the variation in refrigerator shipments, 97 percent of the variation in clothes washer shipments, and 97 percent of the variation in dishwasher shipments.

[c] Present value operating cost is calculated assuming a 19-year operating life for refrigerators, 14-year operating life for clothes washers, and a 12-year operating life for dishwashers. A 37-percent discount rate is used to sum annual operating costs into a present value operating cost.

## Table 9-A.4.1 Estimate of Total Price Elasticity of Demand

| | Residual Shipments (millions) | | | | Total Price (1999$) | | | |
|---|---|---|---|---|---|---|---|---|
| **Appliance** | **1980** | **2002** | **Difference** | **Change** | **1980** | **2002** | **Change** | **Elasticity** |
| Refrigerators | -0.5 | 1.6 | 2.1 | 30% | 1541 | 820 | -61% | -0.48 |
| Clothes Washers | -1.0 | 0.2 | 1.1 | 19% | 1042 | 567 | -59% | -0.32 |
| Dishwashers | -1.0 | -0.01 | 1.0 | 23% | 896 | 464 | -64% | -0.37 |

The negative correlation between total price and residual shipments suggested by these negative price elasticities is illustrated in a graph of residual shipments on the y-axis and total price on the x-axis (Figure 9-A.4.1).



Yellow points are observed price data; red points are interpolated price data.

**Figure 9-A.4.1 Residual Shipments and Appliance Price**

Household income rose during the study period, making it easier for households to purchase appliances. Assuming that a rise in income has a similar impact on shipments as a decline in price, the impact of income is incorporated by defining a third variable, termed *relative* price, which is calculated as total price divided by household income and represented by the following equation.[d]

$$RP = \frac{TP}{Income}$$

Where:

$RP$ = relative price,
$TP$ = total price, and
$Income$ = household income.

---

[d] Recall that the income elasticity of demand cited in the literature review is 0.50 and the price elasticity of demand cited in the review averages -0.35. This suggests that combining the effects of income and price will yield an elasticity less negative than price elasticity alone.

The percent decline in *relative* price for the three appliances divided by the percent decline in residual shipments suggests a rough estimate of *relative* price elasticity equal to -0.40 for refrigerators, -0.26 for clothes washers, and -0.30 for dishwashers (Table 9-A.4.2).

**Table 9-A.4.2 Tabular Estimate of Relative Price Elasticity of Appliance Demand**

| | **Residual Shipments (millions)** | | | **Relative Price (1999$)** | | | |
|---|---|---|---|---|---|---|---|
| **Appliance** | **1980** | **2002** | **Change** | **1980** | **2002** | **Change** | **Elasticity** |
| Refrigerators | -0.532 | 1.597 | 30% | 0.041 | 0.019 | -74% | -0.40 |
| Clothes Washers | -0.953 | 0.174 | 19% | 0.028 | 0.013 | -72% | -0.26 |
| Dishwashers | -0.974 | -0.005 | 23% | 0.024 | 0.011 | -76% | -0.30 |

### 9-A.4.2 Specification of Model

The limited price data suggest it is appropriate to use a simple regression model to estimate the impact of economic variables on shipments, using few explanatory variables. The following equation, chosen for this analysis, includes one physical household variable (housing starts plus replacements) and one *relative* price variable (the sum of purchase price plus operating cost, divided by income).

$$Ship = a + b \times RP + c \times \left[Starts + Rplc\right] \qquad \textbf{Eq. 9A.1}$$

Where:

$Ship$ = quantity of appliance sold,
$RP$ = relative price,
$Starts$ = number of new homes, and
$Rplc$ = number of appliances at the end of their operating life.

The natural logs are taken of all variables so that the estimated coefficients for each variable in the model may be interpreted as the percent change in shipments associated with the percent change in the variable. Thus, the coefficient *b* in this model is interpreted as the *relative* price elasticity of demand for the three appliances.

DOE used the following combined regression equation to estimate an average price elasticity of demand across the three appliances, using pooled data in a single regression. A combined regression specification is justified, given the limited data available and the similarity in price and shipment behavior across appliances (see Figure 9-A.4.1). Thus, the model represented by the combined regression equation is considered the basic model in DOE's analysis of appliance shipments.

$$Ship = a + b \times RP + c \times \left[Starts + Rplc\right] + d \times CW + e \times DW \qquad \textbf{Eq. 9A.2}$$

Where:

$CW$ = quantity of clothes washers sold, and

$DW =$ quantify of dishwashers sold.

### 9-A.4.3 Discussion of Model

The most important assumption used to specify this model is that changes in economic variables over the study period—income, price, and operating cost—are responsible for all observed growth in residual appliance shipments. In other words, DOE assumes no impact from other possible factors, such as changing consumer preferences or increases in the quality of appliances. This assumption seems unlikely, but without additional data, the impact of this assumption on the price elasticity of demand cannot be measured. DOE effectively assumes that changes in consumer preferences and appliance characteristics, while affecting which models are purchased, have relatively little impact on the total number of appliances purchased in a year.

Three additional assumptions used to specify this model deserve comment. The *relative* price variable is specified in the model, assuming that (1) the correct implicit discount rate is used to combine appliance price and operating cost and that (2) rising income has the same impact on shipments as falling total price. The "starts + replacements" variable is specified, assuming (3) that starts and replacements have similar impacts on shipments.

To investigate the first assumption about discount rates, DOE calculated "present value operating cost" using a 20-percent implicit discount rate and performed a second regression analysis based on the models described in equations 9A.1 and 9A.2. The results of this analysis, presented in section 9-A.4.5, indicate that the elasticity of *relative* price is fairly insensitive to changes in the discount rate.

To investigate the second and third assumptions, DOE specified a regression model separating income from total price and replacements from starts, thereby adding two additional explanatory variables to the basic model as shown in the following equation:

$$Ship = a + b \times TP + c \times Incone + d \times Start + e \times Rplc + f \times CW + g \times DW \qquad \textbf{Eq. 9A.3}$$

The results of the regression analysis of this model are presented in section 9-A.4.5. These results suggest that the elasticity of total price (coefficient *b*) is relatively insensitive to changes in the treatment of income and "starts + replacements" in the model.

### 9-A.4.4 Analysis Results

The following sections describe results of analyses using both the individual and combined models for appliances and the effects of a lower consumer discount rate and disaggregated variables.

#### 9-A.4.4.1 Individual Appliance Model

The individual appliance regression equations are specified in the following equation.

$$Ship = a + b \times RP + c \times [Starts + Rplc]$$

In the regression analysis of this model, the elasticity of *relative* price (*b*) is estimated to be -0.40 for refrigerators, -0.31 for clothes washers, and -0.32 for dishwashers (Table 9-A.4.3), averaging -0.35. These elasticities are similar to those reported in the literature survey for appliances (Table 9-A.2.1). They are remarkably similar to the price elasticity calculated using a tabular approach (Table 9-A.4.2).

The estimated coefficient associated with the "starts + replacements" variable is close to one. A coefficient equal to one for this variable would imply that, holding economic variables constant, shipments increase in direct proportion to an increase in "starts + replacements." The high R-squared values (above 95) and t-statistics (above 5) in the results provide a measure of confidence in this analysis, despite the very small data set.

**Table 9-A.4.3 Individual Appliance Model Results**

| | **Refrigerator** | | **Clothes Washer** | | **Dishwasher** | |
|---|---|---|---|---|---|---|
| **Variable** | **Coefficient** | **t-stat** | **Coefficient** | **t-stat** | **Coefficient** | **t-stat** |
| Intercept | -1.51 | -7.26 | -1.47 | -8.23 | -2.08 | -16.78 |
| Relative Price | -0.40 | -6.60 | -0.31 | -5.69 | -0.32 | -7.03 |
| Starts + Replacements | 1.05 | 5.90 | 1.08 | 6.41 | 1.35 | 11.46 |
| $R^2$ | 0.954 | | 0.954 | | 0.975 | |
| Observations | 23 | | 23 | | 23 | |

### 9-A.4.4.2 Combined Appliance Model

The combined appliance regression equation is specified in the following equation.

$$Ship = a + b \times RP + c \times [Starts + Rplc] + d \times CW + e \times DW$$

This regression analysis indicates that the model fits the existing shipments data well (high R-squared) and that the variables included in the model are statistically significant (Table 9-A.4.4). Estimated with this model, the elasticity of *relative* price is -0.34, close to the average value estimated in the individual appliance models (-0.35). It is also similar to elasticity estimates reported in the literature survey and calculated using the tabular approach in Table 9-A.4.2.

**Table 9-A.4.4 Combined Appliance Model Result**

| **Variable** | **Coefficient** | **t-statistic** |
|---|---|---|
| Intercept | -1.60 | -15.54 |
| Relative Price | -0.34 | -10.74 |
| Starts + Replacements | 1.21 | 13.95 |
| CW | -0.20 | -9.04 |
| DW | -0.32 | -6.58 |
| $R^2$ | 0.983 | |
| Observations | 69 | |

## 9-A.4.5 Additional Regression Specifications and Results

As described in section 9-A.4.3, DOE used three assumptions to specify its appliance models. The first, made to aggregate appliance price and operating cost, is that the implicit price variable in the basic regression model is specified using a 37-percent implicit discount rate. The second states that the implicit price variable is defined assuming that rising income has the same impact on shipments as falling total price. The third states that the "starts + replacements" variable is defined assuming that housing starts have a similar impact on shipments as appliance replacements.

### 9-A.4.5.1 Lower Consumer Discount Rate

To investigate the first assumption about discount rates, DOE calculated "present value operating cost" using a 20-percent implicit discount rate and performed a second regression analysis based on the models described in equations 9A.1 and 9A.2. The estimated coefficient associated with the *relative* price variable in these regressions is almost identical to the coefficients estimated for the same variable based on a 37-percent implicit discount rate. The elasticity of *relative* price calculated using a 20-percent discount rate is -0.33 in the combined regression and averages -0.35 for the three appliances (Table 9-A.4.5). The elasticity of price calculated using a 37-percent discount rate is -0.34 in the combined regression and averages -0.35 for the three appliances. DOE concludes from this analysis that the elasticity of *relative* price is fairly insensitive to changes in the discount rate.

**Table 9-A.4.5 Combined and Individual Results, 20 percent discount rate**

| **Three Appliances** | | |
|---|---|---|
| **Variable** | **Coefficient** | **t-Stat** |
| Intercept | -1.53 | -14.61 |
| Total Price / Income | -0.33 | -10.69 |
| Starts + Retirements | 1.20 | 13.65 |
| CW | -0.18 | -8.69 |
| DW | -0.32 | -6.57 |
| $R^2$ | 0.982 | |
| Observations | 69 | |

| | **Refrigerator** | | **Clothes Washers** | | **Dishwasher** | |
|---|---|---|---|---|---|---|
| **Variable** | **Coefficient** | **t-Stat** | **Coefficient** | **t-Stat** | **Coefficient** | **t-Stat** |
| Intercept | -1.36 | -6.26 | -1.41 | -7.49 | -2.04 | -17.23 |
| Total Price / Income | -0.38 | -6.50 | -0.32 | -5.29 | -0.33 | -7.30 |
| Starts + Retirements | 1.04 | 5.73 | 1.06 | 5.83 | 1.34 | 11.64 |
| $R^2$ | | 0.953 | | 0.950 | | 0.977 |
| Observations | | 23 | | 23 | | 23 |

### 9-A.4.5.2 Disaggregated Variables

To investigate the second and third assumptions, DOE constructed a regression model that separates income from total price and replacements from starts, thus adding two additional explanatory variables to the basic model (as shown earlier as Eq. 9A.3 and shown here).

$$Ship = a + b \times TP + c \times Income + d \times Start + e \times Rplc + f \times CW + g \times DW$$

The estimated coefficient associated with the total price variable in these regressions is almost identical to the coefficients estimated for the *relative* price variable reported previously. The elasticity of total price in the above equation is -0.36 in the combined appliance regression and averages -0.35 for the three appliances (Table 9-A.4.6). The elasticity of *relative* price based on the model described in equation 9A.2 is -0.34 in the combined regression (Table 9-A.4.4) and averages -0.35 across the individual appliances (Table 9-A.4.3). DOE concludes that the price elasticity calculated in this analysis is relatively insensitive to the specification of household income and "starts + replacements" variables in the model.

**Table 9-A.4.6 Disaggregated Regression Results, 37 percent discount rate**

| Three Appliances | | |
|---|---|---|
| **Variable** | **Coefficient** | **t-Stat** |
| Intercept | -2.92 | -1.26 |
| Income | 0.58 | 2.92 |
| Total Price | -0.36 | -7.06 |
| Housing Starts | 0.44 | 10.02 |
| Retirements | 0.62 | 8.12 |
| CW | -0.24 | -9.25 |
| DW | -0.46 | -7.68 |
| $R^2$ | | 0.985 |
| Observations | | 69 |

| | **Refrigerator** | | **Clothes Washers** | | **Dishwasher** | |
|---|---|---|---|---|---|---|
| **Variable** | **Coefficient** | **t-Stat** | **Coefficient** | **t-Stat** | **Coefficient** | **t-Stat** |
| Intercept | -6.19 | -2.24 | -6.64 | -1.63 | 1.00 | 0.23 |
| Income | 0.89 | 3.80 | 0.87 | 2.31 | 0.20 | 0.52 |
| Total Price | -0.35 | -5.48 | -0.27 | -2.51 | -0.43 | -5.18 |
| Housing Starts | 0.41 | 7.38 | 0.25 | 3.29 | 0.62 | 8.24 |
| Retirements | 0.56 | 6.06 | 0.56 | 2.09 | 0.65 | 5.86 |
| $R^2$ | | 0.984 | | 0.958 | | 0.979 |
| Observations | | 23 | | 23 | | 23 |

## 9-A.5 LONG RUN IMPACTS

As noted in Table 9-A.2.1, the literature review provides price elasticities over short and long time periods, also referred to as short run and long run price elasticities. As noted in the first two rows of Table 9-A.2.1, one source (*i.e.*, Hymans) shows that the price elasticity of demand is significantly different over the short run and long run for automobiles.[1] Because DOE's forecasts of shipments and national impacts due to standards is over a 30-year time period, consideration must be given to how the *relative* price elasticity is affected once a new standard takes effect.

DOE considers the *relative* price elasticities determined in section 9-A.4 to be short run elasticities. DOE was unable to identify sources specific to household durable goods, such as appliances, to indicate how short run and long run price elasticities differ. Therefore, to estimate how the *relative* price elasticity changes over time, DOE relied on the Hymans study pertaining to automobiles. Based on the Hymans study, Table 9-A.5.1 shows how the automobile price elasticity of demand changes in the years following a purchase price change. With increasing years after the price change, the price elasticity becomes more inelastic until it reaches a terminal value around the tenth year after the price change.

**Table 9-A.5.1 Change in Price Elasticity of Demand for Automobiles following a Purchase Price Change**

| | Years Following Price Change | | | | | |
|---|---|---|---|---|---|---|
| | **1** | **2** | **3** | **5** | **10** | **20** |
| Price Elasticity of Demand | -1.20 | -0.93 | -0.75 | -0.55 | -0.42 | -0.40 |
| Relative Change in Elasticity to 1st year | 1.00 | 0.78 | 0.63 | 0.46 | 0.35 | 0.33 |

**Source:** Hymans, 1971.

Based on the relative change in the automobile price elasticity of demand shown in Table 9-A.5.1, DOE developed a time series of *relative* price elasticities for home appliances. Table 9-A.5.2 presents the time series.

**Table 9-A.5.2 Change in Relative Price Elasticity for Home Appliances Following a Purchase Price Change**

| | Years Following Price Change | | | | | |
|---|---|---|---|---|---|---|
| | **1** | **2** | **3** | **5** | **10** | **20** |
| Relative Change in Elasticity to 1st year | 1.00 | 0.78 | 0.63 | 0.46 | 0.35 | 0.33 |
| *Relative* Price Elasticity | -0.34 | -0.26 | -0.21 | -0.16 | -0.12 | -0.11 |

## 9-A.6 SUMMARY

This appendix describes the results of a literature search, tabular analysis, and regression analyses of the impact of price and other variables on appliance shipments. In the literature, DOE found only a few studies of appliance markets that are relevant to this analysis and no studies after 1980 using time series price and shipments data. The information that can be summarized from the literature suggests that the demand for appliances is price inelastic. Other information in the literature suggests that appliances are a normal good, such that rising incomes increase the demand for appliances. Finally, the literature suggests that consumers use relatively high implicit discount rates, when comparing appliance prices and appliance operating costs.

There are too few price and operating cost data available to perform a complex analysis of dynamic changes in the appliance market. In this analysis, DOE used data available for refrigerators, clothes washers, and dishwashers to evaluate broad market trends and perform a simple regression analysis.

These data indicate an increase in appliance shipments and a decline in appliance price and operating cost over the study period 1980-2002. Household income has also risen during this time. To simplify the analysis, DOE combined the available economic information into one variable, termed *relative* price, and used that variable in a tabular analysis of market trends and a regression analysis.

DOE's tabular analysis of trends in the number of appliances per household suggests that the price elasticity of demand for the three appliances is inelastic. Our regression analysis of these same variables suggests that the *relative* price elasticity of demand is -0.34. The price elasticity is consistent with estimates in the literature. Nevertheless, DOE stresses that the measure is based on a small data set, using a very simple statistical analysis. More important, the measure is based on an assumption that economic variables, including price, income, and operating costs, explain most of the trend in appliances per household in the United States since 1980. Changes in appliance quality and consumer preferences may have occurred during this period, but they are not accounted for in this analysis.

## 9-A.7 DATA USED IN THE ANALYSIS

- **Appliance Shipments** are defined as the annual number of units shipped in millions. These data were collected from the Association of Home Appliance Manufacturers (AHAM)[8] and *Appliance Magazine*[9] as annual values for each year, 1980–2002. AHAM was used for the period 1989–2002, while *Appliance Magazine* was used for the period 1980–1988.

- **Appliance Price** is defined as the shipments-weighted retail sales price of the unit in 1999 dollars. Price values for 1980, 1985, 1986, 1991, 1993, 1994, 1998, and 2002 were collected from AHAM Fact Books.[10] Price values for other years were interpolated from these eight years of data.

- **Housing Starts** data were collected from the U.S. Census construction statistics (C25 reports) as annual values for each year, 1980–2002.[11]

- **Replacements**, driven by equipment retirements, are estimated with the assumption that some fraction of sales arises from consumers replacing equipment at the end of its useful life. As each appliance has a different expected lifespan, replacements are calculated differently for each appliance type. Replacements are estimated as the average of shipments 14–24 years previous for refrigerators, 9–19 years previous for clothes washers, and 7–17 years previous for dishwashers. Historical shipments data were collected from AHAM and *Appliance Magazine.*

- **Annual Electricity Consumption** (UEC) is defined as the energy consumption of the unit in kilowatt-hours. Electricity consumption depends on appliance capacity and efficiency. These data were provided by AHAM for 1980, 1990–1997 and 1999–2002.[12] Data were interpolated in the years for which data were not available.

- **Operating Cost** is the present value of the electricity consumption of an appliance over its expected lifespan. The lifespans of refrigerators, clothes washers, and dishwashers are assumed to be 19, 14, and 12 years respectively. Discount rates of 20 percent[6] and 37 percent[13] were used, producing similar estimates of price elasticity. A study by Hausman recommended a discount rate of "about 20 percent" in its introduction and presented results ranging from 24.1 percent to 29 percent based on his calculations for room air conditioners. A study by Train suggests a range of implicit discount rates averaging 35 percent for appliances.

- **Income:** Median annual household income in 2003 dollars. These data were collected for each year, 1980–2002, from Table H-6 of the U.S. Census.[14]

# REFERENCES

---

[1] S. Hymans. Consumer Durable Spending: Explanation and Prediction, *Brookings Papers on Economic Activity*, 1971. Vol. 1971, No. 1, pp. 234-239.

[2] P. Golder and G. Tellis. Beyond Diffusion: An Affordability Model of the Growth of New Consumer Durables, *Journal of Forecasting*, 1998.

[3] D. Revelt and K. Train. Mixed Logit with Repeated Choices: Household's Choice of Appliance Efficiency Level, *Review of Economics and Statistics*, 1997.

[4] G. Tellis. The Price Elasticity of Selective Demand: A Meta-Analysis of Econometric Models of Sales, *Journal of Marketing Research*, 1988.

[5] U.S. Department of Energy-Energy Information Agency. *The Effect of Income on Appliances in U.S. Households*, 2002. Washington, DC. <http://www.eia.doe.gov/emeu/recs/appliances/appliances.html>

[6] J. Hausman. Individual discount rates and the purchase and utilization of energy using durables, *The Bell Journal of Economics*, 1979.

[7] K. Train. Discount rates in consumer' energy related decisions: a review of the literature, *Energy*, 1985.

[8] Association of Home Appliance Manufacturers. *AHAM Fact Books*, 2000 and 2003. Washington, DC.

[9] Statistical Review. *Appliance Magazine*, April, 1990.

[10] Association of Home Appliance Manufacturers. *AHAM Fact Books*, 1987, 1988, 1993, 1995, 2000, and 2003. Washington, DC.

[11] U.S. Census Bureau. Current Construction Reports, C25 – New One-Family Houses Sold. Washington, DC.

[12] Association of Home Appliance Manufacturers. *AHAM 2003 Fact Book*, 2003. Washington, DC.

[13] K.E. Train, and Atherton, T. Rebates, loans, and customers’ choice of appliance efficiency level: combining stated- and revealed-preference data, *The Energy Journal*, 1995.

[14] U.S. Census Bureau. Income, Historical Income Tables – Households, Table H-6. Washington, DC. <https://www.census.gov/hhes/www/income/data/historical/household/>

# APPENDIX 10-A. USER INSTRUCTIONS FOR SHIPMENTS AND NATIONAL IMPACT ANALYSIS SPREADSHEET

## TABLE OF CONTENTS

# APPENDIX 10-A. USER INSTRUCTIONS FOR SHIPMENTS AND NATIONAL IMPACT ANALYSIS SPREADSHEETS

## 10-A.1 INTRODUCTION

The interested reader can examine and reproduce detailed results of the U.S. Department of Energy's (DOE's) shipments analysis and national impact analysis (NIA) for residential dishwashers using Microsoft Excel spreadsheets that are available on DOE's website. <http://www1.eere.energy.gov/buildings/appliance_standards/residential/dishwashers.html>

The latest version of the shipments and NIA workbook, which is posted on the DOE website, was tested using Microsoft Excel 2010. Use of the spreadsheet requires Microsoft Excel 2010 or a later version. The NIA spreadsheet performs calculations to forecast the change in national energy and water use and the net present value attributable to an energy conservation standard. The energy and water use and associated costs and savings attributable to a given standard are determined by calculating first the product shipments and then the energy and water use and costs for all products shipped under that standard. The differences between results under a standards case and the base case can be compared and the nationwide energy and water savings and net present values (NPVs) determined.

The shipments and NIA workbook for both standard-sized and compact residential dishwashers comprises the following worksheets.

| | |
|---|---|
| **Charts** | Contains tables and graphs showing summary results of the NIA: product purchase prices, market shares of standard-sized and compact dishwashers, and historical and forecasted shipments under each trial standard level (TSL). Tables and figures present total savings in energy and water, discounted incremental product prices, and discounted operating cost savings. |
| **Efficiency Distributions** | Provides efficiency distributions through 2048 in terms of shipment-weighted annual energy use (SWAEU), under the base case and each TSL being considered for both standard-sized and compact dishwashers. |
| **Input and Summary** | Provides for user-input selections under "User Inputs" and presents summary tables for the NIA under the chosen TSL. A summary table gives energy and water savings cumulative to 2048. The worksheet provides discounted incremental product prices and operating cost savings and their NPVs. Data also show weighted average energy and water use and prices for base and standards cases, along with values for dishwasher energy use related to the machine, standby power, and water heating. The worksheet |

| | |
|---|---|
| | enables the user to stipulate several parameters for the calculations: relative price elasticity (-0.34 or no impact); trial standard level to be considered (TSL1, TSL2, or TSL3); forecasted trends in prices (default, low-price decline, or high-price decline); and economic growth scenarios (reference, low-growth, or high-growth) from *Annual Energy Outlook (AEO)2014*. |
| **Historical Shipments** | Contains data regarding historical shipments of dishwashers, 1972–2012. |
| **Price Forecasting** | Contains the forecasts for default, low, and high product price trends as well as a constant product price trend. |
| **Shipments Base Case** | Provides data and a graph related to annual historical and projected shipments of dishwashers through 2048 under the base case (the case with no new efficiency standards). Also provides market shares of replacements and units for new housing and the saturation of dishwashers in households nationwide. |
| **Shipments Standards Case** | Provides data and a graph regarding annual historical and projected shipments of dishwashers through 2048 under the chosen TSL. Provides market shares of replacements and units for new housing and the saturation of dishwashers nationwide. |
| **Base Calc** | Presents shipments (replacement, new, and total); unit and total energy and water consumption; product prices; and operating costs for the base case. The sheet starts with a stock accounting of the chosen product class and uses the survival function DOE developed to calculate the surviving stock each year. |
| **Standards Calc** | Presents shipments (replacement, new, and total); unit and total energy and water consumption; product costs; and operating costs for the chosen TSL. Also provides market impacts, energy and water use from washing dishes by hand, and discounted values for costs and savings. |
| **Housing Projections** | Contains the projected housing stock, construction starts, and demolitions for the three *AEO2014* economic scenarios (reference, low growth, and high growth). |
| **Fuel & Water Prices** | Contains projected average energy (electricity, gas, and oil) and water prices to 2100 under each of the three *AEO2014* economic growth scenarios. |

| | |
|---|---|
| **Site-to-Source Conversion** | Contains the marginal site-to-source conversion factors for both electricity and gas that DOE used in calculating source energy savings. |
| **Lifetime** | Contains data and the survival function DOE used to calculate dishwasher lifetimes. Presents a graph showing dishwasher lifetimes and gives the calculated average lifetime (15.4 years). |

## 10-A.2 BASIC INSTRUCTIONS

Basic instructions for operating the NIA spreadsheets are given here.

1. After downloading the Shipments/NIA workbook from DOE's website, use Microsoft Excel to open it. At the bottom of the workbook, click on the tab for the sheet labeled *Input and Summary*. Be sure that calculation options are set to "Automatic."

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 four inputs listed under "User Input." The inputs are:

    a. Discount Rate: To change the value, type in the desired discount rate.
    b. Relative Price Elasticity: Use the drop-down arrow and select the desired value (-0.34 or "No impact.")
    c. Economic Growth: To change the scenario, use the drop-down arrow and select the desired growth level (reference, high, or low).
    d. Trial Standards Level: To change the standard level, click on the drop-down arrow and select TSL 1, 2, or 3.

4. After the parameters have been set, the results are updated automatically and reported in the "National Impact Summary" table for each product class. The summary table is to the right of the "User Inputs" box.

# APPENDIX 10-B.  FULL-FUEL-CYCLE MULTIPLIERS

## TABLE OF CONTENTS

## LIST OF TABLES

# APPENDIX 10-B. FULL-FUEL-CYCLE MULTIPLIERS

## 10-B.1 INTRODUCTION

This appendix summarizes the methods the U.S. Department of Energy (DOE) used to calculate the full-fuel-cycle (FFC) energy savings estimated from potential standards for residential dishwashers. 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.

This analysis uses several terms to describe aspects of energy use. The physical sources of energy are primary fuels such as coal, natural gas, or liquid fuel. Primary energy is equal to the heat content (British thermal units [Btu]) of the primary fuel used to produce an end-use service. Site energy use is defined as the energy consumed at the point of use in a house or establishment. When natural gas or petroleum fuels are consumed at the site (for example in an on-site furnace), site energy is identical to primary energy, with both equal to the heat content of the primary fuel consumed.

For electricity generated by an off-site power plant, site energy is measured in kilowatt-hours (kWh). In such a case the primary energy is equal to the quads (quadrillion Btu) of primary energy required to generate and deliver electricity to the site. For the FFC analysis, upstream energy use is defined as the energy consumed in extracting, processing, and transporting or distributing primary fuels. FFC energy use is the sum of primary plus upstream energy use.

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 uranium and electricity generated from renewable sources (wind, solar, and hydro). For the former, the upstream fuel cycle relates to the amount of fuel consumed at the power plant. There is no upstream component for the latter, because no fuel *per se* is used.

## 10-B.2 METHODOLOGY

The mathematical approach to determining FCC is discussed in Coughlin (2012).[2] Details on analyzing the fuel production chain are presented in Coughlin (2013).[3] The methods used to calculate FFC energy use are summarized here. 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 often 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, on average, 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).
- $z_x(s)$ is the emissions intensity for fuel *x* (mass of pollutant *s* per physical unit of *x* produced).

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. Fossil fuel quantities are converted to energy units using the heat content factor $q_x$. To convert electricity in kWh to primary energy units, on-site electricity consumption is multiplied by the site-to-power-plant energy use factor, described in chapter 10. The site-to-power-plant energy use factor is defined as the ratio of the total primary energy consumption by the electric power sector (in quads) divided by the total electricity generated each year.

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.

When DOE estimates energy savings attributable to appliance standards, the method for performing the full-fuel-cycle analysis utilizes data and projections published in the *Annual Energy Outlook (AEO)*; in the case of residential dishwashers, the *AEO2014*.[4] Table 10-B.2.1 summarizes the *AEO2014* 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 10-B.2.1 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<br>Energy consumption by sector and source | Generation by fuel type<br>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<br>Liquid fuels supply and disposition<br>International liquids supply and disposition<br>Oil and gas supply | Refining-only energy use<br>Crude supply by source<br>Crude oil imports<br>Domestic crude oil production |
| $c_{nn}$ | Natural gas | Oil and gas supply<br>Natural gas supply, disposition, and prices | U.S. dry gas production<br>Pipeline, lease, and plant fuel |
| $z_x$ | All | Electricity supply, disposition, prices, and emissions | Power sector emissions |

The *AEO2014* 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 for dishwashers, however, arises exclusively from variables taken from the *AEO2014*.

## 10-B.3 ENERGY MULTIPLIERS FOR THE FULL FUEL CYCLE

FFC energy multipliers for selected years are presented in Table 10-B.3.1. The 2040 value was held constant for the analysis period beyond 2040, which is the last year in the *AEO2014* projection. The multiplier for electricity reflects the shares of various primary fuels in total electricity generation throughout the forecast period.

**Table 10-B.3.1 Energy Multipliers for the Full Fuel Cycle (Based on *AEO2014*)**

| | 2019 | 2020 | 2025 | 2030 | 2035 | 2040 |
|---|---|---|---|---|---|---|
| Electricity | 1.043 | 1.044 | 1.045 | 1.046 | 1.047 | 1.047 |
| Natural gas | 1.108 | 1.109 | 1.111 | 1.113 | 1.114 | 1.114 |
| Petroleum fuels | 1.176 | 1.176 | 1.176 | 1.174 | 1.172 | 1.170 |

## REFERENCES

---

1 U.S. Department of Energy–Office of Energy Efficiency and Renewable Energy. Energy Conservation Program for Consumer Products and Certain Commercial and Industrial Equipment. Statement of Policy for Adopting Full Fuel Cycle Analyses into Energy Conservation Standards Program. *Federal Register.* August 18, 2011. Vol. 76, no. 160*:* pp. 51281–51289.

2 Coughlin, K. A Mathematical Analysis of Full Fuel Cycle Energy Use. *Energy*. 2012. 37(1): pp. 698–708. (Last accessed June 22, 2014.) <http://www.sciencedirect.com/science/article/pii/S0360544211006803>

3 Coughlin, K. *Projections of Full-Fuel-Cycle Energy and Emissions Metrics*. 2013. Lawrence Berkeley National Laboratory. Report No. LBNL-6025E.

4 U.S. Energy Information Administration. *Annual Energy Outlook 2014 with Projections to 2040*. April 2014. DOE/EIA-0383(2014). Washington, D.C. (Last accessed June 22, 2014.) <http://www.eia.gov/forecasts/aeo/pdf/0383(2014).pdf >

# APPENDIX 10-C. NATIONAL NET PRESENT VALUE OF CONSUMER BENEFITS USING ALTERNATIVE PRODUCT PRICE FORECASTS

## TABLE OF CONTENTS

## LIST OF TABLES

## LIST OF FIGURES

# APPENDIX 10-C. NATIONAL NET PRESENT VALUE OF CONSUMER BENEFITS USING ALTERNATIVE PRODUCT PRICE FORECASTS

## 10-C.1 INTRODUCTION

Chapter 10 presents net present value (NPV) results for the trial standard levels (TSLs) considered for standard-sized and compact dishwashers. The NPV results reflect a price trend based on an experience rate estimated for "other miscellaneous household appliances" from 1988 to 2013. The U.S. Department of Energy (DOE) used Producer Price Index (PPI) data for "other miscellaneous household appliances" to represent residential dishwashers, because no PPI data specific to residential dishwashers are available. The analysis described in chapter 10 relies on a so-called default scenario for the price trend for dishwashers. DOE also investigated the effects of different product price trends on the consumer NPVs for each TSL. DOE performed a sensitivity analysis using two alternative price trends. This appendix describes the alternative price trends and compares NPV results for the alternative scenarios with those for the default forecast.

## 10-C.2 FORECASTS OF PRODUCT PRICE TRENDS

Using different analytical approaches and different periods of data for other miscellaneous household appliances, DOE performed a sensitivity analysis for two alternative price trends: a high price decline scenario and a low price decline scenario. The high price decline scenario uses the exponential fit approach and the deflated PPI for other miscellaneous household appliances for 1991–2013. The low price decline scenario uses the experience curve approach and the deflated PPI for other miscellaneous household appliances for 1991–2000.

### 10-C.2.1 Exponential Fit for High Price Decline Scenario

To forecast the price trend in the high price decline scenario, DOE used the inflation-adjusted PPI for other miscellaneous household appliances from 1991 to 2013 to fit an exponential model with *year* as the explanatory variable. DOE obtained historical PPI data for other miscellaneous household appliances spanning 1991–2013 from the Bureau of Labor Statistics (BLS).[a] The PPI data reflect nominal prices, adjusted for changes in product quality. An inflation-adjusted (deflated) price index for other miscellaneous household appliances was calculated by dividing the PPI series by the Gross Domestic Product Chained Price Index. In this case, the exponential function takes the form of:

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

---

[a] Series ID PCU3352283352285; http://www.bls.gov/ppi/

Where:

$Y$ = price index for other miscellaneous houshold appliances,
$X$ = time variable,
$a$ = constant, and
$b$ = slope parameter of the time variable.

To estimate the exponential parameters, a least-square fit was performed on the inflation-adjusted price index for other miscellaneous houshold appliances versus *year* from 1991 to 2013. See Figure 10-C.2.1.

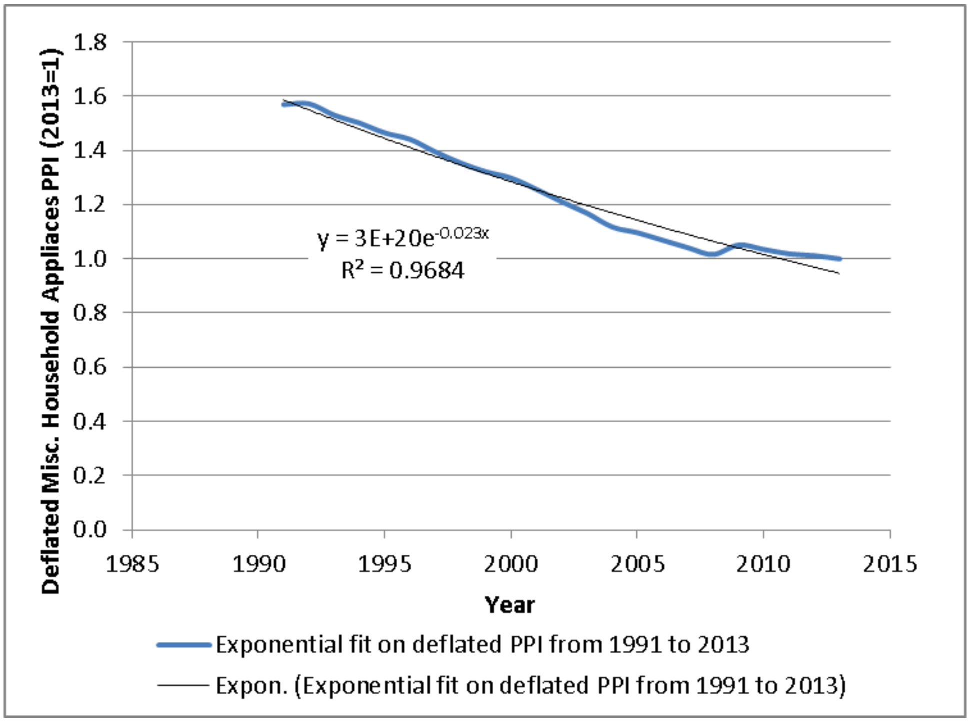


**Figure 10-C.2.1 High Price Decline Scenario: Relative Price of Other Miscellaneous Household Appliances versus Year (1991–2013), with Exponential Fit**

The final estimated exponential function for the low price scenario is:

$$Y = 3.205 \times 10^{20} \cdot e^{(-0.0235)X}$$

The regression performed as an exponential fit results in an R-square of 0.97, which indicates a good fit to the data. DOE then derived a price factor index for the high price decline scenario, with 2013 equal to 1, to project prices in each future year of the analysis period. The index value in a given year is a function of the exponential parameter and *year*.

### 10-C.2.2 Experience Curve for Low Price Decline Scenario

In the low price decline scenario, DOE used the experience curve method to project future prices of residential dishwashers. In the experience curve method, the real product price (or proxy thereof) is related to the cumulative production or “experience” with a product. A common functional relationship used to model the evolution of production costs is:

$$Y = aX^{-b}$$

Where:

$a$ = an initial price (or cost),
$b$ = a positive constant known as the learning rate parameter,
$X$ = cumulative production, and
$Y$ = the price as a function of cumulative production.

As experience (production) accumulates, the cost of producing the next unit decreases. The percentage reduction in cost that occurs with each doubling of cumulative production is known as the learning, or experience, rate (ER) given by:

$$ER = 1 - 2^{-b}$$

In typical experience curve formulations, the experience rate parameter is derived using two historical data series: price (or cost) and cumulative production, which is a function of shipments during a long time span.

To derive an experience rate parameter for residential dishwashers, DOE obtained historical PPI data for other miscellaneous household appliances spanning 1991–2000 from the BLS. An inflation-adjusted price index for household laundry equipment was calculated by dividing the PPI series by the Gross Domestic Product Chained Price Index for the same years. This inflation-adjusted price index (shown as the red line in Figure 10-C.2.2) was used in subsequent steps of the analysis.

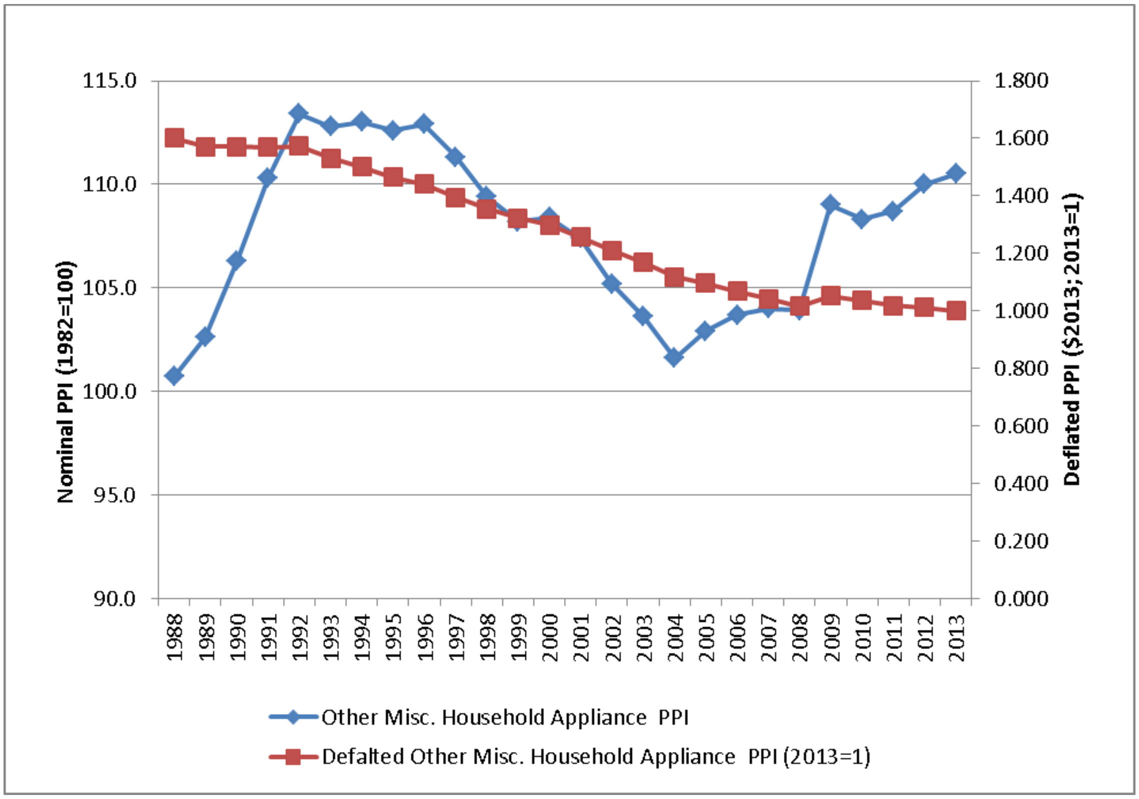


**Figure 10-C.2.2 Historical Nominal and Deflated Price Index for Other Miscellaneous Household Appliances, 1988-2013**

DOE assembled a time-series of historical annual shipments for 1972-2012 for dishwashers. The historical annual shipments data were used to estimate cumulative shipments (production). Figure 10-C.2.3 shows the shipments time series used in the analysis.

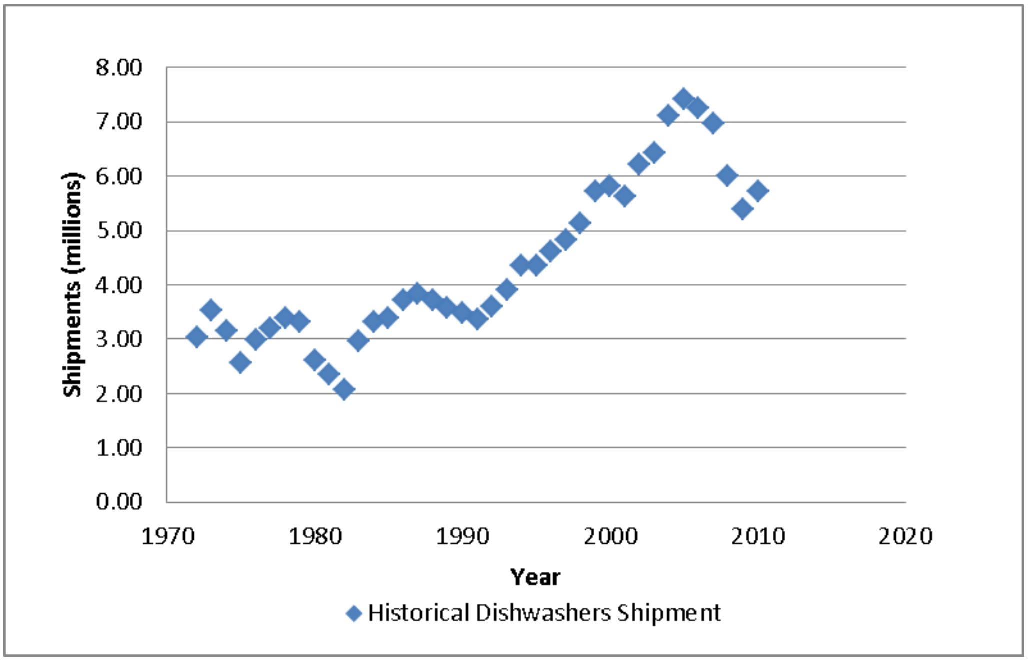


**Figure 10-C.2.3 Historical Total Shipments of Dishwashers, 1972-2012**

To estimate an experience rate parameter, a least-squares power-law fit was performed on the unified price index for 1991-2000 versus cumulative shipments 1991-2000. See Figure 10-C.2.4.

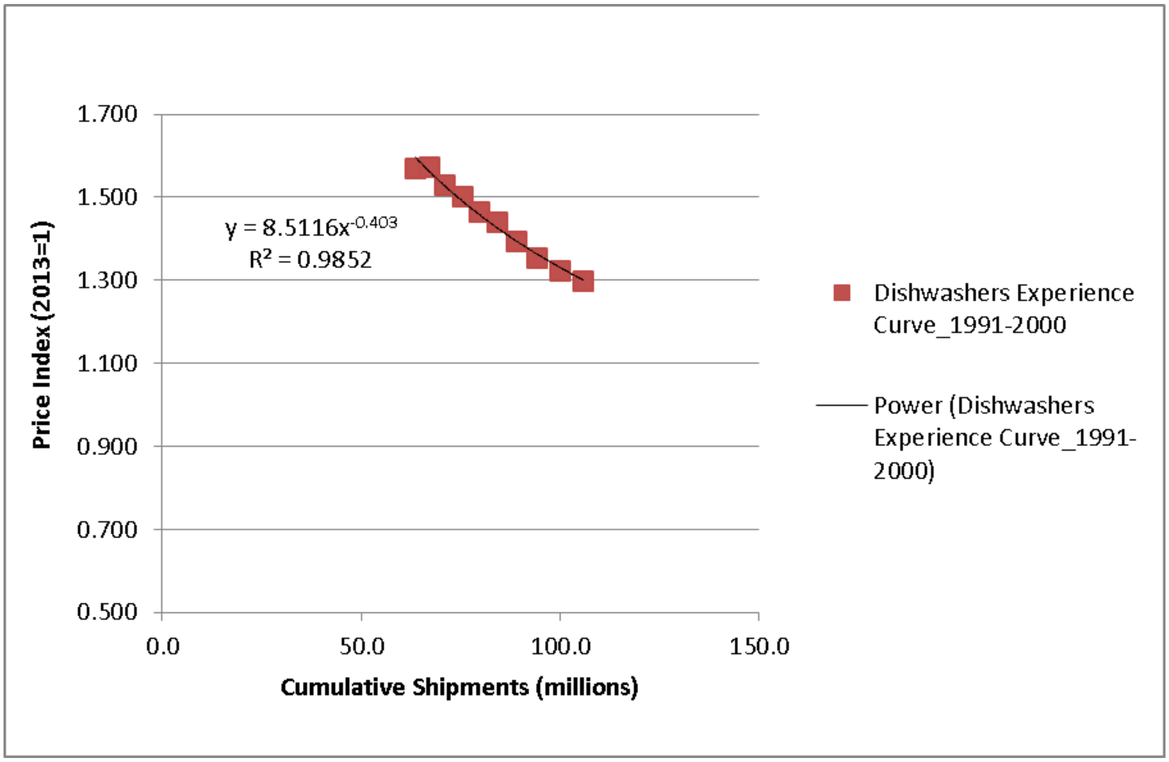


**Figure 10-C.2.4 Low Price Decline Scenario: Relative Price of Other Miscellaneous Household Appliances versus Cumulative Shipments of Dishwashers (1991-2000), with Power Law Fit**

The form of the fitting equation is:

$P(X) = P_o X^{-b}$,

where the two parameters, $b$ (the learning rate parameter) and $P_o$ (the price or cost of the first unit of production), are obtained by fitting the model to the data. Note that the cumulative shipments on the right-hand side of the equation can depend on price, so there is an issue with simultaneity whereby the independent variable may not be truly independent. DOE's use of a simple least-squares fit is equivalent to an assumption of no significant first-price elasticity effects in the cumulative shipments variable.

The final power law function looks like:

$$Y = 8.5116 \cdot X^{-0.403}$$

The regression performed as a power-law fit results in an R-square of 0.985, which indicates a good fit to the data. The estimated experience rate (defined as the fractional reduction in price expected from each doubling of cumulative production) is 24.4 percent. DOE then derived a price factor index for this low price decline scenario, with 2013 equal to 1, to forecast prices in each future year of the analysis period.

## 10-C.3 Summary of Forecasts

Table 10-C.3.1 summarizes the average annual rates of changes for the product price index in each scenario.

**Table 10-C.3.1 Price Trend Sensitivities for Residential Dishwashers**

| Sensitivity | Price Trend | Average Annual Rate of Change % |
|---|---|---|
| Medium (Default) | Experience curve using data from 1988 to 2013 | -1.33 |
| High Price Decline Scenario | Exponential fit using data from 1991 to 2013 | -2.32 |
| Low Price Decline Scenario | Experience curve using data from 1991 to 2000 | -1.25 |

Figure 10-C.3.1 shows the resulting price trends corresponding to each of the sensitivities.

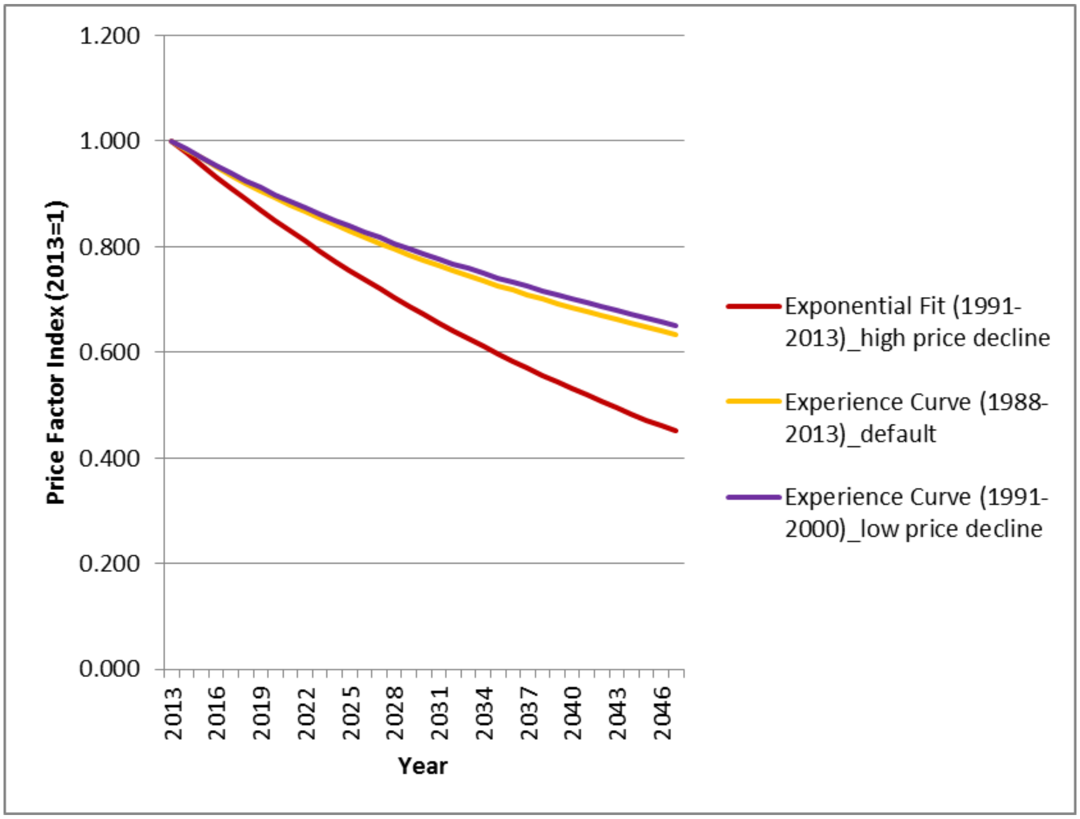


**Figure 10-C.3.1 Price Factor Indexes for Other Miscellaneous Household Appliances for the Default Case and Sensitivity Cases**

## 10-C.4 RESIDENTIAL DISHWASHER NPV RESULTS USING ALTERNATIVE PRODUCT PRICE FORECASTS

**Table 10-C.4.1. Residential Dishwashers: Present Value of Consumer Impacts Under Alternative Product Price Forecasts (3 Percent Discount Rate)**

| Trial Standard Level | | Medium (Default) | Low Price Decline | High Price Decline |
|---|---|---|---|---|
| | | Billion 2013$ | | |
| 1 | Incr. Installed Cost | 0.12 | 0.12 | 0.10 |
| | Operating Cost Savings | 0.26 | 0.26 | 0.27 |
| | Net Present Value | 0.15 | 0.14 | 0.16 |
| 2 | Incr. Installed Cost | 7.06 | 7.17 | 6.12 |
| | Operating Cost Savings | 9.21 | 9.17 | 9.55 |
| | Net Present Value | 2.14 | 2.00 | 3.43 |
| 3 | Incr. Installed Cost | 7.46 | 7.57 | 6.51 |
| | Operating Cost Savings | 23.16 | 23.11 | 23.65 |
| | Net Present Value | 15.70 | 15.54 | 17.14 |

**Table 10-C.4.2 Residential Dishwashers: Present Value of Consumer Impacts Under Alternative Product Price Forecasts (7 Percent Discount Rate)**

| Trial Standard Level | | Medium (Default) | Low Price Decline | High Price Decline |
|---|---|---|---|---|
| | | Billion 2013$ | | |
| 1 | Incr. Installed Cost | 0.07 | 0.07 | 0.06 |
| | Operating Cost Savings | 0.12 | 0.12 | 0.12 |
| | Net Present Value | 0.05 | 0.05 | 0.06 |
| 2 | Incr. Installed Cost | 3.91 | 3.96 | 3.46 |
| | Operating Cost Savings | 4.13 | 4.13 | 4.22 |
| | Net Present Value | 0.23 | 0.17 | 0.75 |
| 3 | Incr. Installed Cost | 4.14 | 4.19 | 3.69 |
| | Operating Cost Savings | 9.69 | 9.69 | 9.81 |
| | Net Present Value | 5.56 | 5.49 | 6.12 |

# APPENDIX 10-D. NATIONAL IMPACTS ANALYSIS USING ALTERNATIVE ECONOMIC GROWTH SCENARIOS

## TABLE OF CONTENTS

## LIST OF TABLES

## LIST OF FIGURES

# APPENDIX 10-D. NATIONAL IMPACTS ANALYSIS USING ALTERNATIVE ECONOMIC GROWTH SCENARIOS

## 10-D.1 INTRODUCTION

This appendix presents results of calculating national energy savings (NES), national water savings (NWS), and net present value (NPV) of potential standards for dishwashers based on alternative national economic growth scenarios. The scenarios use the energy price and housing starts forecasts for the high and the low economic growth cases in the U.S. Energy Information Administration's (EIA's) *Annual Energy Outlook 2014* (*AEO2014*).[1] In the national impact analysis (NIA) for dishwashers described in chapter 10, DOE used the reference case in *AEO2014*.

Figure 10-D.1.1 and Figure 10-D.1.2 show the forecasts for housing starts and residential electricity prices under the three economic growth scenarios considered in the *AEO*. *AEO2014* provides a forecast to 2040. To estimate trends to the end of DOE's forecast period for dishwashers (2048), DOE followed guidelines that the EIA has provided to the Federal Energy Management Program, which call for using the average rate of change for electricity prices during 2030–2040.

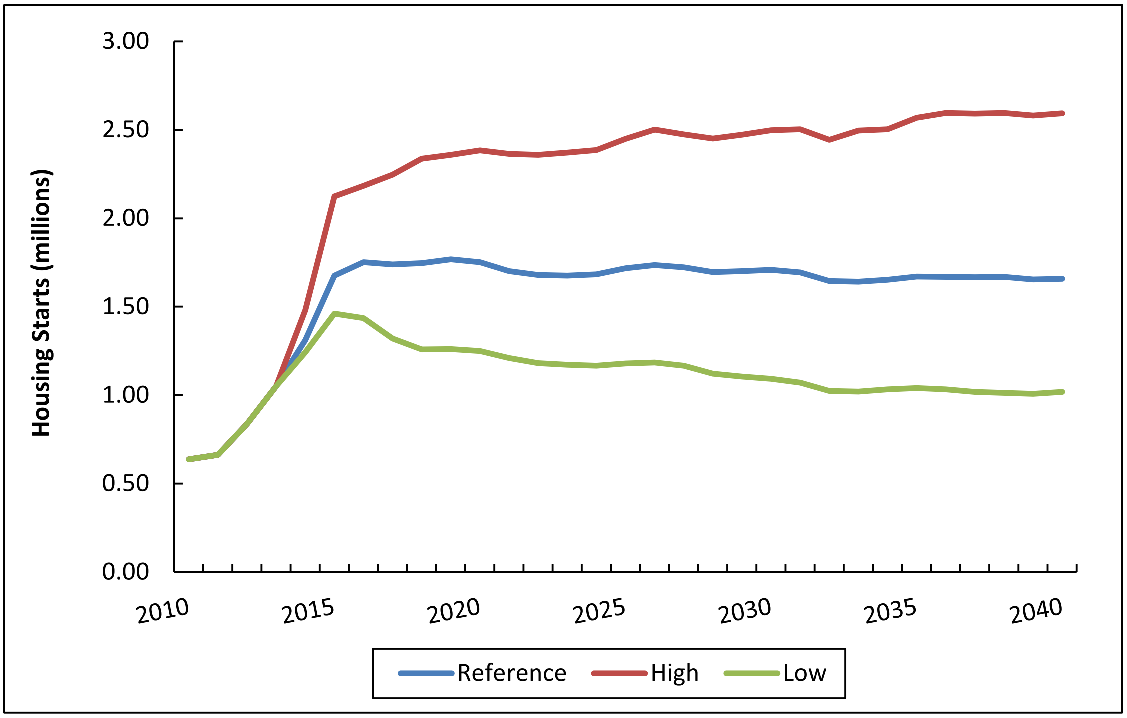


**Figure 10-D.1.1 Forecasts for Housing Starts Under Three *AEO2014* Economic Growth Scenarios**

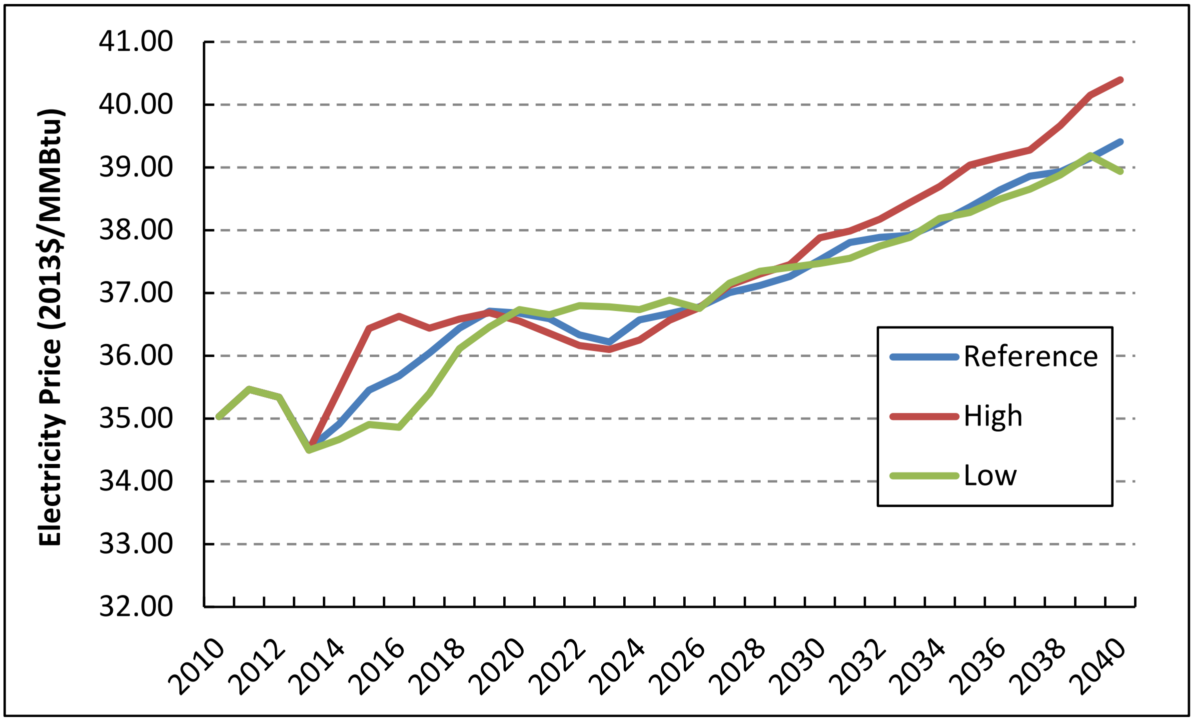


**Figure 10-D.1.2 Forecasts for Average Residential Electricity Prices Under Three *AEO2014* Economic Growth Scenarios**

## 10-D.2 RESULTS FOR HIGH ECONOMIC GROWTH SCENARIO

Table 10-D.2.1 shows the cumulative national energy savings (NES) in quadrillion British thermal units (quads) and the national water savings (NWS) in trillion gallons attributable to proposed standards based on *AEO2014*'s high economic growth scenario. Data are cumulative to the end of the forecast period (2048) for the three trial standard levels (TSLs) being considered for dishwashers.

**Table 10-D.2.1 High Economic Growth Scenario: Cumulative National Energy and Water Savings**

| Trial Standard Level | Efficiency Level Combination | | NES (quads) | NWS (trillion gallons) |
|---|---|---|---|---|
| | Standard | Compact | | |
| 1 | 1 | 0 | 0.01 | 0.04 |
| 2 | 3 | 1 | 1.16 | 0.28 |
| 3 | 4 | 2 | 2.78 | 1.15 |

Table 10-D.2.2 presents the cumulative net present value of consumer benefits for each TSL under *AEO2014*'s high economic growth scenario.

**Table 10-D.2.2 High Economic Growth Scenario: Cumulative Net Present Value of Consumer Benefits for 3-Percent and 7-Percent Discount Rates**

| Trial Standard Level | Efficiency Level Combination | | 3% (Billion 2013$) | 7% (Billion 2013$) |
|---|---|---|---|---|
| | Standard | Compact | | |
| 1 | 1 | 0 | 0.17 | 0.06 |
| 2 | 3 | 1 | 2.76 | 0.36 |
| 3 | 4 | 2 | 18.77 | 6.54 |

## 10-D.3 RESULTS FOR LOW ECONOMIC GROWTH SCENARIO

Table 10-D.3.1 presents the cumulative national NES and NWS attributable to each TSL under *AEO2014*'s low economic growth scenario. Results are cumulative to the end of the forecast period (2048) for the three TSLs being considered for dishwashers.

**Table 10-D.3.1 Low Economic Growth Scenario: Cumulative National Energy and Water Savings**

| Trial Standard Level | Efficiency Level Combination | | NES (quads) | NWS (trillion gallons) |
|---|---|---|---|---|
| | Standard | Compact | | |
| 1 | 1 | 0 | 0.00 | 0.03 |
| 2 | 3 | 1 | 0.88 | 0.21 |
| 3 | 4 | 2 | 2.11 | 0.87 |

Table 10-D.3.2 presents the cumulative net present value of consumer benefits for each TSL under *AEO2014*'s low economic growth scenario.

**Table 10-D.3.2 Low Economic Growth Scenario: Cumulative Net Present Value of Consumer Benefits for 3-Percent and 7-Percent Discount Rates**

| Trial Standard Level | Efficiency Level Combination | | 3% (Billion 2013$) | 7% (Billion 2013$) |
|---|---|---|---|---|
| | Standard | Compact | | |
| 1 | 1 | 0 | 0.12 | 0.05 |
| 2 | 3 | 1 | 1.76 | 0.16 |
| 3 | 4 | 2 | 13.60 | 4.88 |

## REFERENCES

---

1 U.S. Energy Information Administration. *Annual Energy Outlook 2014 with Projections to 2040.* April 2014. Washington, D.C. Report Number: DOE/EIA-0383(2014). (Last accessed June 22, 2014.) <http://www.eia.gov/forecasts/aeo/pdf/0383(2013).pdf>

# APPENDIX 12-A: RESIDENTIAL DISHWASHER NOTICE OF PROPOSED RULEMAKING TECHNICAL SUPPORT DOCUMENT

## Manufacturer Impact Analysis Interview Guide for Interviews Conducted in Support of the May 2012 Direct Final Rule

The Department of Energy (DOE) conducts the manufacturer impact analysis (MIA) as part of the rulemaking process for amended energy conservation standards for dishwashers. In this analysis, DOE uses publicly available information and information provided by manufacturers during interviews to assess possible impacts on manufacturers due to amended energy conservation standards.

The Association of Home Appliance Manufacturers (AHAM) and the American Council for an Energy Efficient Economy (ACEEE) released a multi-product standards agreement (Consensus Agreement) that addressed negotiated standards for refrigerators/freezers, clothes washers, clothes dryers, room air conditioners, and dishwashers. For dishwashers, the Consensus Agreement proposes updated standards for standard and compact product classes (Table 1.1). DOE's rulemaking process allows for a direct publication of a final rule if DOE concludes that standards proposed in the Consensus Agreement meet certain statutory criteria. In order to evaluate the product classes and standards proposed in the Consensus Agreement for dishwashers, DOE is requesting information on the topics in this questionnaire.

DOE is requesting information on the product classes in the table below

**Table 1.1 AHAM-ACEEE Multi-Product Standards Agreement - Dishwashers**

| **Product Class** | **Product Class Description** | **Annual Energy Use** *(kWh/year)* | **Water Use** *(gallons/cycle)* |
|---|---|---|---|
| 1. Standard | Standard (≥ 8 place settings plus 6 serving pieces) | 307 | 5.0 |
| 2. Compact | Compact (< 8 place settings plus 6 serving pieces) | 222 | 3.5 |

## 1 KEY ISSUES

1.1 In general, what are the key issues for your company regarding amended energy conservation standards for dishwashers and this rulemaking?

1.2 Are any of the issues more or less significant for the compact versus standard-size product classes?

1.3 Do any of the issues become more significant at higher efficiency levels?

1.4 Do you have any suggestions for incorporating any of these issues into the into DOE's manufacturing impact model?

## 2 COMPANY OVERVIEW AND ORGANIZATIONAL CHARACTERISTICS

DOE is interested in understanding manufacturer impacts at the plant or profit center level directly pertinent to dishwasher production. However, the context within which this profit center operates and the details of plant production are not always readily available from public sources. Understanding the organizational setting around the dishwasher industry profit center will help DOE understand the probable future of the manufacturing activity with and without amended energy conservation standards.

2.1 What percentage of your dishwasher manufacturing corresponds to each product class, both in terms of revenue and shipments? Please indicate if you do not manufacture products in any given product class. Please also indicate whether you purchase your dishwashers from other manufacturers (i.e. private label), and whether the factory that supplies the product is located in the United States.

**Table 2.2 Dishwasher Revenue and Shipment Volumes by Product Class**

| Product Class Number | Product Type | 2010 Revenue | 2010 Shipments | % Private Label | % Made in U.S. |
|---|---|---|---|---|---|
| 1 | Standard | | | | |
| 2 | Compact | | | | |

2.2 What is your company’s approximate market share in the dishwasher market?

## 3 ENGINEERING AND LIFE-CYCLE COST ANALYSIS

The following series of exhibits and questions address technical characteristics of key residential dishwasher components for both baseline and improved-efficiency products.

### 3.1 Baseline Dishwashers

Based on preliminary observation, DOE expects a “baseline” dishwasher (i.e. one that just meets existing AEU and water consumption standards) to include the following design features impacting energy use: electromechanical controls, no soil sensor, a non-insulated plastic tub, a tubular in-tub heater (with a normal power dry feature), a temperature switch, a tub float for fill control, a plastic filter for large particles plus a macerator, one lower spray arm with a spray tower, and a single-speed pump motor.

- Are these features consistent with what you would expect for a baseline standard-size dishwasher?
- Would you expect the same design features to be incorporated in a baseline compact dishwasher?
- How do the design features found in baseline dishwashers address customer utility?

## 3.2 Incremental Efficiency Levels

DOE proposes to evaluate efficiency levels based on the AEU and water use specifications prescribed by ENERGY STAR and the Consortium for Energy Efficiency (CEE), along with certain gap-fill and maximum levels that are currently available on the market as listed in the ENERGY STAR and California Energy Commission (CEC) product databases.

Table 3.1 and Table 3.2 show the proposed efficiency levels for both product classes.

**Table 3.3 Dishwasher Efficiency Levels – Standard-Size Product Class**

| Level | Efficiency Level Description | Annual Energy Use *(kWh/year)* | Water Consumption *(gallons/cycle)* |
|---|---|---|---|
| Baseline | DOE Standard | 355 | 6.5 |
| 1 | ENERGY STAR (current) | 324 | 5.8 |
| 2 | ENERGY STAR (July 1, 2011)/CEE Tier 1/Consensus Agreement | 307 | 5.0 |
| 3 | CEE Tier 2 | 295 | 4.25 |
| 4 | Gap Fill* | 234 | 3.8 |
| 5 | Maximum Available* | 180 | 1.6 |

*Source: ENERGY STAR-qualified dishwashers as of January 30, 2011.

**Table 3.4 Dishwasher Efficiency levels -- Compact Product Class**

| Level | Efficiency Level Description | Annual Energy Use *(kWh/year)* | Water Consumption *(gallons/cycle)* |
|---|---|---|---|
| Baseline | DOE Standard | 260 | 4.5 |
| 1 | ENERGY STAR (current) | 234 | 4.0 |
| 2 | ENERGY STAR (July 1, 2011)/CEE Tier 1/Consensus Agreement | 222 | 3.5 |
| 3 | Gap Fill* | 200 | 2.8 |
| 4 | Gap Fill* | 174 | 2.7 |
| 5 | Maximum Available* | 154 | 2.1 |

*Source: ENERGY STAR-qualified dishwashers as of January 30, 2011.

- Are the proposed efficiency levels appropriate?
- Can you suggest more appropriate “max-tech” efficiency levels?

3.3 Are the design options listed in Table 3.3 below for each efficiency level representative of the features your company incorporates at each of these levels? Also, please indicate the incremental costs associated with the design options your company uses at each efficiency level.

The design options listed at each efficiency level reflect the incremental changes made to the unit at the previous level. These are based on DOE’s preliminary observations, and do not necessarily represent the final list of design options DOE will analyze for this rulemaking. These incremental changes assume a baseline unit as described in section 3.1.

**Table 3.5 Standard-Size Dishwasher Design Options and Incremental Costs**

| Level | Design Options Description | Design Options (if different) | Incremental Costs |
|---|---|---|---|
| 1 | Electronic controls with a linear power supply, stainless steel large and fine particle filters with no macerator, and multiple spray arms. | | |
| 2 | A turbidity sensor for soil sensing, insulation around the plastic tub, a switch mode power supply, and a 3-speed pump motor. | | |
| 3 | An in-line flow-through water heater, no power dry feature, a circulation fan to aid condensation drying, a stainless steel tub with complete bitumen insulation plus cotton insulation for the door, a temperature sensor, a flow meter, a small heat exchanger for inlet water pre-heating, a diverter valve for the multiple spray arms, and a variable speed pump motor. | | |
| 4 | Similar to EL3, with a humidity sensor controlling the circulation fan, and lower wash and rinse temperatures. | | |
| 5 | No circulation fan to aid condensation drying, a flow-through heater integrated in the pump, cotton insulation around the entire tub, and a larger heat exchanger for inlet water pre-heating. | | |

- What tradeoffs can be made between the wash and dry cycles to achieve higher efficiencies?
- Do you find the reliability/life of electronic controls to differ from mechanical ones?
- What are the impacts on customer utility of the design changes used to increase efficiency?
- Are these design options and associated costs different for compact dishwashers?

3.4 Are installation costs a function of efficiency? Maintenance costs? Repair costs?

- If yes, would you please characterize this relationship by providing incremental installation, maintenance, and/or repair cost data?
- How are these costs different for standard vs. compact dishwashers?

## 4 MARKUPS AND PROFITABILITY

One of the primary objectives of the MIA is to assess the impact of amended energy conservation standards on industry profitability. In this section, DOE would like to understand the current markup structure of the industry and how amended energy conservation standards would impact your company's markup structure and profitability.

DOE estimated the manufacturer production costs for the two product classes of dishwashers. DOE defines manufacturer production cost as all direct costs associated with manufacturing a product: direct labor, direct materials, and overhead (which includes depreciation). The manufacturer markup is a multiplier applied to manufacturer production cost to cover non-production costs, such as SG&A and R&D, as well as profit. *It does not reflect a "profit margin."*

The manufacturer production cost times the manufacturer markup equals the manufacturer selling price. Manufacturer selling price is the price manufacturers charge their first customers, but *does not* include additional costs along the distribution channels.

**DOE estimated a baseline markup of 1.24 for dishwashers.**

4.1 Is the 1.24 baseline markup representative of an average industry markup?

4.2 Please comment on the baseline markups DOE calculated as compared to your company's baseline markups for the dishwasher product classes.

**Table 4.6 Residential Dishwasher Baseline Manufacturer Markups by Product Class**

| Product Class | Product Type | Estimated Baseline Markup | Manufacturer Comments or Revised Estimates |
|---|---|---|---|
| 1 | Standard | 1.24 | |
| 2 | Compact | 1.24 | |

4.3 How are markups and margins determined in this industry? How would standards potentially impact this pricing/margin structure? Please indicate if profit levels vary between product classes or product line. If yes, please explain why.

4.4 One of the possible scenarios DOE uses to model impacts on industry profitability is the impact of commoditization of premium products. Because the market disruption caused by standards can alter the pricing of premium products, DOE is interested in understanding if efficiency is a feature that earns a premium. Within each product class, do markups vary by efficiency level? If yes, please provide estimates for your markups by product class and efficiency level in Table 4.2 and Table 4.3.

**Table 4.2 Estimated Markups for Standard Size Dishwashers**

| Efficiency Level | Annual Energy Use *(kWh/year)* | Estimated Markup | Manufacturer Comments |
|---|---|---|---|
| 1 | 324 | | |
| 2 | 307 | | |
| 3 | 295 | | |
| 4 | 234 | | |
| 5 | 180 | | |

**Table 4.3 Estimated Markups for Compact Dishwashers**

| Efficiency Level | Annual Energy Use *(kWh/year)* | Estimated Markup | Manufacturer Comments |
|---|---|---|---|
| 1 | 234 | | |
| 2 | 222 | | |
| 3 | 200 | | |
| 4 | 174 | | |
| 5 | 154 | | |

4.5 What factors or product attributes besides efficiency affect the profitability of dishwashers within a product class?

4.6 Does your markup change with selected design options? Is the markup on incremental costs for more efficient designs different than the markup on the baseline models (as is assumed for retailer markups used in the analyses)?

4.7 Would you expect changes in your estimated profitability following an amended energy conservation standard? If so, please explain why. Can you suggest any scenarios that would model these expected changes?

4.8 What is the structure of your distribution channel and how does that influence your markup? Does that change between product classes or across the industry?

## 5 FINANCIAL PARAMETERS

DOE’s contractor has developed a “strawman” model of the dishwasher industry financial performance called the Government Regulatory Impact Model (GRIM), using publicly available data. However, this public information might not be reflective of manufacturing at the dishwasher profit center. This section attempts to understand the financial parameters for dishwasher manufacturing and how your company’s financial situation could differ from the industry aggregate picture.

5.1 In order to accurately collect information about dishwasher manufacturing, please compare your financial parameters to the GRIM parameters tabulated below.

**Table 5.7 Financial Parameters for Residential Dishwasher Manufacturing**

| GRIM Input | Definition | Industry Estimated Value *(%)* | Your Actual (If Different from DOE's Estimate) |
|---|---|---|---|
| Income Tax Rate | Corporate effective income tax paid (percentage of earnings before taxes, EBT) | 33.3% | |
| Discount Rate | Weighted average cost of capital (inflation-adjusted weighted average of corporate cost of debt and return on equity) | 8.1% | |
| Working Capital | Current assets less current liabilities (percentage of revenues) | 7.0% | |
| Net PPE | Net plant property and equipment (percentage of revenues) | 16.7% | |
| SG&A | Selling, general, and administrative expenses (percentage of revenues) | 13.3% | |
| R&D | Research and development expenses (percentage of revenues) | 2.3% | |
| Depreciation | Amortization of fixed assets (percentage of revenues) | 7.4% | |
| Capital Expenditures | Outlay of cash to acquire or improve capital assets (percentage of revenues, not including acquisition or sale of business units) | 3.2% | |
| Cost of Goods Sold | Includes material, labor, overhead, and depreciation (percentage of revenues) | 80.6% | |

5.2 Do any of the financial parameters in Table 5.1 change *based on product class*? Please describe any differences.

5.3 Do any of the financial parameters in Table 5.1 change for a particular *subgroup of manufacturers*? Please describe any differences.

5.4 DOE accounts for one time product and capital conversion costs including research and development, as well as capital expenditures for facility changes and the depreciation of these fixed assets. Beyond these short term changes in cost structure, how would you expect an amended energy conservation standard to impact any of the financial parameters for the industry over time?

## 6 CONVERSION COSTS

Amended energy conservation standards may cause your company to incur capital and product conversion costs to redesign existing products and make changes to existing production lines to be compliant with the amended energy conservation standard. Depending on their magnitude, the conversion costs can have a substantial impact on the outputs used by DOE to evaluate the industry impacts. Understanding the nature and magnitude of the conversion costs is critical portion of the MIA. The MIA considers two types of conversion costs:

- *Capital conversion costs* are one-time investments in plant, property, and equipment

(PPE) necessitated by an amended 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* are costs related research, product development, testing, marketing and other costs for redesigning products necessitated by an amended energy conservation standard.

DOE asks a number of questions to understand the nature and magnitude of your expected capital and product conversion costs.

6.1 Table 6.1 through Table 6.4 show the efficiency levels analyzed in the Engineering Analysis for the product categories covered by this rulemaking. Because DOE is using an efficiency level approach for the Engineering Analysis, the design options described in section 3 represent one possible path to reach these efficiency levels. If you would apply different design options to reach each efficiency level, please describe those changes in detail.

Please provide estimates for your capital conversion costs by product class and efficiency level in Table 6.1 and Table 6.2. In the description column, DOE is interested in understanding the kinds of changes that would need to be implemented to production lines and production facilities at each efficiency level. Where applicable, please quantify the number and cost of new production equipment, molds, etc. that would be required to implement the specified design changes.

**Table 6.8 Expected Capital Conversion Costs for Standard Size Dishwashers**

| **Efficiency Level** | **Annual Energy Use** *(kWh/year)* | **Total Capital Conversion Costs** | **Description** |
|---|---|---|---|
| 1 | 324 | | |
| 2 | 307 | | |
| 3 | 295 | | |
| 4 | 234 | | |
| 5 | 180 | | |

**Table 6.9 Expected Capital Conversion Costs for Compact Dishwashers**

| **Efficiency Level** | **Annual Energy Use** *(kWh/year)* | **Total Capital Conversion Costs** | **Description** |
|---|---|---|---|
| 1 | 234 | | |
| 2 | 222 | | |
| 3 | 200 | | |
| 4 | 174 | | |
| 5 | 154 | | |

6.2 Would the changes in question 6.1 be similar across all of your production lines and factories for each product class?

6.3 Are there certain efficiency levels that would require relatively minor changes to existing products? Are there certain efficiency levels where the capital or product conversion costs significantly increase over the previous efficiency levels? Would your answer change for different product classes? Please describe these changes qualitatively.

6.4 For each of the product categories shown in Table 6.1 and Table 6.2, which efficiency level changes could be made within existing platform designs and which would result in major product redesigns?

6.5 For the efficiency levels put forth, which design options would require only minor changes to production lines, major changes to production lines, substantial modifications to existing facilities, or the development of entirely new manufacturing facilities?

6.6 What level of product conversion costs would you expect to incur at each of these efficiency levels for each product class? Please provide your estimates in Table 6.3 and Table 6.4 considering such expenses as product development expenses, prototyping, testing, certification, and marketing. In the description column, please describe the assumptions behind the estimates provided.

**Table 6.3 Expected Product Conversion Costs for Standard Size Dishwashers**

| **Efficiency Level** | **Annual Energy Use** *(kWh/year)* | **Total Product Conversion Costs** | **Description** |
|---|---|---|---|
| 1 | 324 | | |
| 2 | 307 | | |
| 3 | 295 | | |
| 4 | 234 | | |
| 5 | 180 | | |

**Table 6.4 Expected Product Conversion Costs for Compact Dishwashers**

| **Efficiency Level** | **Annual Energy Use** *(kWh/year)* | **Total Product Conversion Costs** | **Description** |
|---|---|---|---|
| 1 | 234 | | |
| 2 | 222 | | |
| 3 | 200 | | |
| 4 | 174 | | |
| 5 | 154 | | |

6.7 Please provide additional qualitative information to help DOE understand the types and nature of your investments, including the plant and tooling changes and the product development effort required at different efficiency levels.

# 7 CUMULATIVE REGULATORY BURDEN

In assessing the impact to industry, DOE seeks to understand the cumulative regulatory burden facing manufacturers. Cumulative regulatory burden refers to the financial burden that stems from overlapping effects of new or revised DOE standards and/or other regulatory actions affecting the same product or industry. In this regard, DOE will consider other regulations (beyond efficiency) such as materials regulations and building codes that will adversely impact the cost to either the manufacturer or consumer.

7.1 Have you had any r&d expenditures related to complying with the dishwasher energy conservation standards enacted by the Energy Independence and Security Act of 2007, which became effective in January 2010? What r&d, product development, and testing expenses were required to make your dishwasher compliant? Did you incur any capital expenses to make your products comply? Will any of these changes be coordinated with the changes required by this rulemaking?

7.2 In assessing cumulative regulatory burden, DOE considers the impacts of other regulations for which the starting effective date falls within a six year timeframe extending from three years before to three years after the proposed dishwasher standards become effective. Below is a list of other relevant regulations that could affect manufacturers of dishwashers. Please provide any comments on the listed regulations and provide an estimate for your expected compliance cost.

**Table 7.10 Other Regulations Identified by DOE**

| Regulation | Estimated or Actual Effective Date(s) | Comments | Expected Expense for Compliance |
|---|---|---|---|
| Residential clothes dryer energy conservation standards | 2014 | | |
| Residential clothes washer energy conservation standards | 2015 | | |
| Phosphate regulations in detergent in 16 states | 2009-2010 | | |
| ENERGY STAR draft qualifying criteria, potentially including wash performance | TBD | | |

7.3 Are there any other recent or impending regulations that dishwasher manufacturers face (from DOE or otherwise)? If so, please identify the regulation, the corresponding effective dates, and your expected compliance cost.

7.4 Under what circumstances would you be able to coordinate any expenditure related to these other regulations with an amended energy conservation standard?

# 8 DIRECT EMPLOYMENT IMPACT ASSESSMENT

The impact of amended 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 dishwasher manufacturer employment and solicit manufacturer views on how domestic employment patterns might be affected by amended energy conservation standards.

8.1 Where are your dishwasher manufacturing facilities that produce products for the United States located? What types of products are manufactured at each location? Please provide annual shipment figures for your company's dishwasher manufacturing at each location by product class. Please also provide employment levels at each of these facilities.

**Table 8.11 Dishwasher Revenue and Shipment Volumes by Product Class**

| Facility | Location | Product Types Manufactured | Employees | Annual Shipments |
|---|---|---|---|---|
| *Example* | *Sheboygan, WI* | *Standard Size Dishwashers* | *200* | *100,000* |
| 1 | | | | |
| 2 | | | | |
| 3 | | | | |
| 4 | | | | |
| 5 | | | | |

8.2 Would your domestic employment levels be expected to change significantly under amended energy conservation standards? If so, please explain how they would change if higher efficiency levels are required.

8.3 Would the workforce skills necessary under amended energy conservation standards require extensive retraining or replacement of employees at your manufacturing facilities?

8.4 Would amended energy conservation standards require extensive retraining of your service/field technicians? If so, could you expand on how your service infrastructure would be impacted in general as a result of amended energy conservation standards?

## 9 MANUFACTURING CAPACITY AND NON-US SALES

9.1 How would amended energy conservation standards impact your company's manufacturing capacity?

9.2 For any design changes that would require new production equipment, please describe how much downtime would be required. What impact would downtime have on your business? Are there any design changes that could not be implemented before the compliance date of the final rule for certain product classes?

9.3 What percentage of your company's dishwasher sales is made within the United States?

9.4 What percentage of your dishwashers is produced in the United States?

9.5 What percentage of your U.S. production of dishwashers is exported?

9.6 Are there any foreign companies with North American production facilities?

9.7 Would amended energy conservation standards impact your domestic vs. foreign manufacturing or sourcing decisions? Is there an efficiency level that would cause you to move exiting domestic production facilities outside the U.S.?

## 10 IMPACT ON COMPETITION

Amended 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 amended energy conservation standard.

10.1 How would amended energy conservation standards affect your ability to compete in the marketplace? Would the effects on your company be different than others in the industry?

10.2 Would you expect your market share to change if amended energy conservation standards become effective?

10.3 Do any firms hold intellectual property that gives them a competitive advantage following amended energy conservation standards?

10.4 How would industry competition change as a result of amended energy conservation standards?

## 11 IMPACTS ON SMALL BUSINESS

11.1 The Small Business Administration (SBA) denotes a small business in the dishwasher manufacturing industry as having less than 500 total employees, including the parent company and all subsidiaries.[1] By this definition, is your company considered a small business?

11.2 Are there any reasons that a small business manufacturer 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 small business size standards published on August 22, 2008, as amended, by the SBA to determine whether a company is a small business. To be categorized as a small business, a manufacturer of “other major household appliances” (NAICS #335228, which includes residential dishwasher manufacturers) and its affiliates may employ a maximum of 500 employees. The 500 employee threshold includes all employees in a business’s parent company and any other subsidiaries.

11.3 To your knowledge, are there any small businesses for which the adoption of amended energy conservation standards would have a particularly severe impact? If so, why?

11.4 To your knowledge, are there any niche manufacturers or component manufacturers for which the adoption of amended energy conservation standards would have a particularly severe impact? If so, why?

# APPENDIX 12-B: RESIDENTIAL DISHWASHER NOTICE OF PROPOSED RULEMAKING TECHNICAL SUPPORT DOCUMENT

## Government Regulatory Impact Model

## 12-B.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 value of the industry or manufacturers(s) following a regulation or a series of regulations. The model structure also allows an analysis of multiple products with regulations taking effect over a period of time, and of multiple regulations on the same products.

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 (TSLs).

Output from the model consists of summary financial metrics, graphs of major variables, and, when appropriate, access to the complete cash flow calculation.

## 12-B.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 three major blocks: the industry income statement, the cash flow statement, and the discounted 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. The discounted cash flow brings annual cash flows back to the industry net present value (INPV), by discounting them at the industry weighted average cost of capital. Below are definitions of listed items on the printout of the output sheet (see section 12-B.3).

### Industry Income Statement

*Revenues:* Annual revenues - computed by multiplying equipment unit price at each efficiency level by the appropriate manufacturer markup;

*Total Shipments:* Total annual shipments for the industry were obtained from the National Impact Analysis shipments forecast;

*Materials:* The portion of COGS that includes materials;

*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;

*Depreciation:* Annual depreciation computed as a percentage of COGS. While included in overhead, the depreciation is shown as a separate line item;

*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;

*Standard SG&A:* Selling, general, and administrative costs are computed as a percentage of Revenues;

*R&D:* GRIM separately accounts for ordinary research and development (R&D) as a percentage of Revenues;

*Product Conversion Costs:* Product conversion costs are one-time investments in research, development, testing, and marketing focused on making product designs comply with the amended energy conservation standard. GRIM allocates these costs over the period between the standard's announcement and effective dates;

*Stranded Assets:* In the year the standard becomes effective, a onetime write-off of stranded assets is accounted for;

*Earnings Before Interest and Taxes (EBIT):* Includes profits before deductions for interest paid and taxes;

*Per Unit EBIT:* GRIM calculates EBIT per unit shipped to Calibrate the preservation of EBIT markup scenario and properly account for demand elasticity;

*EBIT as a Percentage of Revenues:* GRIM calculates EBIT as a percentage of revenues to compare with the industry's average reported in financial statements;

*Taxes:* Taxes on EBIT are calculated by multiplying the tax rate contained in Major Assumptions by EBIT.

*Net Operating Profits After Taxes (NOPAT):* Computed by subtracting Cost of Goods Sold, SG&A, R&D, Product Conversion Cost, and Taxes from Revenues.

## Cash Flow Statement

*NOPAT repeated:* NOPAT is repeated in the Statement of Cash Flows;

*Depreciation repeated:* Depreciation is added back in the Statement of Cash Flows because it is a non-cash expense;

*Loss on Disposal of Stranded Assets:* The residual undepreciated value of stranded assets is also added back in the Statement of Cash Flows because it is a non-cash expense;

*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.

*Cash Flow From Operations:* Calculated by taking NOPAT, adding back non-cash items such as a Depreciation, and subtracting out Change in Working Capital;

*Ordinary Capital Expenditures:* Ordinary investments in property, plant, and equipment to maintain and replace existing production assets, computed as a percentage of Revenues;

*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 product designs can be fabricated and assembled under the new regulation;

*Free Cash Flow:* Annual cash flow from operations and investments; computed by subtracting Capital Investment from Cash Flow from Operations;

### Discounted Cash Flow

*Free Cash Flow repeated:* Free Cash Flow is repeated in the Discounted Cash Flow;

*Terminal Value:* Estimate of the continuing value of the industry after 2047. Computed by growing the Free Cash Flow in year 2047 at a constant rate in perpetuity;

*Present Value Factor:* Factor used to calculate an estimate of the present value of an amount to be received in the future;

*Discounted Cash Flow:* Free Cash Flows multiplied by the Present Value Factor. For 2047 the discounted cash flow includes the discounted Terminal Value; and

*INPV at TSL:* The sum of Discounted Cash Flows.

# 12-B.3 Model Industry Income Statement and Cash Flow Statement

| | | Base Yr | | Ancmt Yr | | | Std Yr | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Industry Income Statement (in millions)** | **2013** | **2014** | **2015** | **2016** | **2017** | **2018** | **2019** | **2020** | **2021** | **2022** |
| Revenues | $ 1,800.8 | $ 1,863.9 | $ 1,961.8 | $ 1,922.9 | $ 1,894.7 | $ 1,887.6 | $ 2,239.9 | $ 2,225.8 | $ 2,202.8 | $ 2,193.3 |
| Total Shipments | 6.450 | 6.791 | 7.266 | 7.241 | 7.257 | 7.348 | 7.233 | 7.309 | 7.340 | 7.418 |
| - Materials | $ 845.4 | $ 875.0 | $ 921.0 | $ 902.7 | $ 889.4 | $ 886.1 | $ 1,160.7 | $ 1,153.4 | $ 1,141.5 | $ 1,136.6 |
| - Labor | $ 292.6 | $ 302.9 | $ 318.8 | $ 312.5 | $ 307.9 | $ 306.8 | $ 316.9 | $ 314.9 | $ 311.7 | $ 310.3 |
| - Depreciation | $ 90.0 | $ 93.2 | $ 98.1 | $ 96.1 | $ 94.7 | $ 94.4 | $ 112.9 | $ 112.2 | $ 111.1 | $ 110.6 |
| - Overhead | $ 224.2 | $ 232.0 | $ 244.3 | $ 239.4 | $ 235.9 | $ 235.0 | $ 231.1 | $ 229.6 | $ 227.3 | $ 226.3 |
| - Standard SG&A | $ 239.5 | $ 247.9 | $ 260.9 | $ 255.7 | $ 252.0 | $ 251.0 | $ 297.9 | $ 296.0 | $ 293.0 | $ 291.7 |
| - R&D | $ 41.4 | $ 42.9 | $ 45.1 | $ 44.2 | $ 43.6 | $ 43.4 | $ 51.5 | $ 51.2 | $ 50.7 | $ 50.4 |
| - Product Conversion Costs | $ - | $ - | $ - | $ 12.1 | $ 21.2 | $ 27.2 | $ 1.2 | $ - | $ - | $ - |
| - Stranded Assets | $ - | $ - | $ - | $ - | $ - | $ - | $ 199.2 | $ - | $ - | $ - |
| Earnings Before Interest and Taxes (EBIT) | $ 67.6 | $ 70.0 | $ 73.7 | $ 60.1 | $ 50.0 | $ 43.7 | $ (131.6) | $ 68.4 | $ 67.7 | $ 67.4 |
| Per Unit EBIT ($) | $ 10.48 | $ 10.31 | $ 10.14 | $ 8.30 | $ 6.89 | $ 5.94 | $ (18.19) | $ 9.36 | $ 9.22 | $ 9.09 |
| *EBIT/Revenues (%)* | *3.8%* | *3.8%* | *3.8%* | *3.1%* | *2.6%* | *2.3%* | *-5.9%* | *3.1%* | *3.1%* | *3.1%* |
| - Taxes | $ 23.0 | $ 23.8 | $ 25.0 | $ 20.4 | $ 17.0 | $ 14.8 | $ - | $ 23.3 | $ 23.0 | $ 22.9 |
| **Net Operating Profit after Taxes (NOPAT)** | **$ 44.6** | **$ 46.2** | **$ 48.6** | **$ 39.7** | **$ 33.0** | **$ 28.8** | **$ (131.6)** | **$ 45.1** | **$ 44.7** | **$ 44.5** |
| | | | | | | $ 1.4 | | | | |
| **Cash Flow Statement** | | | | | | | | | | |
| NOPAT | $ 44.6 | $ 46.2 | $ 48.6 | $ 39.7 | $ 33.0 | $ 28.8 | $ (131.6) | $ 45.1 | $ 44.7 | $ 44.5 |
| + Depreciation | $ 90.0 | $ 93.2 | $ 98.1 | $ 96.1 | $ 94.7 | $ 94.4 | $ 112.9 | $ 112.2 | $ 111.1 | $ 110.6 |
| + Loss on Disposal of Stranded Assets | $ - | $ - | $ - | $ - | $ - | $ - | $ 199.2 | $ - | $ - | $ - |
| - Change in Working Capital | $ - | $ 4.4 | $ 6.9 | $ (2.7) | $ (2.0) | $ (0.5) | $ 24.7 | $ (1.0) | $ (1.6) | $ (0.7) |
| Cash Flows from Operations | $ 134.7 | $ 135.0 | $ 139.9 | $ 138.5 | $ 129.7 | $ 123.7 | $ 155.9 | $ 158.4 | $ 157.4 | $ 155.7 |
| - Ordinary Capital Expenditures | $ 90.0 | $ 93.2 | $ 98.1 | $ 96.1 | $ 94.7 | $ 94.4 | $ 112.0 | $ 111.3 | $ 110.1 | $ 109.7 |
| - Capital Conversion Costs | $ - | $ - | $ - | $ 43.9 | $ 76.9 | $ 98.9 | $ - | $ - | $ - | $ - |
| **Free Cash Flow** | **$ 44.6** | **$ 41.8** | **$ 41.8** | **$ (1.5)** | **$ (41.9)** | **$ (69.6)** | **$ 43.9** | **$ 47.1** | **$ 47.2** | **$ 46.1** |
| | | | | | | $ 2.3 | | | | |
| **Discounted Cash Flow** | | | | | | | | | | |
| Free Cash Flow | $ 44.6 | $ 41.8 | $ 41.8 | $ (1.5) | $ (41.9) | $ (69.6) | $ 43.9 | $ 47.1 | $ 47.2 | $ 46.1 |
| Terminal Value | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - |
| *Present Value Factor* | *0.000* | *1.000* | *0.922* | *0.849* | *0.783* | *0.722* | *0.665* | *0.613* | *0.565* | *0.521* |
| Discounted Cash Flow | **$ -** | **$ 41.8** | **$ 38.5** | **$ (1.3)** | **$ (32.8)** | **$ (50.2)** | **$ 29.2** | **$ 28.9** | **$ 26.7** | **$ 24.0** |

| | |
|---|---|
| **INPV at TSL 2** | **$ 382.9** |

# APPENDIX 14A. SOCIAL COST OF CARBON FOR REGULATORY IMPACT ANALYSIS UNDER EXECUTIVE ORDER 12866

## TABLE OF CONTENTS

## LIST OF TABLES

## LIST OF FIGURES

# 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.

---

[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

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 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.

**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

---

[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).

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 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 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. See section 16-A.5 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).

---

[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).

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 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]

### *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

---

[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%, 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 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.

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.

---

[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).

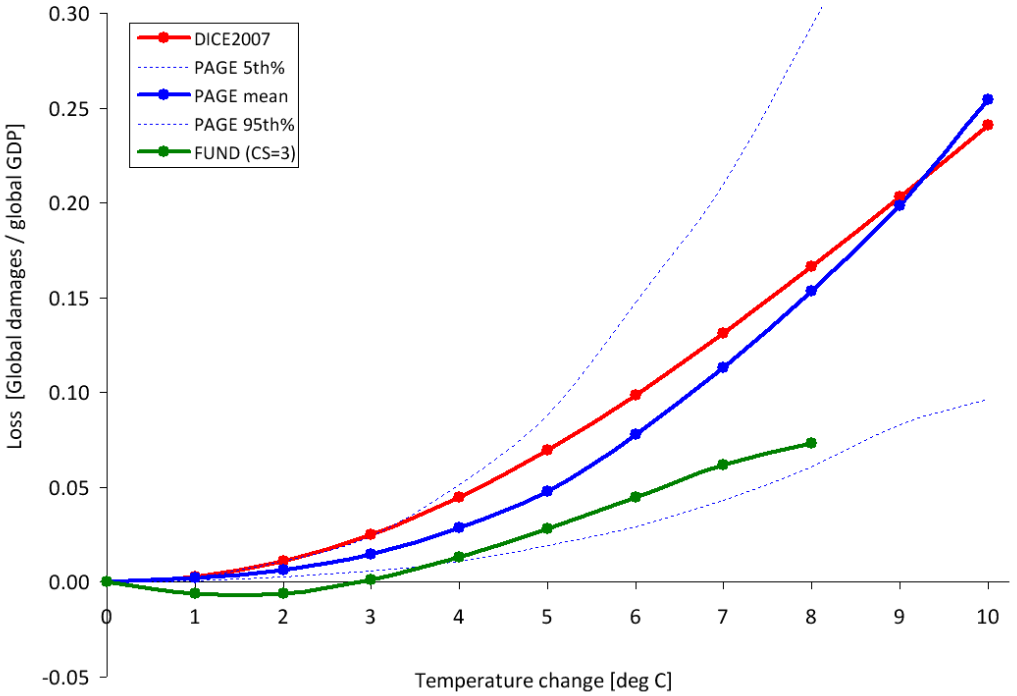


**Figure 14A.4.1 Annual Consumption Loss as a Fraction of Global GDP in 2100 Due to an Increase in Annual Global Temperature in the DICE, FUND, and PAGE models**[f]

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.

---

[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.

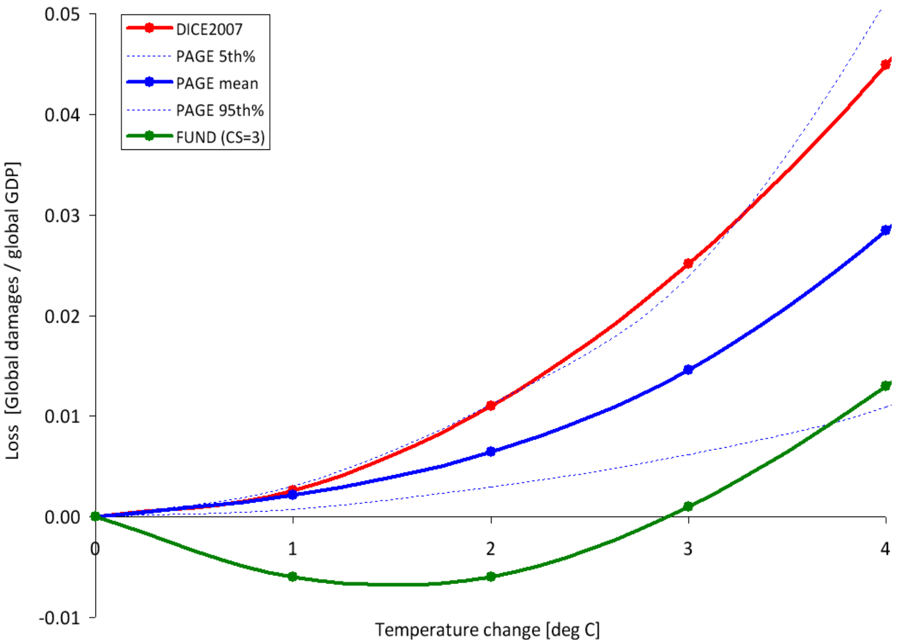


**Figure 14A.4.2 Annual Consumption Loss for Lower Temperature Changes in DICE, FUND, and PAGE**

### 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

---

[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.

presents a problem that the United States alone cannot solve. Even if the United States were to 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

---

[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*.

account for how damages in other regions could affect the United States (*e.g.*, global migration, 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):

---

[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.

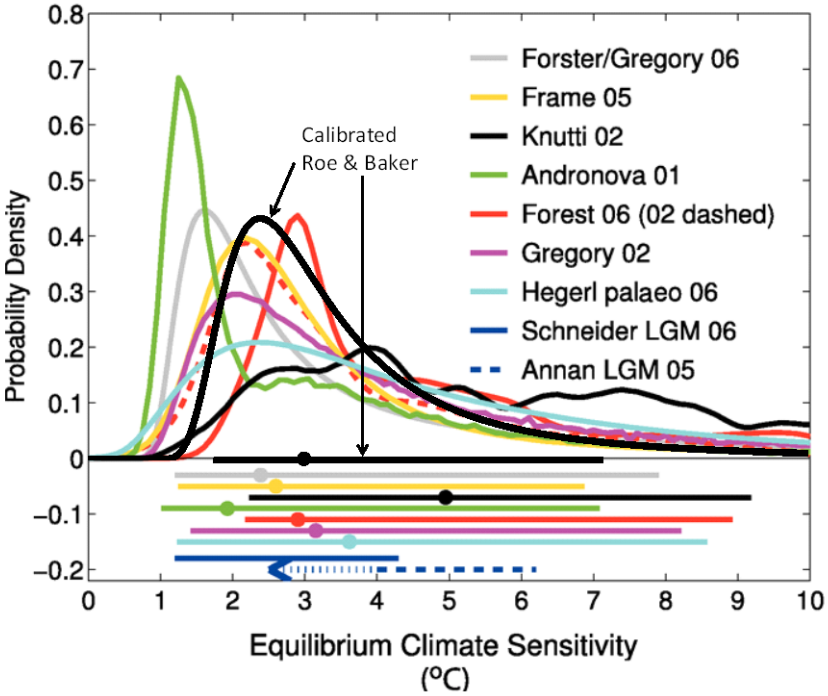


**Figure 14A.4.3** **Estimates of the Probability Density Function for Equilibrium Climate Sensitivity (°C)**

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 $CO_2$e (i*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 $CO_2$e 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: $\eta$ (coefficient of relative risk aversion or elasticity of the marginal utility of consumption) and $\rho$ (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.

- $\eta$. Most papers in the climate change literature adopt values for $\eta$ 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 $\eta$ should be greater than 1 and may be as high as 3, because $\eta$ equal to 1 suggests savings rates that do not conform to observed behavior.

- $\rho$. With respect to the pure rate of time preference, most papers in the climate change literature adopt values for $\rho$ 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 $\rho$ □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 $\eta$ 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 $\eta$ 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 $\eta$ 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 ρ = 0.1 percent per year, η = 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 η = 1). Using Stern's assumption that ρ = 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).

---

[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.

---

[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]

---

[bb] Nordhaus (2008) runs DICE2007 with $\rho = 1.5$ and $\eta = 2$. The default approach in PAGE2002 (version 1.4epm) treats $\rho$ and $\eta$ as random parameters, specified using a triangular distribution such that the min, mode, and max = 0.1, 1, and 2 for $\rho$, and 0.5, 1, and 2 for $\eta$, respectively. The FUND default value for $\eta$ is 1, and Tol generates SCC estimates for values of $\rho$ = 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

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.

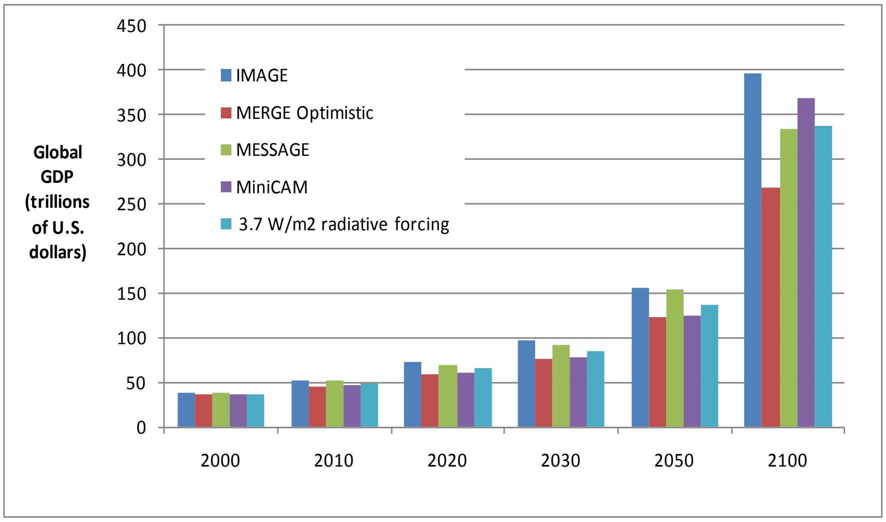


**Figure 14A.5.1 Level of Global GDP across EMF Scenarios**

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 (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.

---

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.

**Table 14A.5.2 Social Cost of $CO_2$, 2010 – 2050 (in 2007 dollars)**

| Discount<br>Year | 5%<br>Avg | 3%<br>Avg | 2.5%<br>Avg | 3%<br>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%**<br>Avg | **3%**<br>Avg | **2.5%**<br>Avg | **3.0%**<br>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.

## REFERENCES

1. Andronova, N., and M. Schlesinger. 2001. “Objective estimation of the probability density function for climate sensitivity.” *J. Geophys. Res.*, 106(D19), 22605–22611.

2. Annan, J., et al., 2005. “Efficiently constraining climate sensitivity with paleoclimate simulations.” *Scientific Online Letters on the Atmosphere*, 1, 181–184.

3. Anthoff D, C. Hepburn, and R. Tol. 2009a. “Equity Weighting and the Marginal Damage Costs of Climate Change.” *Ecological Economics* 68:836-849.

4. Anthoff, D., R. Tol, and G. Yohe. 2009b. “Risk aversion, time preference, and the social cost of carbon.” *Environmental Research Letters* 4: 024002 (7pp).

5. Arrow, K. 2007. “Global climate change: a challenge to policy.” *Economist’s Voice* 4(3):Article 2.

6. Arrow, K. 2000. “A Comment on Cooper.” *The World Bank Research Observer*. vol 15, no. 2.

7. Arrow, K., et al. 1996. *Benefit-Cost Analysis in Environmental, Health, and Safety Regulation: A Statement of Principles*. Washington, D.C., AEI Press. pp. 13-14.

8. Arrow, K.J., et al. 1996. ”Intertemporal equity, discounting and economic efficiency,” in Climate Change 1995: Economic and Social Dimensions of Climate Change, Contribution of Working Group III to the *Second Assessment Report of the Intergovernmental Panel on Climate Change*.

9. Campbell, J., P. Diamond, and J. Shoven. 2001. “Estimating the Real Rate of Return on Stocks Over the Long Term.” Presented to the Social Security Advisory Board. August.

10. Campbell, K. et al. 2007. *The age of consequences: The foreign policy and national security implications of global climate change*. Center for Strategic & International Studies, 119 pp.

11. Castles, I. and D. Henderson. 2003. “The IPCC Emission Scenarios: An Economic-Statistical Critique.” *Energy and Environment* 14(2-3): 159-185.

12. Chetty, R. 2006. “A New Method of Estimating Risk Aversion.” *American Economic Review* 96(5): 1821–1834.

13. Dasgupta P. 2006. “Comments on the Stern Review’s economics of climate change.” University of Cambridge working paper.

14. Dasgupta P. 2008. “Discounting climate change.” *Journal of Risk and Uncertainty* 37:141-169.

15. Easterling, W., et al. 2007. *Climate Change 2007: Impacts, Adaptation, and Vulnerability*. Intergovernmental Panel on Climate Change, 976 pp.

16. Evans D., and H. Sezer. 2005. “Social discount rates for member countries of the European Union.” *J. Econ. Stud*. 32 47–59.

17. Forest, C., et al. 2002. “Quantifying uncertainties in climate system properties with the use of recent observations.” *Science* 295, 113.

18. Forest, D., P. Stone, and A. Sokolov. 2006. “Estimated PDFs of climate system properties including natural and anthropogenic forcings.” *Geophys. Res. Lett*., 33, L01705.

19. Forster, P., and J. Gregory. 2006. “The climate sensitivity and its components diagnosed from Earth radiation budget data.” *J. Clim*., 19, 39–52.

20. Frame, D., et al. 2005. “Constraining climate forecasts: The role of prior assumptions.” *Geophys. Res. Lett*., 32, L09702.

21. Gingerich, P. 2006. “Environment and evolution through the Paleocene-Eocene thermal maximum.” *Trends Ecol. Evol.* 21: 246-253.

22. Gollier, C. 2008. “Discounting with fat-tailed economic growth.” *Journal of Risk and Uncertainty* 37:171-186.

23. Gollier, C. and M. Weitzman (2009). "How Should the Distant Future be Discounted When Discount Rates are Uncertain?" Harvard University, mimeo, Nov 2009.

24. Gregory, J., et al. 2002a. “An observationally based estimate of the climate sensitivity.” *J. Clim*., 15(22), 3117–3121.

25. Groom, B., Koundouri, P., Panipoulou, E., Pantelidis, T. 2006. “An econometric approach to estimating long-run discount rates.” *Journal of Applied Econometrics.*

26. Hall R, and C. Jones . 2007. "The value of life and the rise in health spending." Quarterly *Journal of Economics* 122(1):39-72.

27. Hansen, J.,M. Sato, P. Kharecha, G. Russell, D. W. Lea and M. Siddall. 2007. "Climate change and trace gases." *Phil. Trans. Roy. Soc. A* 365: 1925-1954.

28. Hegerl G, et al. 2007. "Understanding and attributing climate change." in Solomon S, et al. (eds) *Climate Change 2007: the physical science basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, UK: Cambridge University Press.

29. Hegerl, G., T. Crowley, W. Hyde, and D. Frame. 2006. "Constraints on climate sensitivity from temperature reconstructions of the past seven centuries." *Nature* 440.

30. Holtsmark, B., and K. Alfsen. 2005. "PPP Correction of the IPCC Emission Scenarios – Does it Matter?" *Climatic Change* 68(1-2): 11-19.

31. Hope C. 2006. "The marginal impact of CO2 from PAGE2002: an integrated assessment model incorporating the IPCC's five reasons for concern." *The Integrated Assessment Journal* 6(1):19-56.

32. Hope C. 2008. "Optimal carbon emissions and the social cost of carbon under uncertainty." *The Integrated Assessment Journal* 8(1):107-122.

33. Intergovernmental Panel on Climate Change (2007). "Summary for Policymakers." In *Climate Change 2007: The Physical Science Basis, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press.

34. Just, R., D. Hueth, and A. Schmitz. 2004. *The Welfare Economics of Public Policy*. Glos UK: Edward Elgar Publishing Limited.

35. Knutti, R., T. Stocker, F. Joos, and G. Plattner. 2002. "Constraints on radiative forcing and future climate change from observations and climate model ensembles." *Nature*, 416, 719–723.

36. Kriegler, E. et al. 2009. "Imprecise probability assessment of tipping points in the climate system." *Proc. Natl. Acad. Sci.* 106: 5041-5046.

37. Kotlikoff, L. and D. Rapson. 2006. “Does It Pay, at the Margin, to Work and Save? – Measuring Effective Marginal Taxes on Americans’ Labor Supply and Saving.” National Bureau of Economic Research, Working Paper, No. 12533.

38. Le Treut H., et al. 2007. “Historical Overview of Climate Change.” in Solomon et al., *Climate Change 2007.*

39. Lenton, T., et al. 2008. “Tipping elements in the Earth’s climate system.” *Proc. Natl. Acad. Sci.* 105: 1786-1793.

40. Levy, M., et al. 2005. “Ecosystem conditions and human well-being.” In: *Ecosystems and Human Well-being: Current State and Trends, Volume 1.* [R. Hassan, R. Scholes, and N. Ash, eds.] Washington: Island Press. pp. 123-164.

41. Lind, R. 1990. “Reassessing the Government’s Discount Rate Policy in Light of New Theory and Data in a World Economy with a High Degree of Capital Mobility.” *Journal of Environmental Economics and Management* 18, S-8-S-28.

42. Mastrandre, M. 2009. “Calculating the benefits of climate policy: Examining the assumptions of Integrated Assessment Models.” Pew Center on Global Climate Change Working Paper, 60 pp.

43. Meehl, G, et al. 2007. “Global Climate Projections.” in Solomon et al., *Climate Change 2007.*

44. National Research Council (2009). *Hidden Costs of Energy: Unpriced Consequences of Energy Production and Use*. National Academies Press.

45. Newbold S, Daigneault A. 2009. “Climate response uncertainty and the benefits of greenhouse gas emissions reductions.” *Environmental and Resource Economics* 44:351-377.

46. Newell, R., and W. Pizer. 2003. Discounting the distant future: how much do uncertain rates increase valuations? *Journal of Environmental Economics and Management* 46: 52-71.

47. Nordhaus, W. 1994. “Expert Opinion on Climate Change.” *American Scientist* 82: 45-51.

48. Nordhaus, W. 2007a. *Accompanying notes and documentation on development of DICE-2007 model: notes on DICE-2007.delta.v8 as of September 21, 2007.*

49. Nordhaus, W. 2007b. “Alternative measures of output in global economic-environmental models: Purchasing power parity or market exchange rates?” *Energy Economics* 29: 349-372.

50. Nordhaus W. 2008. *A Question of Balance: Weighing the Options on Global Warming Policies*. New Haven, CT: Yale University Press.

51. Nordhaus, W. 2009. “An Analysis of the Dismal Theorem. Cowles Foundation Discussion Paper. No. 1686. January.

52. Nordhaus W., and Boyer J. 2000. *Warming the World: Economic Models of Global Warming*. Cambridge, MA: MIT Press.

53. Pindyck, R. 2009. “Uncertain Outcomes and Climate Change Policy.” NBER Working Paper, No. 15259. August.

54. Ramsey, F. 1928. “A Mathematical Theory of Saving.” *The Economic Journal* 38(152): 543-559.

55. Roe, G. 2008. “Feedbacks, timescales, and seeing red.” *Annual Review of Earth and Planetary Sciences* 37:5.1-5.23.

56. Roe, G., and M. Baker. 2007. “Why is climate sensitivity so unpredictable?” *Science* 318:629-632.

57. Schneider von Deimling, T., H. Held, A. Ganopolski, and S. Rahmstorf. 2006. “Climate sensitivity estimated from ensemble simulations of glacial climate.” *Clim. Dyn*., 27, 149–163.

58. Smith, J. et al. 2009. “Transient dwarfism of soil fauna during the Paleocene-Eocene Thermal Maximum.” *Proc. Natl. Acad. Sci.* 106: 17665-17660.

59. Stern, N., et al. (2006), *Stern Review: The Economics of Climate Change,* HM Treasury, London.

60. Stern N. 2008. “The economics of climate change.” *American Economic Review* 98(2):1-37.

61. Sterner, T., and U. Persson. 2008. An even Sterner review: Introducing relative prices into the discounting debate. *Rev. Env. Econ. Pol.* 2: 61-76.

62. Summers, L., and R. Zeckhauser. 2008. "Policymaking for Prosperity." Journal of Risk and Uncertainty 37: 115-140.

63. Szpiro, G. 1986. "Measuring Risk Aversion: An Alternative Approach." *The Review of Economics and Statistics* 68(1): 156-9.

64. Tol, R. 2002a. "Estimates of the damage costs of climate change. Part I: benchmark estimates." *Environmental and Resource Economics* 21:47-73.

65. Tol, R. 2002b. "Estimates of the damage costs of climate change. Part II: dynamic estimates." *Environmental and Resource Economics* 21:135-160.

66. Tol, R. 2006. "Exchange Rates and Climate Change: An Application of FUND." *Climatic Change* 75(1-2): 59-80.

67. Tol, R. 2009. "An analysis of mitigation as a response to climate change." Copenhagen Consensus on Climate. Discussion Paper.

68. U.S. Department of Defense. 2010. Quadrennial Defense Review Report. February.

69. Warren, R., et al. 2006. "Spotlight Impact Functions in Integrated Assessment." Tyndall Center for Climate Change Research, Working Paper 91.

70. Weitzman, M. 2009. "On modeling and interpreting the economics of catastrophic climate change." *Review of Economics and Statistics* 91:1-19.

71. Weitzman, M. 2007. "A review of The Stern Review of the Economics of Climate Change*."* *Journal of Economic Literature* 45:703-724.

72. Weitzman, M. 1999. In Portney P.R. and Weyant J.P. (eds.), *Discounting and Intergenerational Equity*, Resources for the Future, Washington, D.C.

73. Weitzman, M. 1998. "Why the Far-Distant Future Should Be Discounted at Its Lowest Possible Rate." *Journal of Environmental Economics and Management* 36 (3): 201-208.

74. Wing, S. et al. 2005. "Transient floral change and rapid global warming at the Paleocene-Eocene boundary." *Science* 310: 993-996.

## 14A.9 ANNEX

### Table 14A.9.1 Annual SCC Values: 2010–2050 (in 2007 dollars)

| Discount Rate<br>Year | 5%<br>Avg | 3%<br>Avg | 2.5%<br>Avg | 3%<br>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.

---

[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.

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 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$^2$.

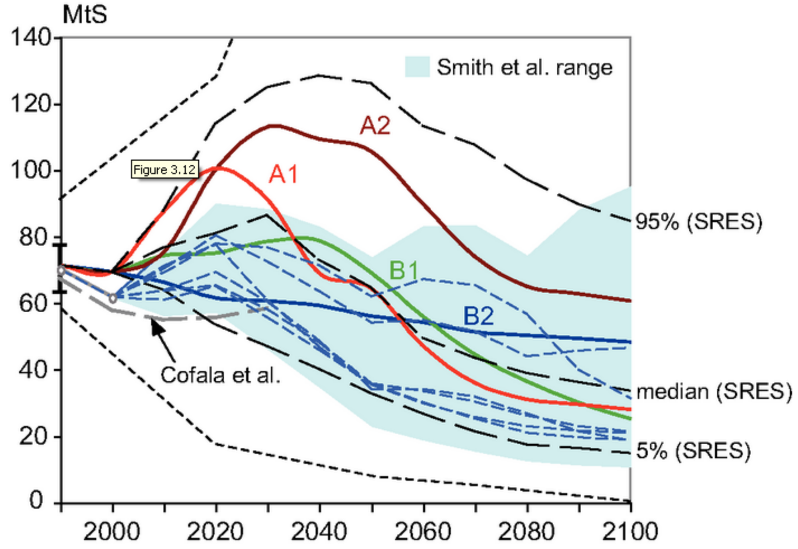


**Figure 14A.9.2 Sulfur Dioxide Emission Scenarios**

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

---

[jj] United Nations. 2004. *World Population to 2300*.

http://www.un.org/esa/population/publications/longrange2/WorldPop2300final.pdf 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.

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.

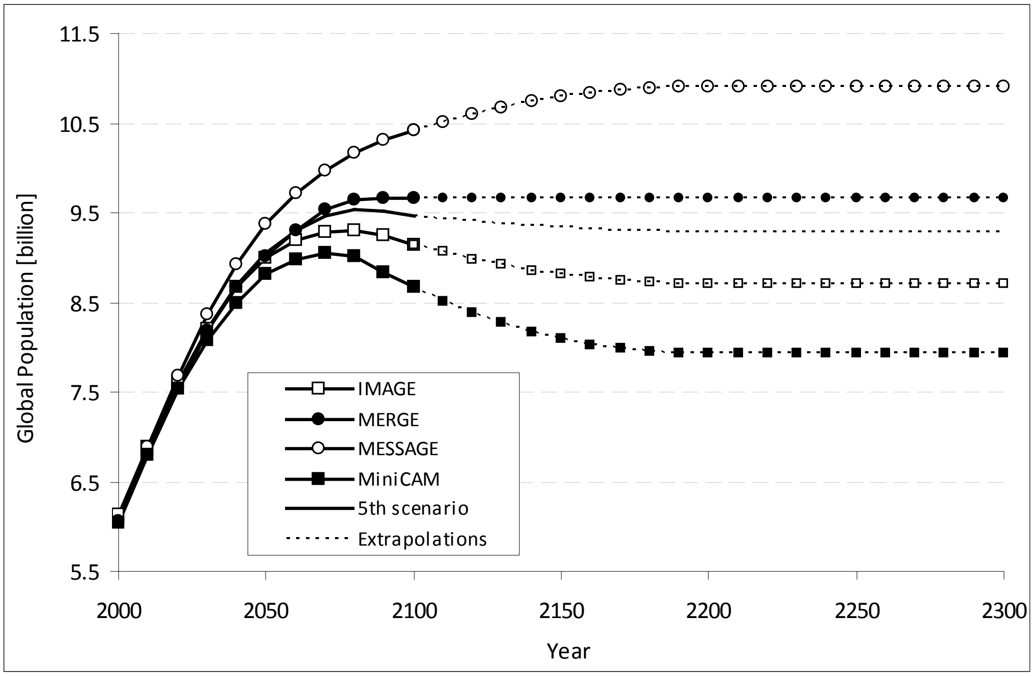


**Figure 14A.9.3 Global Population, 2000-2300 (Post-2100 extrapolations assume the population growth rate changes linearly to reach a zero growth rate by 2200.)**

Note: In the fifth scenario, 2000-2100 population is equal to the average of the population under the 550 ppm $CO_2$e, full-participation, not-to-exceed scenarios considered by each of the four models.

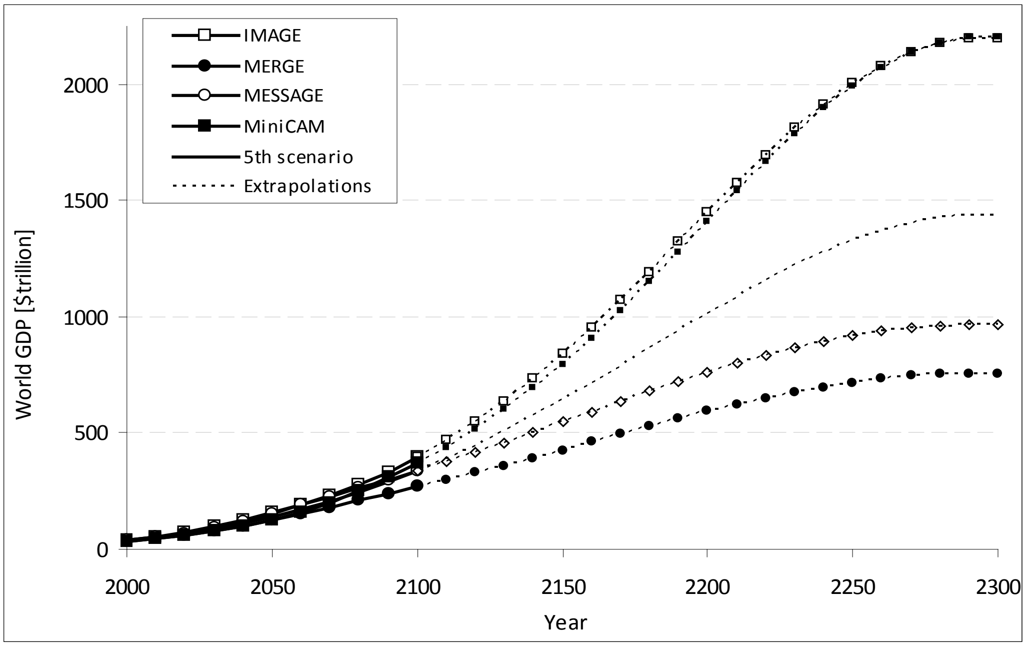


**Figure 14A.9.4 World GDP, 2000-2300 (Post-2100 extrapolations assume GDP per capita growth declines linearly, reaching zero in the year 2300)**

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.

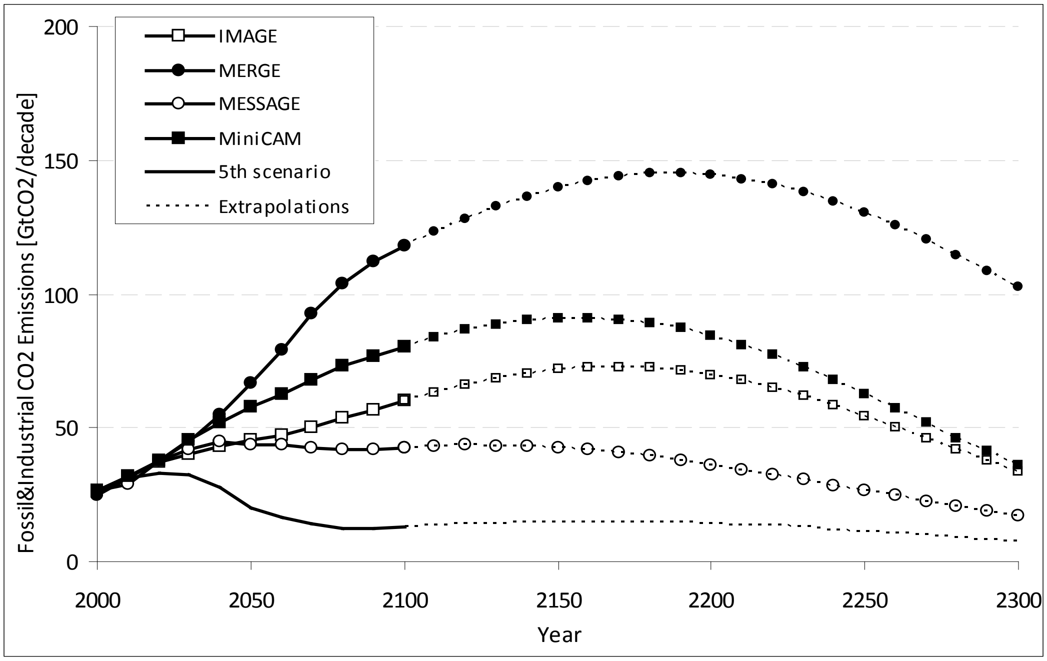


**Figure 14A.9.5 Global Fossil and Industrial $CO_2$ Emissions, 2000-2300 (Post-2100 extrapolations assume growth rate of $CO_2$ intensity ($CO_2$/GDP) over 2090-2100 is maintained through 2300)**

Note: In the fifth scenario, 2000-2100 emissions are equal to the average of the emissions under the 550 ppm $CO_2$e, full-participation, not-to-exceed scenarios considered by each of the four models.

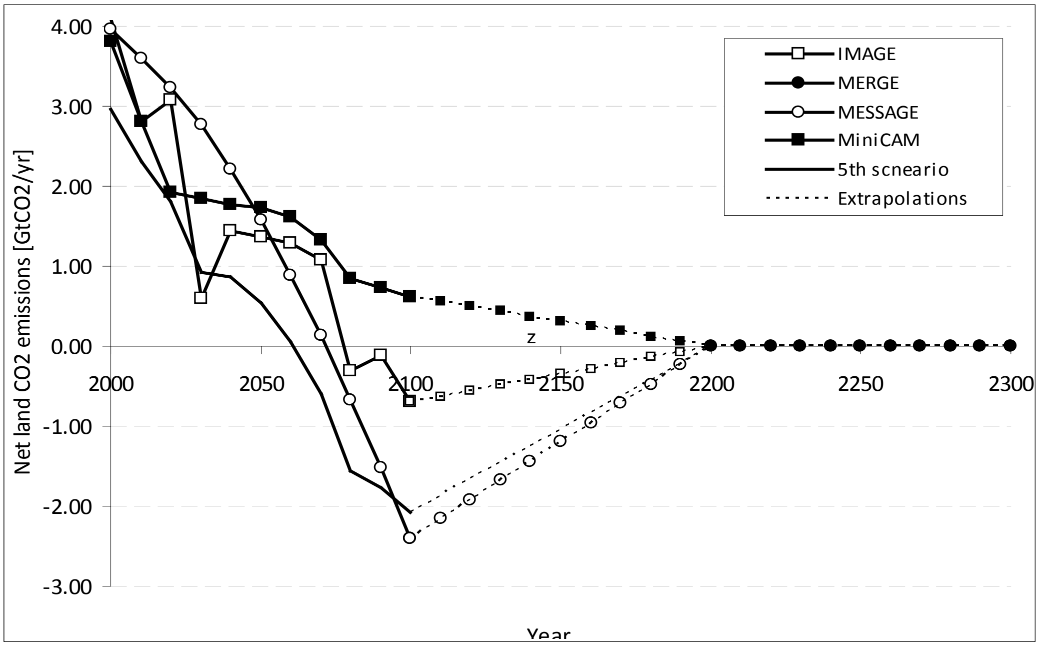


**Figure 14A.9.6 Global Net Land Use $CO_2$ Emissions, 2000-2300 (Post-2100 extrapolations assume emissions decline linearly, reaching zero in the year 2200)**[kk]

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).

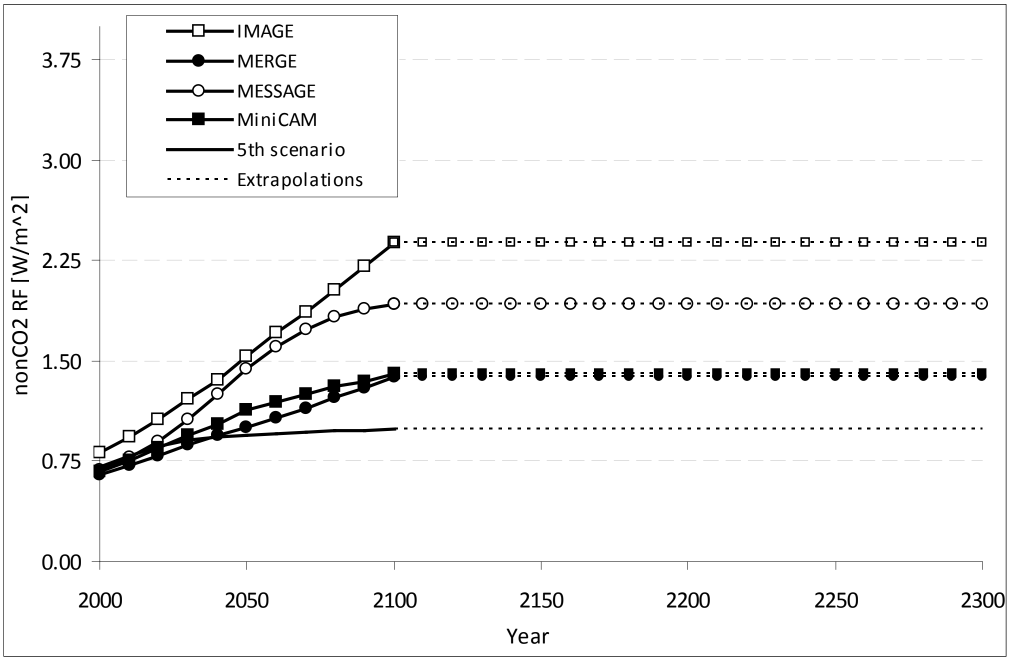


**Figure 14A.9.7 Global Non-$CO_2$ Radiative Forcing, 2000-2300 (Post-2100 extrapolations assume constant non-$CO_2$ radiative forcing after 2100)**

Note: In the fifth scenario, 2000-2100 emissions are equal to the average of the emissions under the 550 ppm $CO_2$e, full-participation, not-to-exceed scenarios considered by each of the four models.

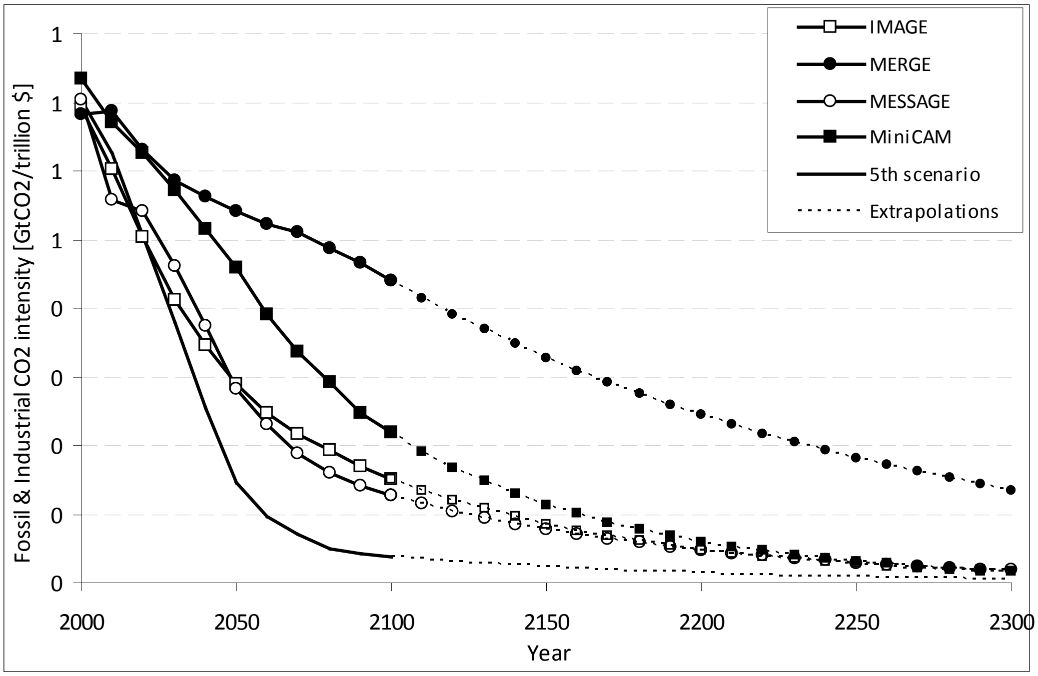


**Figure 14A.9.8 Global $CO_2$ Intensity (fossil & industrial $CO_2$ emissions/GDP), 2000-2300 (Post-2100 extrapolations assume decline in $CO_2$/GDP growth rate over 2090-2100 is maintained through 2300)**

Note: In the fifth scenario, 2000-2100 emissions are equal to the average of the emissions under the 550 ppm $CO_2$e, 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 |

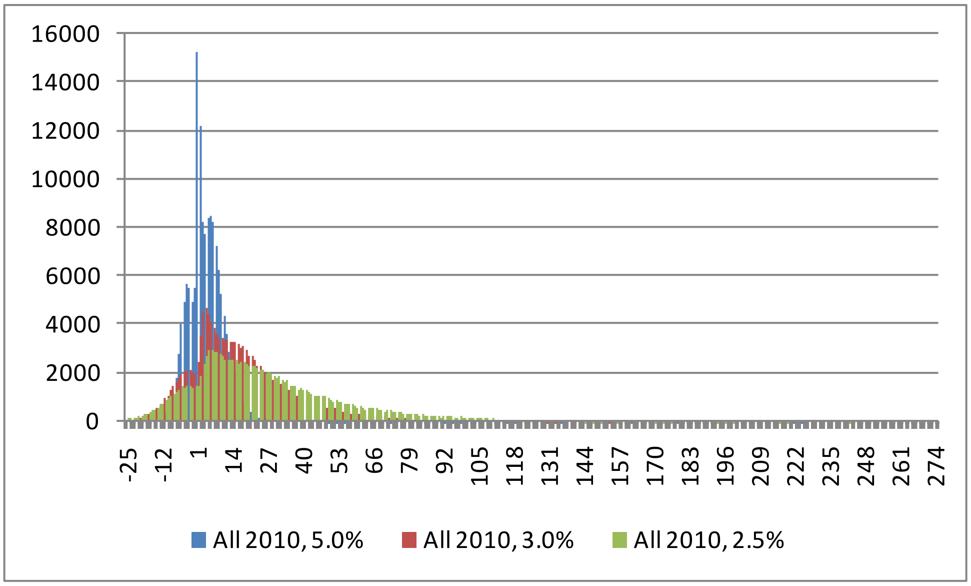


**Figure 14A.9.9 Histogram of Global SCC Estimates in 2010 (2007$/ton CO$_2$), by discount rate**

* The distribution of SCC values ranges from -$5,192 to $66,116, but the X-axis has been truncated at approximately the 1$^{st}$ and 99$^{th}$ 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 14-B. TECHNICAL UPDATE OF SOCIAL COST OF CARBON FOR REGULATORY IMPACT ANALYSIS UNDER EXECUTIVE ORDER 12866

## TABLE OF CONTENTS

## LIST OF TABLES

## LIST OF FIGURES

# APPENDIX 14-B. TECHNICAL UPDATE OF SOCIAL COST OF CARBON FOR REGULATORY IMPACT ANALYSIS UNDER EXECUTIVE ORDER 12866

## 14-B.1 PREFACE

The following text is reproduced almost verbatim from the May 2013 report of the Interagency Working Group on the Social Cost of Carbon of the United States Government. Minor changes were made to the working group's report to make it more consistent with the rest of this technical support document.

## 14-B.2 PURPOSE

The purpose of this document is to update the schedule of social cost of carbon (SCC) [a] estimates from the 2010 interagency technical support document (TSD) (Interagency Working Group on Social Cost of Carbon 2010).[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 14-B.3 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 14-B.4 presents the updated schedule of SCC estimates for 2010 – 2050 based on these versions of the models.

---

[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]

## 14-B.3 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.

### 14-B.3.1 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.

#### 14-B.3.1.1 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).[2][d] 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

---

[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]

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.

#### 14-B.3.1.2 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 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 °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.

---

[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/RICEmodels.htm.

[f] For a review of post-IPCC AR4 research on sea level rise, see Nicholls et al. (2011)[5] and NAS (2011).[6]

#### 14-B.3.1.3 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.

### 14-B.3.2 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.

---

[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.

### 14-B.3.2.1 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.

### 14-B.3.2.2 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 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.

### 14-B.3.2.3 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.

#### 14-B.3.2.4 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.

#### 14-B.3.2.5 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% 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.

### 14-B.3.3 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]

#### 14-B.3.3.1 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.

#### 14-B.3.3.2 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.

#### 14-B.3.3.3 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.

#### 14-B.3.3.4 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.

### 14-B.3.3.5 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.

### 14-B.3.3.6 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.

## 14-B.4 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 14-B.4.1 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 14-B.4.1 Revised Social Cost of $CO_2$, 2010 – 2050 (in 2007 dollars per ton of $CO_2$)**

| Discount Rate | 5.0% | 3.0% | 2.5% | 3.0% |
|---|---|---|---|---|
| Year | Avg | Avg | Avg | 95th |
| 2010 | 11 | 33 | 52 | 90 |
| 2015 | 12 | 38 | 58 | 109 |
| 2020 | 12 | 43 | 65 | 129 |
| 2025 | 14 | 48 | 70 | 144 |
| 2030 | 16 | 52 | 76 | 159 |
| 2035 | 19 | 57 | 81 | 176 |
| 2040 | 21 | 62 | 87 | 192 |
| 2045 | 24 | 66 | 92 | 206 |
| 2050 | 27 | 71 | 98 | 221 |

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 14-B.4.2 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.

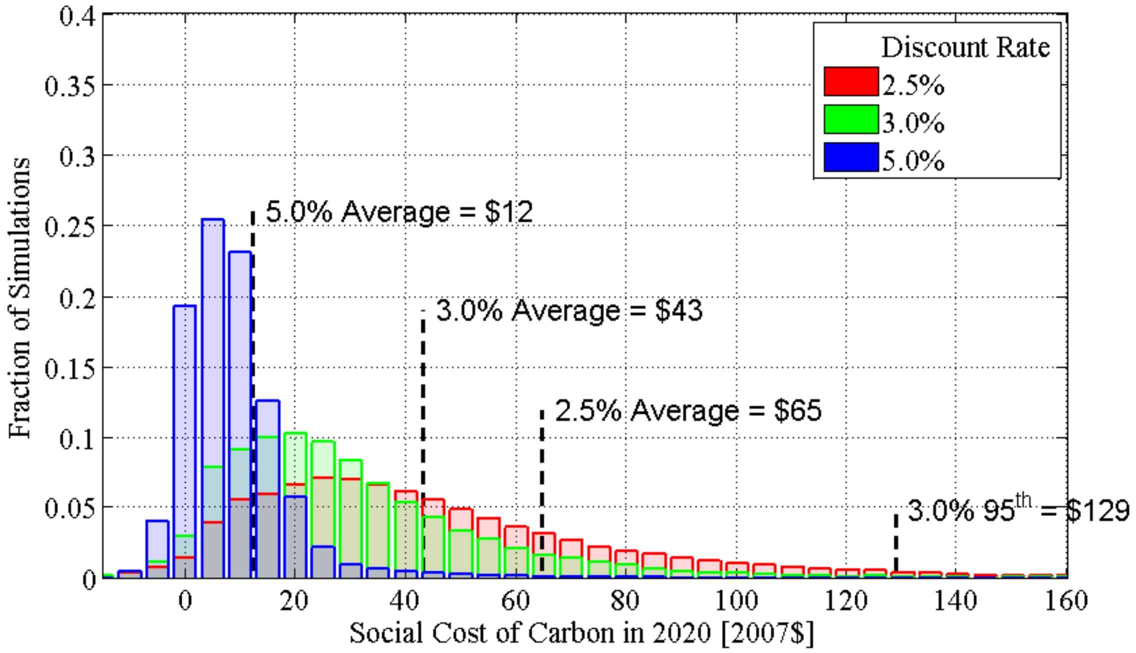


**Figure 14-B.4.2 Distribution of SCC Estimates for 2020 (in 2007$ per ton $CO_2$)**

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 14-B.4.2 illustrates how the growth rate for these four SCC estimates varies over time.

**Table 14-B.4.2 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% | 4.3% |
| 2020-2030 | 3.4% | 2.1% | 1.7% | 2.4% |
| 2030-2040 | 3.0% | 1.8% | 1.5% | 2.0% |
| 2040-2050 | 2.6% | 1.6% | 1.3% | 1.5% |

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.

## 14-B.5 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.

## REFERENCES

1. Interagency Working Group on Social Cost of Carbon, *Social Cost of Carbon for Regulatory Impact Analysis under Executive Order 12866*, February, 2010. United States Government. <http://www.whitehouse.gov/sites/default/files/omb/inforeg/for-agencies/Social-Cost-of-Carbon-for-RIA.pdf>

2. Nordhaus, W., *A Question of Balance*. 2008. Yale University Press: New Haver.

3. Nordhaus, W., Economic aspects of global warming in a post-Copenhagen environment. *Proceedings of the National Academy of Sciences*, 2010. 107(26): pp. 11721-11726

4. Randall, D. A., R.A. Wood, S. Bony, R. Colman, T. Fichefet, J. Fyfe, V. Kattsov, A. Pitman, J. Shukla, J. Srinivasan, R.J. Stouffer, A. Sumi and K.E. Taylor, *Climate Models and Their Evaluation*. In *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller, Editor. 2007. Cambridge University Press: Cambridge, United Kingdom and New York, NY, USA

5. Nicholls, R. J., N. Marinova, J.A. Lowe, S. Brown, P. Vellinga, D. de Gusmão, J. Hinkel and R.S.J. Tol, Sea-level rise and its possible impacts given a 'beyond 4°C world' in the twenty-first century. *Phil. Trans. R. Soc. A* 2011. 369(1934): pp. 161-181

6. National Academy of Sciences, *Climate Stabilization Targets: Emissions, Concentrations, and Impacts over Decades to Millennia*. 2011. National Academies Press, Inc: Washington, DC.

7. Anthoff, D. and R. S. J. Tol, The uncertainty about the social cost of carbon: a decomposition analysis using FUND. *Climatic Change*, 2013(Forthcoming)

8. Forster, P., V. Ramaswamy, P. Artaxo, T. Berntsen, R. Betts, D.W. Fahey, J. Haywood, J. Lean, D.C. Lowe, G. Myhre, J. Nganga, R. Prinn, G. Raga, M. Schulz and R. Van Dorland, *Changes in Atmospheric Constituents and in Radiative Forcing*. In *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller Editor. 2007. Cambridge University Press: Cambridge, United Kingdom and New York, NY, USA

9. Hope, C., Critical issues for the calculation of the social cost of CO2: why the estimates from PAGE09 are higher than those from PAGE2002. *Climatic Change*, 2012(Forthcoming)

10. Hope, C., *The PAGE09 Integrated Assessment Model: A Technical Description*. 2011, Cambridge Judge Business School http://www.jbs.cam.ac.uk/fileadmin/user_upload/research/workingpapers/wp1104.pdf

11. Hope, C., *The Social Cost of CO2 from the PAGE09 Model*. 2011, Cambridge Judge Business School http://www.jbs.cam.ac.uk/fileadmin/user_upload/research/workingpapers/wp1105.pdf

12. Hope, C., *New Insights from the PAGE09 Model: The Social Cost of CO2*. 2011, Cambridge Judge Business School http://www.jbs.cam.ac.uk/fileadmin/user_upload/research/workingpapers/wp1108.pdf

13. Hope, C., The Marginal Impact of CO2 from PAGE2002: An Integrated Assessment Model Incorporating the IPCC's Five Reasons for Concern. *The Integrated Assessment Journal*, 2006. 6(1): pp. 19-56

## ANNEX

**Table 14-B.5.1 Annual SCC Values: 2010-2050 (2007$/ton $CO_2$)**

| Discount Rate<br>Year | 5.0%<br>Avg | 3.0%<br>Avg | 2.5%<br>Avg | 3.0%<br>95th |
|---|---|---|---|---|
| 2010 | 11 | 33 | 52 | 90 |
| 2011 | 11 | 34 | 54 | 94 |
| 2012 | 11 | 35 | 55 | 98 |
| 2013 | 11 | 36 | 56 | 102 |
| 2014 | 11 | 37 | 57 | 106 |
| 2015 | 12 | 38 | 58 | 109 |
| 2016 | 12 | 39 | 60 | 113 |
| 2017 | 12 | 40 | 61 | 117 |
| 2018 | 12 | 41 | 62 | 121 |
| 2019 | 12 | 42 | 63 | 125 |
| 2020 | 12 | 43 | 65 | 129 |
| 2021 | 13 | 44 | 66 | 132 |
| 2022 | 13 | 45 | 67 | 135 |
| 2023 | 13 | 46 | 68 | 138 |
| 2024 | 14 | 47 | 69 | 141 |
| 2025 | 14 | 48 | 70 | 144 |
| 2026 | 15 | 49 | 71 | 147 |
| 2027 | 15 | 49 | 72 | 150 |
| 2028 | 15 | 50 | 73 | 153 |
| 2029 | 16 | 51 | 74 | 156 |
| 2030 | 16 | 52 | 76 | 159 |
| 2031 | 17 | 53 | 77 | 163 |
| 2032 | 17 | 54 | 78 | 166 |
| 2033 | 18 | 55 | 79 | 169 |
| 2034 | 18 | 56 | 80 | 172 |
| 2035 | 19 | 57 | 81 | 176 |
| 2036 | 19 | 58 | 82 | 179 |
| 2037 | 20 | 59 | 84 | 182 |
| 2038 | 20 | 60 | 85 | 185 |
| 2039 | 21 | 61 | 86 | 188 |
| 2040 | 21 | 62 | 87 | 192 |
| 2041 | 22 | 63 | 88 | 195 |
| 2042 | 22 | 64 | 89 | 198 |
| 2043 | 23 | 65 | 90 | 200 |
| 2044 | 23 | 65 | 91 | 203 |
| 2045 | 24 | 66 | 92 | 206 |
| 2046 | 24 | 67 | 94 | 209 |
| 2047 | 25 | 68 | 95 | 212 |
| 2048 | 25 | 69 | 96 | 215 |
| 2049 | 26 | 70 | 97 | 218 |
| 2050 | 27 | 71 | 98 | 221 |

**Table 14-B.5.2 202 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 | 11 | 15 | 27 | 58 | 129 | 139 | 327 | 515 | 991 |
| MERGE | 4 | 6 | 9 | 16 | 34 | 78 | 82 | 196 | 317 | 649 |
| MESSAGE | 4 | 8 | 11 | 20 | 42 | 108 | 107 | 278 | 483 | 918 |
| MiniCAM Base | 5 | 9 | 12 | 22 | 47 | 107 | 113 | 266 | 431 | 872 |
| 5th Scenario | 2 | 4 | 6 | 11 | 25 | 85 | 68 | 200 | 387 | 955 |

| 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 | -17 | -1 | 5 | 17 | 34 | 44 | 59 | 90 | 113 | 176 |
| MERGE | -7 | 2 | 7 | 16 | 30 | 35 | 49 | 72 | 91 | 146 |
| MESSAGE | -19 | -4 | 2 | 12 | 27 | 32 | 46 | 70 | 87 | 135 |
| MiniCAM Base | -9 | 1 | 8 | 18 | 35 | 45 | 59 | 87 | 108 | 172 |
| 5th Scenario | -30 | -12 | -5 | 6 | 19 | 24 | 35 | 57 | 72 | 108 |

**Table 14-B.5.3 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 | 10 | 18 | 38 | 91 | 95 | 238 | 385 | 727 |
| MERGE | 2 | 4 | 6 | 11 | 23 | 56 | 58 | 142 | 232 | 481 |
| MESSAGE | 3 | 5 | 7 | 13 | 29 | 75 | 74 | 197 | 330 | 641 |
| MiniCAM Base | 3 | 5 | 8 | 14 | 30 | 73 | 75 | 184 | 300 | 623 |
| 5th Scenario | 1 | 3 | 4 | 7 | 17 | 58 | 48 | 136 | 264 | 660 |

| 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 | -14 | -3 | 1 | 9 | 20 | 25 | 35 | 54 | 69 | 111 |
| MERGE | -8 | -1 | 3 | 9 | 18 | 22 | 31 | 47 | 60 | 97 |
| MESSAGE | -16 | -5 | -1 | 6 | 16 | 18 | 28 | 43 | 55 | 88 |
| MiniCAM Base | -9 | -1 | 3 | 10 | 21 | 27 | 35 | 53 | 67 | 107 |
| 5th Scenario | -22 | -10 | -5 | 2 | 10 | 13 | 20 | 33 | 42 | 63 |

**Table 14-B.5.4 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 | 5 | 10 | 28 | 27 | 71 | 123 | 244 |
| MERGE | 1 | 1 | 2 | 3 | 7 | 17 | 17 | 45 | 75 | 153 |
| MESSAGE | 1 | 1 | 2 | 4 | 9 | 24 | 22 | 60 | 106 | 216 |
| MiniCAM Base | 1 | 1 | 2 | 3 | 8 | 21 | 21 | 54 | 94 | 190 |
| 5th Scenario | 0 | 1 | 1 | 2 | 5 | 18 | 14 | 41 | 78 | 208 |

| 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 | -3 | -1 | 2 | 3 | 6 | 11 | 15 | 25 |
| MERGE | -6 | -3 | -2 | 0 | 3 | 4 | 7 | 12 | 16 | 27 |
| MESSAGE | -10 | -6 | -4 | -1 | 2 | 2 | 5 | 9 | 13 | 23 |
| MiniCAM Base | -7 | -3 | -2 | 0 | 3 | 4 | 7 | 11 | 15 | 26 |
| 5th Scenario | -11 | -7 | -5 | -2 | 0 | 0 | 3 | 6 | 8 | 14 |

# APPENDIX 17-A. REGULATORY IMPACT ANALYSIS: SUPPORTING MATERIALS

## TABLE OF CONTENTS

## LIST OF TABLES

## LIST OF FIGURES

# APPENDIX 17-A. REGULATORY IMPACT ANALYSIS: SUPPORTING MATERIALS

## 17-A.1 INTRODUCTION

This appendix contains sections discussing the following topics:

- Projections of annual market share increases for the alternative policies;
- NIA-RIA Integrated Model;
- XENERGY penetration curves used to analyze consumer rebates, including:
    - Background material,
    - DOE's adjustment of these curves for this analysis, and
    - The method DOE used for interpolating the curves;
- Detailed tables of rebates offered for the considered products; and
- Background material on Federal and state tax credits for appliances.

## 17-A.2 MARKET SHARE ANNUAL INCREASES BY POLICY

Table 17-A.2.1 shows the annual increases in market shares of standard-sized residential dishwashers meeting the target efficiency level for the proposed TSL (TSL 2). DOE used these market share increases as inputs to the NIA-RIA spreadsheet model.

**Table 17-A.2.1 Annual Increases in Market Shares Attributable to Alternative Policy Measures for Standard-Sized Residential Dishwashers**

| Year | Consumer Rebates | Consumer Tax Credits | Manufacturer Tax Credits | Voluntary Energy Efficiency Targets | Bulk Government Purchases |
|---|---|---|---|---|---|
| 2019 | 4.5% | 2.7% | 1.4% | 2.0% | 0.05% |
| 2020 | 4.5% | 2.7% | 1.4% | 4.0% | 0.11% |
| 2021 | 4.5% | 2.7% | 1.4% | 6.1% | 0.16% |
| 2022 | 4.5% | 2.7% | 1.4% | 8.0% | 0.22% |
| 2023 | 4.5% | 2.7% | 1.4% | 9.9% | 0.27% |
| 2024 | 4.5% | 2.7% | 1.4% | 11.7% | 0.33% |
| 2025 | 4.5% | 2.7% | 1.4% | 13.4% | 0.38% |
| 2026 | 4.5% | 2.7% | 1.4% | 15.0% | 0.43% |
| 2027 | 4.5% | 2.7% | 1.4% | 16.6% | 0.49% |
| 2028 | 4.5% | 2.7% | 1.4% | 18.1% | 0.54% |
| 2029 | 4.5% | 2.7% | 1.4% | 18.1% | 0.54% |
| 2030 | 4.5% | 2.7% | 1.4% | 18.1% | 0.54% |
| 2031 | 4.5% | 2.7% | 1.4% | 18.1% | 0.54% |
| 2032 | 4.5% | 2.7% | 1.4% | 18.1% | 0.54% |
| 2033 | 4.5% | 2.7% | 1.4% | 18.0% | 0.54% |
| 2034 | 4.5% | 2.7% | 1.4% | 18.0% | 0.54% |
| 2035 | 4.5% | 2.7% | 1.4% | 18.0% | 0.54% |
| 2036 | 4.5% | 2.7% | 1.4% | 18.0% | 0.54% |
| 2037 | 4.5% | 2.7% | 1.4% | 18.0% | 0.54% |
| 2038 | 4.5% | 2.7% | 1.4% | 17.9% | 0.54% |
| 2039 | 4.5% | 2.7% | 1.4% | 17.9% | 0.54% |
| 2040 | 4.5% | 2.7% | 1.4% | 17.9% | 0.54% |
| 2041 | 4.5% | 2.7% | 1.4% | 17.9% | 0.54% |
| 2042 | 4.5% | 2.7% | 1.4% | 17.9% | 0.54% |
| 2043 | 4.5% | 2.7% | 1.4% | 17.9% | 0.54% |
| 2044 | 4.5% | 2.7% | 1.4% | 17.8% | 0.54% |
| 2045 | 4.5% | 2.7% | 1.4% | 17.8% | 0.54% |
| 2046 | 4.5% | 2.7% | 1.4% | 17.8% | 0.54% |
| 2047 | 4.5% | 2.7% | 1.4% | 17.8% | 0.54% |
| 2048 | 4.5% | 2.7% | 1.4% | 17.8% | 0.54% |

## 17-A.3 NIA-RIA INTEGRATED MODEL

For this analysis, DOE used its integrated NIA-RIA[a] model approach that built on the NIA model discussed in Chapter 10 and documented in Appendix 10-A.The resulting integrated NIA-RIA model featured both the NIA analysis inputs and results and the RIA inputs and had the capability to generate results for each of the RIA policies. A separate module produced results summaries for the tables and figures in the RIA document. For the RIA methodology documentation in Chapter 17, the module created summaries of parameters calculated by the model for the consumer rebates policy, generated its penetration curves (discussed in Section 17-A.4.3 below), and reported market share impacts for the rebate and tax credit policies by product class. For the RIA results reported in Chapter 17, the module produced graphs of the market share increases resulting from each of the policies analyzed and created summary tables for the national energy savings (NES) and net present value (NPV) results. This module also generated tables of market share increases for each policy reported in Section 17-A.2 of this Appendix.

## 17-A.4 CONSUMER REBATE POLICY MARKET PENETRATION CURVES

This section first discusses the theoretical basis for the market penetration curves that DOE used to analyze the Consumer Rebates policy. 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 each specific product class and efficiency level in the analysis. The resulting curves for standard-sized residential dishwashers product classes are in Chapter 17.

### 17-A.4.1 Introduction

XENERGY, Inc.[b], 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.

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

---

[a] NIA = national impact analysis; RIA = regulatory impact analysis

[b] XENERGY is now owned by KEMA, Inc. (www.kema.com)

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 17-A.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 17-A.4.1).

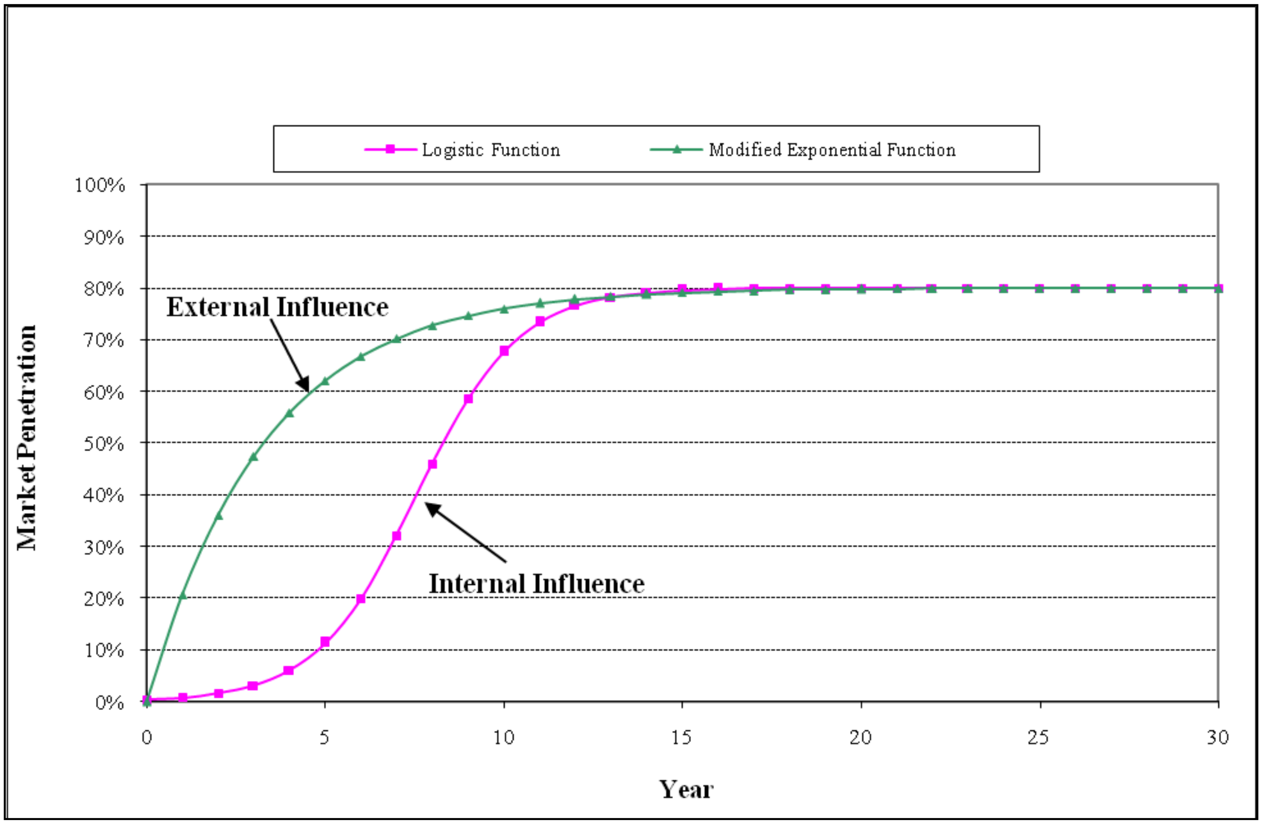


**Figure 17-A.4.1 S-Curves Showing Effects of External and Internal Sources on Adoption of New Technologies**

### 17-A.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 base case market shares of the target-level technology.

### 17-A.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.[c] 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.[d] 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.

---

[c] The RIA chapter refers to these curves as *penetration curves*. This section, in references to the original source, uses the term *implementation curve*.

[d] 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 can be considered proportional to the rebate impacts.

## 17-A.5 CONSUMER REBATE PROGRAMS

DOE performed a search for rebate programs that offered incentives for standard-sized residential dishwashers. Some organizations nationwide, comprising electric utilities and regional agencies, offer rebate programs for this equipment. Table 17-A.5.1 provides the organizations' names, states, rebate amounts, and program websites. If there is more than one entry for an organization, it offers different rebates in different states. When an organization offers rebates through several utilities, it is represented only once in each table.

DOE calculated the rebate amount it used in its analysis of the Rebates policy case from a sample of 63 rebates from 57 organizations. The rebate amount DOE calculated for commercial clothes washers is $34.03 (in 2013$). This amount refers to the simple average of the individual amounts offered by the programs reported in Table 17-A.5.1.

**Table 17-A.5.1 Rebates for Standard- Sized Residential Dishwashers**

| Organization | State | Rebate | Website |
|---|---|---|---|
| Empire | AR | $50 | https://www.empiredistrict.com/Dochandler.ashx?id=5780 |
| Burbank Water and Power | CA | $35 | http://www.burbankwaterandpower.com/incentives-for-residents/residential-rebates-home-rewards |
| Burbank Water and Power | CA | $20 | http://www.burbankwaterandpower.com/incentives-for-residents/residential-rebates-home-rewards |
| City of Lompoc | CA | $50 | http://www.cityoflompoc.com/utilities/conservation/ |
| City of Glendale Water & Power (GWP) | CA | $40 | http://www.glendalewaterandpower.com/save_money/residential/sh_energy_saving_rebates.aspx |
| City of Glendale Water & Power (GWP) | CA | $30 | http://www.glendalewaterandpower.com/save_money/residential/sh_energy_saving_rebates.aspx |
| City of Hercules | CA | $50 | http://www.ci.hercules.ca.us/index.aspx?page=157 |
| Lassen Municipal Utility District | CA | $35 | http://www.lmud.org/help/rebate-center/ |
| Pacific Power | CA | $20 | http://dsireusa.org/incentives/incentive.cfm?Incentive_Code=CA187F&re=0&ee=0 |
| Plumas-Sierra Rural Electric | CA | $35 | http://www.psrec.coop/downloads/Appliance_Rebate.pdf |
| City of Riverside | CA | $50 | http://www.greenriverside.com/Green-Rebate-Programs-7/Residential/Energy-Efficiency-112/Rebate-135/Energy_Star_ |
| SMUD | CA | $50 | https://www.smud.org/en/residential/save-energy/rebates-incentives-financing/appliances/index.htm |
| Truckee Donner public Utility District | CA | $75 | http://www.tdpud.org/departments/conservation/residential/rebates-for-your-home |
| Colorado Springs Utilities | CO | $50 | https://www.csu.org/Pages/Dishwashers.aspx |
| Delta-Montrose Electric Association (DMEA) | CO | $30 | http://www.dmea.com/index.php?option=com_content&view=article&id=74&Itemid=107 |
| Empire Electric Association, Inc. | CO | $30 | http://eea.coop/energy-efficiency.html |
| City of Fort Collins | CO | $25 | http://www.fcgov.com/utilities/residential/conserve/water-efficiency/clothes-washer-dishwasher-rebates/ |
| Gunnison County Electric Associaton, Inc (GCEA) | CO | $45 | http://www.dsireusa.org/incentives/incentive.cfm?Incentive_Code=CO158F&currentpageid=3&EE=1&RE=0 |
| La Plata Electric Association, Inc | CO | $40 | http://www.lpea.com/rebates_credits/appliance_rebate.html |
| Morgan Country REA | CO | $50 | http://www.mcrea.org/Energy_Center/Energy_Efficiency_Credit_Information/index.html |
| Mountain View Electric Association, Inc | CO | $30 | http://www.mvea.coop/residence/energy-efficiency-rebates/ |
| Pudre Valley REA | CO | $30 | http://www.pvrea.com/rebates/dishwasher |

| Organization | State | Rebate | Website |
|---|---|---|---|
| San Miguel Power Association | CO | $60 | http://smpa.coopwebbuilder2.com/sites/smpasmpa/files/PDF/Rebates/Energy%20Star%20Appliance%20Rebate%20Application.pdf |
| Sangre de Cristo Electric Association, Inc. | CO | $40 | http://www.myelectric.coop/products/eec.cfm |
| Southeast Colorado Power Association | CO | $40 | http://secpa.com/products-services/appliances/ |
| United Power | CO | $30 | http://www.unitedpower.com/mainNav/yourEnergyOptions/rebate/applianceRebate.aspx |
| Xcel Energy | CO | $15 | http://www.xcelenergy.com/Save_Money_&_Energy/Residential/Home_Efficiency/Home_Performance_with_ENERGY_STAR_-_CO |
| OCALA Utility Services | FL | $75 | http://www.ocalafl.org/uploadedFiles/Utility_Services_Redesign/Forms_and_Documents/Rebate-Form-Dishwasher.pdf |
| Rocky Mountain Power | ID | $20 | http://www.homeenergysavings.net/homeowner/category/appliances/in/utah/incentives-appliances?region=utah |
| Bright Energy Solutions (offered by 16 utilities) | IA | $25 | http://www.brightenergysolutions.com/municipalities/?category=home&state=ia |
| Central Iowa Power Cooperative (CIPCO) (offered by 12 utilities) | IA | $25 | http://swiarec.coopwebbuilder.com/content/residential-incentives |
| City of Ames | IA | $50 | http://www.cityofames.org/index.aspx?page=998 |
| Muscatine Power and Water | IA | $25 | http://www.mpw.org/greenmuscatine/rebates.aspx |
| Kentucky Utilities Company (KU) | KY | $50 | http://www.lge-ku.com/rebate/home/default.asp |
| Louisville Gas & Electric (LG&E) | KY | $50 | http://www.lge-ku.com/rebate/home/default.asp |
| MuniHelps (offered by 16 utilities) | MA | $25 | http://www.munihelps.org/energy-rebate-programs.html |
| Town of Concord | MA | $50 | http://www.concordma.gov/pages/ConcordMA_LightPlant/appliance |
| Reading Municipal Light Department | MA | $50 | http://www.rmld.com/sites/rmld/files/file/file/rebate.pdf |
| Taunton Municipal Lighting Plant (TMLP) | MA | $25 | http://www.tmlp.com/page.php?content=appliance_rebates |
| Wakefield Municipal Gas and Light Department (WMGLD) | MA | $50 | http://www.wmgld.com/specialprograms.php |
| Wellesley Municipal Light Plant | MA | $25 | http://www.wellesleyma.gov/pages/WellesleyMA_WMLP/Application%202014%201%20page.pdf |
| Energy Optimization (offered by 11 utilities) | MI | $25 | http://www.michigan-energy.org/thumbproducts |
| Minnesota Valley Electric Cooperative | MN | $25 | http://www.mvec.net/residential/efficiency-rebates/ |

| **Organization** | **State** | **Rebate** | **Website** |
|---|---|---|---|
| South Central Electric Association (SCE) | MN | $15 | http://southcentralelectric.com/content/forms-and-applications |
| Missouri River Energy Services (23 Member Cooperatives) | MN | $25 | http://www.brightenergysolutions.com/municipalities/?category=home&state=mn |
| Alliant Energy | MN | $15 | http://www.alliantenergy.com/SaveEnergyAndMoney/Rebates/HomeMN/030051 |
| Anoka Municipal Utility | MN | $25 | http://www.anokaelectric.govoffice3.com/index.asp?Type=B_BASIC&SEC={016973E4-8F48-44F8-846C-C4EA4CA5C71D} |
| Southern Minnesota Municipal Power Agency (offered by 18 utilities) | MN | $25 | http://smmpa.org/members/lake-city-utilities/home-services/energy-star%C2%AE-for-your-home-(1).aspx |
| New Ulm Minnesota | MN | $25 | http://www.ci.new-ulm.mn.us/index.asp?SEC=743A5650-3018-4B6E-B7B0-662834287912&DE=89E00F68-1EF5-4A75-BECE-E3DE07703621&Type=B_BASIC |
| Shakopee Public Utilities | MN | $25 | http://spucweb.com/wp-content/uploads/2014-Residential-Rebates-Appliances.pdf |
| Willmar Municipal Utilities | MN | $50 | http://wmu.willmar.mn.us/main/index.php?option=com_content&view=category&layout=blog&id=58&Itemid=255 |
| Yellowstone Valley Electric Cooperative | MT | $25 | http://www.yvec.com/member-programs/energy-star-rebates/ |
| Central New Mexico Electric Cooperative, Inc. | NM | $30 | http://cnmec.org/index.php?page=rebates |
| Four County Electric Membership Corporation | NC | $50 | http://www.fourcty.org/index.php?p=5&s=79 |
| Bright Energy Solutions (offered by 5 utilities) | ND | $25 | http://www.brightenergysolutions.com/municipalities/?category=home&state=nd&municipality=62 |
| City of Ashland | OR | $25 | http://www.ashland.or.us/Page.asp?NavID=14039 |
| Duquesne Light | PA | $24 | http://www.rebate-zone.com/default.asp?PN=DL0278 |
| Bright Energy Solutions (offered by 11 utilities) | PA | $25 | http://www.brightenergysolutions.com/municipalities/?category=home&state=sd |
| CoServ | TX | $15 | http://www.coserv.com/TogetherWeSave/2014ResidentialRebates/ENERGYSTARDishwasher/tabid/328/Default.aspx |
| Rocky Mountain Power | UT | $10 | https://www.rockymountainpower.net/res/sem/utah/esnh/bi.html |
| Collumbia REA | WA | $15 | http://www.columbiarea.com/content/rebate-offers |
| Barron Electric | WI | $25 | http://www.barronelectric.com/content/appliance-and-recycling |
| Rocky Mountain Power | WY | $20 | http://www.homeenergysavings.net/homeowner/category/appliances/in/wyoming/dishwashers |

## 17-A.6 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.

### 17-A.6.1 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, 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 distributor 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 any 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. 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.

### 17-A.6.2 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.[20]

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.[21]

### 17-A.6.3 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.[22, 23] 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).[22, 24]

Montana has had an Energy Conservation Tax Credit for residential measures since 1998.[25] 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.

## REFERENCES

1. Rufo, M. and F. Coito, *California's Secret Energy Surplus: The Potential for Energy Efficiency*, 2002. XENERGY Inc. (Last accessed March, 2013.) <http://www.issuelab.org/resource/californias_secret_energy_surplus_the_potential_for_energy_efficiency>

2. Hall, B. H. and B. Khan, Adoption of New Technology. *Working Paper No. E03-330*, 2003

3. Lekvall. P and C. Wahlbin, "A Study of Some Assumptions Underlying Innovation Diffusion Functions". *Swedish Journal of Economics*, 1973

4. Geroski, P. A., Models of Technology Diffusion. *Research Policy*, 2000. 29: pp. 603-625

5. Van den Bulte, C., "Want to Know How Diffusion Speed Varies Across Countries and Products? Try a Bass Model". *Product Development & Management Association*, 2002. XXVI(4)

6. Rufo, M., Telephone Conversation with Barbara Atkinson of LBNL, *personal communication.* Itron, Inc. January 2008 and March 2009.

7. Blum, H., Atkinson B., and Lekov, A., *A Framework for Comparative Assessments of Energy Efficiency Policy Measures*, May, 2011.

8. Tax Incentives Assistance Project, *Consumer Tax Incentives: Home Heating & Cooling Equipment.*, 2011. (Last accessed March, 2013.) <www.energytaxincentives.org/consumers/heating-cooling.php>

9. *Energy Policy Act of 2005*, in *119 STAT. 594 Public Law 109-58. Section 1333, 26 USC 25C note*,. 2005. http://www.gpo.gov/fdsys/pkg/BILLS-109hr6pcs/pdf/BILLS-109hr6pcs.pdf

10. *American Recovery and Reinvestment Act of 2009*, 2009. Government Printing Office. (Last accessed March, 2013.) <http://frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=111_cong_bills&docid=f:h1enr.pdf>

11. Tax Incentives Assistance Project, *The Tax Incentives Assistance Project (TIAP)*, 2013. (Last accessed March, 2013.) <http://energytaxincentives.org/>

12. Foster, R., J. Grevatt, N. Lange, and T. Gee, *Efficiency Programs and Distributors: Opportunities to Fully Leverage the Supply Chain for Greater Impact*, August 12-17, 2012. American Council for an Energy-Efficient Economy. Asilomar, CA. <http://www.aceee.org/files/proceedings/2012/data/papers/0193-000198.pdf>

13. Tusa, C. S., D. Pierson, P. Mammola, and J. P. Vora, *JPM/HARDI 2011 HVAC Survey*, 2011. <http://www.hardinet.org/mid-season-hvac-distributor-survey>

14. Internal Revenue Service, *SOI Tax Stats - Individual Income Tax Returns, Estimated Data Line Counts*, (Last accessed March, 2013.) <http://www.irs.gov/pub/irs-soi/10inlinecount.pdf>

15. Internal Revenue Service, *1979 Annual Report*, *Commissioner of Internal Revenue*, (Last accessed March, 2013.) <http://www.irs.gov/pub/irs-soi/79dbfullar.pdf>

16. Internal Revenue Service, *1980 Annual Report*, *Commissioner of Internal Revenue.*, (Last accessed March, 2013.) <http://www.irs.gov/pub/irs-soi/80dbfullar.pdf>

17. Internal Revenue Service, *1981 Annual Report: Commissioner of Internal Revenue and the Chief Counsel for the Internal Revenue Service*, (Last accessed March, 2013.) <http://www.irs.gov/pub/irs-soi/81dbfullar.pdf>

18. U.S. Department of the Treasury–Internal Revenue Service, *Form 8909: Energy Efficient Appliance Credit*, (Last accessed March, 2013.) <www.irs.gov/pub/irs-pdf/f8909.pdf>

19. *Emergency Economic Stabilization Act of 2008*, (Last accessed September, 2011.) <http://www.gpo.gov/fdsys/pkg/PLAW-110publ343/pdf/PLAW-110publ343.pdf>

20. Database of State Incentives for Renewables and Efficiency (DSIRE), *Energy-Efficient Appliance Manufacturing Tax Credit*, 2013. (Last accessed March, 2013.) <http://www.dsireusa.org/incentives/incentive.cfm?Incentive_Code=US42F&re=1&ee=1&utm_source=FEB2013+DSIRE+NNL&utm_campaign=February2013&utm_medium=email>

21. Tax Incentives Assistance Project, *Manufacturers Incentives*, (Last accessed March, 2013.) <http://energytaxincentives.org/builders/appliances.php>

22. Database of State Incentives for Renewables and Efficiency (DSIRE), *Oregon Incentives/Policies for Renewable Energy*, *Residential Energy Tax Credit*, 2013. (Last accessed March, 2013.) <http://www.dsireusa.org/incentives/incentive.cfm?Incentive_Code=OR17F&re=1&ee=1>

23. Oregon Department of Energy, *HB 3672 (2011)Tax Credit Extension Bill*, 2013. <http://www.oregon.gov/energy/CONS/docs/HB3672summary.pdf>

24. Oregon Department of Energy, *ODOE: Energy Conservation*, *Heat Pumps and Air Conditioning Systems*, 2013. <http://www.oregon.gov/energy/CONS/docs/HB3672summary.pdf>

25. Montana Department of Revenue, *Energy Related Tax Relief: Energy Conservation Installation Credit*, (Last accessed March, 2013.) <http://revenue.mt.gov/home/individuals/taxrelief_energy>