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

DISHWASHERS

January 2022

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Assistant Secretary
Office of Energy Efficiency and Renewable Energy
Building Technologies Program
Appliances and Commercial Equipment Standards
Washington, DC 20585

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EXECUTIVE SUMMARY

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EXECUTIVE SUMMARY

ES.1 INTRODUCTION

This preliminary technical support document (TSD) describes in detail the approaches to and results of preliminary activities that the U.S. Department of Energy (DOE) performed in investigating amended energy conservation standards for dishwashers. This executive summary summarizes DOE's preliminary activities and results. Additionally, this executive summary delineates issues identified during the analyses about which DOE seeks comments from interested parties. Those issues are highlighted in the public meeting presentation and are discussed further in chapter 2 of the preliminary TSD.

ES.2 SUMMARY OF THE PROCESS

Section 6295(o)(2)(A) of the Energy Policy and Conservation Act (EPCA),[a] Public Law 94-163 (42 U.S.C. 6291−6317, as codified) requires DOE to establish energy conservation standards that achieve the maximum improvement in energy efficiency that is technologically feasible and economically justified. (42 U.S.C. 6295(o)(2)(A)) DOE establishes those standards during rulemakings for energy-consuming consumer and industrial products. When evaluating the potential need for amendments to standards. DOE presents the initial analytical results in a preliminary TSD such as this one. DOE publishes in the *Federal Register* a notice that announces the date and place of a public meeting, as well as the availability of the preliminary TSD and presentation materials that interested parties may review before the meeting. The notice also highlights the major analyses DOE performed in this preliminary stage.

Chapter 1 of this preliminary TSD summarizes DOE's appliance standards program and how it applies to this action, and then outlines the structure of this document. Chapter 2 of the preliminary TSD summarizes the analytical framework for this evaluation. Subsequent chapters describe in detail the preliminary analyses performed at this stage. Descriptions include inputs, sources, methods, and results.

ES.3 KEY ANALYSES AND RESULTS

The following sections summarize the key analyses DOE performed and the results obtained in developing this preliminary TSD.

ES.3.1 Market and Technology Assessment

When initiating an analysis of potential energy conservation standards for appliances, DOE obtains information on the present and past industry structure and market characteristics for the products concerned. DOE assesses industries and products both quantitatively and qualitatively, based on publicly available information.

[a] All references to EPCA in this document refer to the statute as amended through the Energy Act of 2020, Public Law 116-260 (Dec. 27, 2020).

For this preliminary analysis, DOE addressed (1) manufacturer market share and characteristics, (2) existing regulatory and non-regulatory initiatives for improving product efficiency, and (3) trends in product characteristics and retail markets. This data and resource material were used throughout the analysis.

DOE reviewed available public literature to develop an overall understanding of the dishwasher industry in the United States. In particular, DOE sought information on: (1) major and minor manufacturers, (2) shipments estimates, and (3) industry trends. Chapter 3 of the preliminary TSD describes the market analysis and resulting information.

DOE typically uses information about existing and past technology options and working prototype designs to determine which technologies and combinations of technologies manufacturers use to attain higher performance levels. In consultation with interested parties, DOE develops a list of technologies to be considered.

DOE developed a list of technologies for dishwashers from trade publications, technical papers, manufacturer literature, and through consultation with manufacturers of components and systems. Because existing products contain many technologies for improving product efficiency, product literature and direct examination provided additional information.

ES.3.2 Screening Analysis

The screening analysis examines whether technologies identified in the technology assessment: (1) are technologically feasible; (2) are practicable to manufacture, install, and service; (3) have an adverse impact on product utility or availability; (4) have adverse impacts on health and safety; and/or (5) utilize proprietary technology that represents a unique pathway to achieving a given efficiency level. In the subsequent engineering analysis, DOE further examined the technology options that it did not remove from consideration in the screening analysis. Chapter 4 of the preliminary TSD contains details on the screening analysis for dishwashers.

ES.3.3 Engineering Analysis

The engineering analysis establishes the relationship between the costs of manufacturing dishwashers and their efficiencies. These relationships serve as the basis for calculating costs and benefits of modified product designs for consumers, manufacturers, and the Nation. Chapter 5 of the preliminary TSD describes the product classes DOE analyzed, the representative baseline units, the efficiency levels DOE considered, the methodology DOE used to develop the manufacturing production cost model, and the cost-efficiency results.

ES.3.3.1 Product Classes Analyzed

When evaluating and establishing energy conservation standards, DOE may establish separate standards for a group of covered products (*i.e.*, establish a separate product class) if

DOE determines that separate standards are justified based on the type of energy used, or if DOE determines that a product's capacity or other performance-related feature justifies a different standard. (42 U.S.C. 6295(q)(1)(A) and (B)) In making a determination whether a performance-related feature justifies a different standard, DOE must consider factors such as the utility to the consumer of the feature and other factors DOE determines are appropriate. (42 U.S.C. 6295(q)(1))

For dishwashers, the current energy conservation standards specified in Title 10 of the Code of Federal Regulations (CFR), section 403.32(f) are based on two product classes, shown in Table ES.3.3.1 below, and are differentiated by capacity.

Table ES.3.3.1 Dishwasher Product Classes

1. Standard Product Class with capacity equal to or greater than eight place settings plus six serving pieces
2. Compact Product Class with capacity less than eight place settings plus six serving pieces

Additionally, in a final rule published on October 30, 2020, DOE established a new product class for dishwashers that includes standard-size dishwashers with a "normal cycle" of 60 minutes or less, that are not currently subject to energy or water conservation standards. Subsequently, on August 11, 2021, DOE published a notice of proposed rulemaking (NOPR) that proposes to revoke the final rule that established the new short-cycle product class for dishwashers. 86 FR 43970. Thereafter, on January 11, 2022, DOE issued a final rule which revoked the final rule that established the new product class for dishwashers.[b] Accordingly, DOE is not considering the new short-cycle product class in the preliminary analysis.

revoking the final rule that established a new product class for dishwashers. Accordingly, potential standards for the new product class of dishwashers are not addressed in the present process.

ES.3.3.2 Efficiency Levels Defined

For each analyzed product class, DOE selects a baseline model as a reference point against which any changes resulting from energy conservation standards can be measured. The baseline model in each product class represents the characteristics of common or typical products in that class. Typically, a baseline model is one that just meets the current minimum energy conservation standards. The current dishwasher standard for energy consumption is based on 215 annual dishwasher cycles, which is the number of cycles specified in the current dishwasher test procedure at 10 CFR 430, Subpart B, Appendix C1 (Appendix C1). However, in the dishwasher test procedure NOPR published on December 22, 2021, DOE proposed to adopt a new dishwasher test procedure, Appendix C2, which would be applicable upon the compliance date of any future amended conservation standards. 86 FR 72738. Appendix C2 proposes to update

[b] https://www.energy.gov/sites/default/files/2022-01/short-cycle-product-class-fr.pdf

the annual dishwasher cycles to 184 cycles/year. Accordingly, for this preliminary analysis, DOE considered the current standards for dishwashers established in 10 CFR 430.32(f) as the baseline efficiency level for each product class after adjusting the standard for 184 cycles/year.

DOE also analyzed four higher efficiency levels, including the qualification criteria specified in ENERGY STAR Product Specification for Residential Dishwashers, Version 6.0 (hereinafter, ENERGY STAR V. 6.0),[1] ENERGY STAR Most-Efficient,[2] and a maximum technologically feasible (max-tech) level, for the standard product class, and two higher efficiency levels, including the qualification criteria specified in ENERGY STAR V. 6.0 and a max-tech level, for the compact product class, consistent with products and design options available on the market. Table ES.3.3.2, and Table ES.3.3.3, provide the efficiency levels, based on the annual energy use in kilowatt hours per year (kWh/year), and per-cycle water use in gallons per cycle (gal/cycle).

Table ES.3.3.2 Efficiency Levels for Standard Product Class Dishwashers

Efficiency Level	Annual Energy Use* *(kWh/year)*	Per-Cycle Water Consumption *(gal/cycle)*
0 – Baseline	263	5.00
1 – ENERGY STAR V. 6.0	232	3.50
2 – Gap-fill	223	3.30
3 – ENERGY STAR Most Efficient	206	3.20
4 – Max-Tech	193	2.40

* Using 184 annual cycles.

Table ES.3.3.3 Efficiency Levels for Compact Product Class Dishwashers

Efficiency Level	Annual Energy Use* *(kWh/year)*	Per-Cycle Water Consumption *(gal/cycle)*
0 – Baseline	178	3.50
1 – ENERGY STAR V. 6.0	174	3.10
2 – Max-Tech	124	1.60

* Using 184 annual cycles.

Chapter 5 of the preliminary TSD includes additional details on how DOE developed the efficiency levels for its analysis.

ES.3.3.3 Manufacturer Costs

DOE typically uses data submitted by the Association of Home Appliance Manufacturers (AHAM) as the primary source of cost information for the engineering analysis. In the absence of aggregated incremental manufacturing cost data for dishwashers, however, DOE relied primarily on its detailed efficiency-level and reverse-engineering approaches to determine the manufacturer product cost (MPC) required to achieve higher efficiency levels. This analysis consists of disassembling representative units, analyzing the materials and manufacturing processes, analyzing the design approaches manufacturers use, and developing a spreadsheet analysis to ascribe costs to the various designs. Chapter 5 of the preliminary TSD includes information on the inputs used to determine the incremental MPC.

DOE's engineering analysis produced cost-efficiency curves for each of the analyzed dishwasher product classes. The cost-efficiency curves are described by the efficiency levels DOE analyzed and the increase in MPC required to improve a baseline-efficiency product to each of the considered efficiency levels. Table ES.3.3.4 and Table ES.3.3.5 present the results of the engineering analysis for dishwashers.

Table ES.3.3.4 Standard Dishwasher Incremental Manufacturing Costs

Efficiency Level	Annual Energy Use *(kWh/year)*	Water Consumption *(gal/cycle)*	Incremental Costs *($2020)*
Baseline	263	5.0	$ -
EL 1	232	3.5	$ 18.27
EL 2	223	3.3	$ 27.53
EL 3	206	3.2	$ 71.12
EL 4	193	2.4	$ 113.86

Table ES.3.3.5 Compact Dishwasher Incremental Manufacturing Costs

Efficiency Level	Annual Energy Use *(kWh/year)*	Water Consumption *(gal/cycle)*	Incremental Costs *($2020)*
Baseline	178	3.50	$ -
EL 1	174	3.10	$ -
EL 2	124	1.60	$ 37.41

ES.3.4 Markups to Determine Product Price

In chapter 6 of this preliminary TSD, DOE calculates the markups to manufacturer selling prices (MSPs) that occur throughout the distribution channels for dishwashers, converting the estimated manufacturer costs derived from the engineering analysis to consumer prices. In calculating markups, DOE identified the distribution channels for dishwashers and the markup associated with each step in the channels. The manufacturer markup converts MPC to MSP. DOE developed an average manufacturer markup by examining the annual Securities and Exchange Commission (SEC) 10-K reports filed by publicly traded manufacturers primarily engaged in appliance manufacturing. DOE estimated the markups taken by retailers and also included sales taxes. DOE developed separate retailer markups for baseline products (baseline markups) and for the incremental cost attributable to more expensive, more efficient products (incremental markups). Table ES.3.4.1 summarizes the markups DOE developed for the prices consumers pay for dishwashers.

Table ES.3.4.1 Markups for Determining Dishwashers Product Price

Distribution Step	Markup	
	Baseline	**Incremental**
Manufacturer	1.24	
Retailer	1.49	1.24
Wholesaler	1.35	1.20
General Contractor	1.38	1.27
Sales Tax	1.0728	
Overall	1.92	1.59

ES.3.5 Energy and Water Use Analysis

To conduct the life-cycle cost (LCC) and payback period (PBP) analyses, DOE must determine the operating cost savings to consumers from using more efficient products. The goal of the energy and water use analysis is to determine the annual energy and water consumption of dishwashers for use in the LCC and PBP analyses. Energy and water use characterizations generate a range of energy and water use values that reflect real-world dishwasher use in American homes. By incorporating data on how dishwashers are used by U.S. consumers, DOE can estimate the energy and water that would be consumed (or potentially saved) by units having various efficiency levels.

To establish a reasonable range of energy consumption in the field for dishwashers, DOE primarily used data from the Energy Information Administration (EIA)'s *2015 Residential Energy Consumption Survey* (*RECS 2015*).[3] *RECS* is a national sample survey of housing units that collects statistical information on the consumption of and expenditures for energy in housing units along with data on energy-related characteristics of the housing units and occupants. *RECS 2015* collected data on 5,686 housing units and was constructed by EIA to be a national representation of the household population in the United States. DOE's assumptions for establishing a consumer dishwasher sample included the following considerations.

- The household had and used a dishwasher.
- Dishwasher use was greater than zero.

The energy and water use analysis requires DOE to establish a range of total annual usage or number of cycles in order to estimate annual energy consumption by a dishwasher unit. DOE estimated the number of dishwasher cycles per year for each sample household using data given by *RECS 2015* on the number of loads washed per week at 185 cycles per year.

Table ES.3.5.1 presents the energy and water use estimated at each efficiency level that DOE is considering for dishwashers.

Table ES.3.5.1 Dishwashers: Average Annual Energy Use by Efficiency Level

Efficiency Level	PC 1: Standard-Sized				
	Annual Electricity Use (kWh/yr)	Annual Natural Gas Use (MMBtu/yr)	Annual Liquid Petroleum Gas Use (MMBtu/yr)	Annual Distillate Oil Use (MMBtu/yr)	Annual Water Use (1000 gal/yr)
0	173	0.32	0.03	0.02	0.92
1	169	0.22	0.02	0.01	0.64
2	164	0.21	0.02	0.01	0.60
3	148	0.21	0.02	0.01	0.59
4	150	0.15	0.01	0.01	0.44
	PC 2: Compact				
0	115	0.22	0.02	0.01	0.64
1	119	0.20	0.02	0.01	0.57
2	95	0.10	0.01	0.01	0.29

ES.3.6 Life-Cycle Cost and Payback Period Analysis

DOE analyzed the net financial effect on consumers of potential standards for dishwashers by evaluating the LCC and PBP of the product (chapter 8 of this preliminary analysis TSD). In performing this analysis, DOE used the cost-efficiency relationship derived from the engineering and markups analyses, along with the energy and water costs derived from the energy and water use characterization. Because the operating costs of a more expensive, higher-efficiency product may decrease in response to new standards, at some time in the life of that product the net savings in operating costs since the time of purchase equal the increase in the purchase price of the product. The time required for a product to reach that cost-equivalency point is known as the PBP. DOE's analysis produces a simple PBP based on using single-point average values to estimate the purchase price and undiscounted first-year operating cost.

DOE identified several inputs for estimating the LCC and simple PBP, including retail prices and installation costs, energy and water prices, discount rates, and product lifetimes. DOE examined installation, maintenance, and repair costs for the efficiency levels considered in this preliminary analysis. Typically, incremental changes in energy efficiency produce no, or only minor, changes in installation, repair, and maintenance costs over baseline efficiency products. The LCC and simple PBP analysis utilized values that reflect unit energy consumption in the field. For electricity and natural gas prices, DOE used marginal and average prices which vary by season and region. DOE estimated regional monthly electricity prices for 2020 using data published from Form 861-M.[4] For natural gas prices, DOE obtained 2020 data for calculating regional monthly prices of natural gas from the EIA publication, *Natural Gas Navigator*.[5] EIA provides historical monthly natural gas consumption and expenditures by state. These data were used to determine 10-year average summer and winter marginal prices factors for the *RECS 2015* geographical areas, which are then used to convert average monthly energy prices into marginal monthly energy prices. For liquid petroleum gas (LPG) and distillate oil, DOE collected 2019 average LPG and distillate oil prices from EIA's State Energy Consumption, Price, and Expenditures Estimates (SEDS). DOE assigned an average price to all sampled households based on each household's location and its baseline energy consumption. For sampled households that were assigned a product efficiency that is greater than or equal to the efficiency of the considered efficiency level, DOE assigned a marginal price to each household based on its location and the reduction in energy consumption. DOE then used projections of the prices from EIA's *Annual Energy Outlook* (*AEO*) 2021[6] to estimate future electricity, natural gas, LPG and distillate oil prices.

DOE obtained the most recent, complete dataset on public supply water and wastewater prices from the *2016 Water and Wastewater Rate Survey* conducted by Raftelis Financial Consultants and the American Water Works Association.[7] DOE also developed water prices for consumers who rely on private well water systems for their water needs rather than the public supply system based on the historical data of *American Housing Survey* (*AHS*).[8] DOE then used historic trend of national water price index (U.S. city average) to extrapolate and to forecast 2027 water and wastewater prices.[9]

DOE developed discount rates by estimating the finance cost for consumers to purchase appliances. For each product class, DOE developed samples of individual households that use dishwashers. By developing such samples, DOE was able to calculate the LCC to account for the variability in energy consumption and electricity price among users of dishwashers.

DOE used probability distributions to characterize discount rates and product lifetimes. DOE developed discount rates for consumers that purchase dishwashers. DOE developed discount rates from estimates of the interest rate, or finance cost, applied to purchases of consumer products. Following accepted principles of financial theory, the finance cost of raising funds to purchase products can be interpreted as (1) the financial cost of any debt incurred by the purchase, principally interest charges on debt; or (2) the opportunity cost of any equity used for the purchase, principally forfeited interest earnings on household equity. The average lifetime assumed is 15.2 years.

To estimate the percentage of consumers who would be affected by a standard at each efficiency level, the LCC analysis considered the projected distribution of efficiencies for dishwashers purchased under the no-new-standards case. To account for the variability in energy consumption and energy prices among users, DOE developed samples of individual households that use dishwashers. Using the projected distribution of efficiencies for each product class, DOE assigned a specific product efficiency to each sample household. If a household was assigned a product efficiency that equaled or exceeded the efficiency of the efficiency level under consideration, the LCC calculation showed that the household would be unaffected by that standard level.

Table ES.3.6.1 through Table ES.3.6.4 show the LCC and simple PBP results for consumer dishwasher product classes by efficiency level.

Table ES.3.6.1 Summary of LCC and PBP Results by Efficiency Level for Standard-Sized Dishwashers

EL	Average Costs *(2020$)*				Simple Payback *(Years)*	Average Lifetime *(Years)*
	Installed Cost	First Year Operating Cost	Lifetime Operating Cost	LCC		
Baseline	$441	$57	$672	$1,113		15.2
1	$469	$52	$612	$1,081	5.9	15.2
2	$484	$51	$597	$1,080	7.0	15.2
3	$551	$49	$568	$1,119	12.9	15.2
4	$617	$47	$542	$1,159	16.7	15.2

Note: The average LCC, LCC savings, and simple PBP for each efficiency level are calculated assuming that all consumers use products having the given efficiency level. Thus, results for all efficiency levels can be compared under the same conditions.

Table ES.3.6.2 Summary of Life-Cycle Costs Relative to the No-New-Standards Case Efficiency Distribution for Standard-Sized Dishwashers

EL	Life-Cycle Costs and Savings	
	Average Savings *(2020$)*	Percent of Consumers Who Experience Net Cost
1	$32	3%
2	$4	43%
3	($35)	77%
4	($72)	88%

Note: The LCC savings for each efficiency level are calculated relative to the no-new-standards case efficiency distribution. The calculation includes households that experience zero LCC savings (no impact).

Table ES.3.6.3 Summary of LCC and PBP Results by Efficiency Level for Compact Dishwashers

CSL	Average Costs *(2020$)*				Simple Payback *(Years)*	Average Lifetime *(Years)*
	Installed Cost	First Year Operating Cost	Lifetime Operating Cost	LCC		
Baseline	$485	$44	$519	$1,004		
1	$485	$44	$511	$996	0.0	15.2
2	$543	$36	$420	$963	7.1	15.2

Note: The average LCC, LCC savings, and simple PBP for each efficiency level are calculated assuming that all consumers use products having the given efficiency level. Thus, results for all efficiency levels can be compared under the same conditions.

Table ES.3.6.4 Summary of Life-Cycle Costs Relative to the No-New-Standards Case Efficiency Distribution for Compact Dishwashers

EL	Life-Cycle Costs and Savings	
	Average Savings *(2020$)*	Percent of Consumers Who Experience Net Cost
1	$8	5%
2	$36	40%

Note: The LCC savings for each efficiency level are calculated relative to the no-new-standards case efficiency distribution. The calculation includes households that experience zero LCC savings (no impact).

ES.3.7 Shipments Analysis

DOE projects product shipments to calculate the national impacts of potential standards on energy use, net present value (NPV) of costs and savings, and manufacturers. DOE used historical shipments data in combination with saturation of dishwashers in newly constructed homes to estimate shipments of dishwashers. To project shipments of replacement units, DOE utilized the 15.2-year estimated lifetime to develop a retirement function for dishwashers. DOE applied that retirement function to the current stock of products. DOE's shipments model, which takes a stock accounting approach, uses historical product shipment data as inputs to estimate the age distribution of in-service product stocks for all years. To estimate shipments to new construction or first-time owners, DOE used projections of housing starts coupled with dishwashers' saturation data.

DOE's shipments model for dishwashers considers shipments to replace existing units and to first-time owners. DOE used an accounting method that tracks the total stock of units by vintage to determine shipments to the replacement market.

Figure ES.3.7.1 shows the projected shipments in the no-new-standards case and the historical shipments DOE used to calibrate those projected shipments.

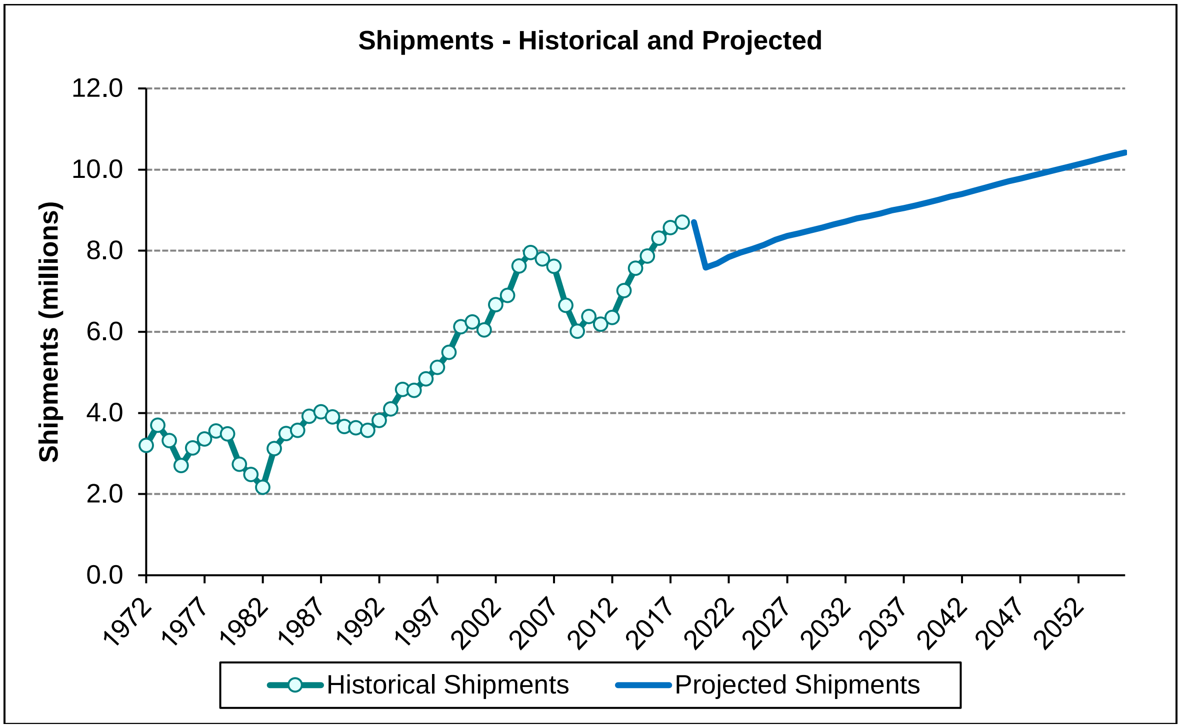

Figure ES.3.7.1 Dishwasher Historical Shipments and No-New-Standards Case Projection

Chapter 9 of this preliminary TSD provides additional details regarding the shipments analysis.

ES.3.8 National Impact Analysis

The national impact analysis (NIA) estimates impacts on the nation of potential energy conservation standards for dishwashers. Those impacts encompass:

- National energy savings (NES) attributable to standards;
- Monetary value of energy savings attributable to standards;
- Increased total installed costs attributable to standards; and
- NPV of the energy savings attributable to standards (the difference between the value of the energy savings and the total installed costs).

DOE calculated annual NES as the difference between national energy consumption in the no-new-standards case and under each efficiency level. DOE estimated energy consumption and savings based on site energy use. DOE then converted site energy consumption and savings to the primary energy consumed at power stations to supply the site electricity. Cumulative energy savings are the sum of the annual NES.

The NES results, shown in Table ES.3.8.1, are cumulative for the units shipped during the period 2027–2056. The energy savings, given in quadrillion Btu (quads), are shown as primary energy savings.

Table ES.3.8.1 Cumulative Primary National Energy Savings for Dishwashers (Quads)

Product Class	Efficiency Level			
	1	**2**	**3**	**4**
Standard-Sized	0.003	0.051	0.451	0.587
Compact	0.000	0.051		

On August 18, 2011, DOE published a statement of policy in the *Federal Register* announcing its intention to start using full-fuel-cycle (FFC) measures of energy use and greenhouse gas and other emissions in the national impact and emissions analyses in energy conservation standards rulemakings. 76 FR 51281; amended by 77 FR 49701 (Aug. 17, 2012). Table ES.3.8.2 summarizes the NES for the FFC.

Table ES.3.8.2 Cumulative Full-Fuel-Cycle Energy Savings for Dishwashers (Quads)

Product Class	Efficiency Level			
	1	**2**	**3**	**4**
Standard-Sized	0.004	0.054	0.470	0.624
Compact	0.000	0.054		

DOE calculated the NPV of monetary savings for consumers in each year after potential standards would take effect for the base case and each standards case. DOE calculated savings throughout the lifetime of products shipped in 2027–2056. DOE used discount rates of 3 percent and 7 percent, respectively, to discount future costs and savings to the present. DOE calculated the NPV as the difference between the present value of operating cost savings and the present value of total installed costs. The NPV results for dishwashers are shown in Table ES.3.8.3 and Table ES.3.8.4. As with the NES results, NPV results are presented as a function of efficiency level.

Table ES.3.8.3 Dishwashers: Cumulative Consumer Net Present Value, Discounted at 3 Percent

Product Class	Efficiency Level			
	1	**2**	**3**	**4**
	Billion 2020$			
Standard-Sized	0.047	0.143	(3.026)	(6.009)
Compact	0.001	0.280		

Table ES.3.8.4 Dishwashers: Cumulative Consumer Net Present Value, Discounted at 7 Percent

Product Class	Efficiency Level			
	1	2	3	4
	Billion 2020$			
Standard-Sized	0.022	0.001	(2.027)	(4.068)
Compact	0.001	0.074		

ES.3.9 Preliminary Manufacturer Impact Analysis

The manufacturer impact analysis (MIA) assesses the potential impacts of amended energy conservation standards on manufacturers of dishwashers, including effects on expenditures for capital conversions, marketing costs, shipments, and research and development costs. Impacts to direct employment are also addressed in the MIA. Potential impacts might lead to changes in manufacturing practices for dishwashers. See chapter 12 of the preliminary TSD for details.

ES.4 ISSUES ON WHICH THE DEPARTMENT SEEKS PUBLIC COMMENT

DOE is interested in receiving comments from interested parties on all aspects of this preliminary TSD, especially comments or data that might improve DOE's analyses. DOE welcomes data or information that will help resolve the following specific issues, which were raised during preparation of this preliminary TSD.

ES.4.1 Product Databases

DOE seeks comment on whether manufacturer model counts from publicly available databases accurately reflect manufacturer market shares on a model- or sales-weighted basis. See chapter 3 and chapter 8 of the preliminary TSD.

ES.4.2 Shipments Information

DOE seeks information on annual dishwasher shipments disaggregated by product class and efficiency level. See chapter 3 of the preliminary TSD.

ES.4.3 Design Options

DOE developed a preliminary list of technology options and design paths for improving dishwasher efficiency. DOE requests feedback on whether there are additional technologies available that may improve dishwasher performance. See chapter 3 of the preliminary TSD.

ES.4.4 Efficiency Levels and Cost Estimates

DOE seeks comment on whether the efficiency levels (baseline, ENERGY STAR V. 6.0, intermediate, ENERGY STAR Most Efficient, and max-tech) identified in this analysis for each product class are appropriate. In particular, DOE observed that the compact dishwasher baseline and EL 1 design options were the same. DOE seeks comment on the differences, if any, between baseline and EL 1 (*i.e.,* ENERGY STAR V. 6.0) compact dishwasher design options. DOE also seeks comment on whether the MPCs at each efficiency level are appropriate given the associated incremental changes manufacturers would likely make to meet these levels. See chapter 5 of the preliminary TSD.

ES.4.5 Energy and Water Use Analysis

DOE relied on usage information for dishwashers as determined from RECS 2015 to establish the annual number of cycles for dishwashers. DOE requests input on its proposed method for determining usage hours and energy use. DOE seeks comment on the methodological approach to the energy and water use analysis. See chapter 7 of the preliminary TSD.

ES.4.6 Maintenance and Repair Costs

DOE seeks input from interested parties on characterizing maintenance and repair costs for more-efficient dishwashers. DOE requests comment on the cost characterizations. See chapter 8 of the preliminary TSD.

ES.4.7 Efficiency Distribution of Dishwashers

DOE requests data from interested parties to characterize the current mix of consumer dishwasher efficiencies in the market.

ES.4.8 Historical Shipments of Dishwashers

DOE requests historical shipments data for dishwashers, disaggregated by product class. DOE also seeks historical shipments data showing percentage of shipments by efficiency level for as many product classes as possible.

ES.4.9 Domestic Small Manufacturers

DOE seeks input on whether the dishwashers market contains any domestic small manufacturers that DOE has not identified in its analysis. See chapter 12 of the preliminary TSD.

ES.4.10 Manufacturer Subgroups Disproportionately Affected

DOE seeks comment on any other potential manufacturer subgroups, besides small business manufacturers, that could be disproportionally affected by potential amended energy conservation standards for dishwashers. See chapter 12 of the preliminary TSD.

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CHAPTER 1. INTRODUCTION

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CHAPTER 1. INTRODUCTION

1.1 PURPOSE OF THE DOCUMENT

This preliminary technical support document (TSD) is a stand-alone report that provides the technical analyses and results supporting the information presented in the preliminary notice of public meeting (NOPM) and executive summary for dishwashers.

1.2 OVERVIEW OF STANDARDS FOR DISHWASHERS

The Energy Policy and Conservation Act of 1975 (EPCA or the Act)[a], Public Law 94-163 (42 U.S.C. 6291–6317, as codified), among other things, authorizes the U.S. Department of Energy (DOE) to regulate the energy efficiency of a number of consumer products and industrial equipment. Title III, Part B[b] of EPCA established the Energy Conservation Program for Consumer Products Other Than Automobiles, which sets forth a variety of provisions designed to improve energy efficiency. These products include dishwashers that are the subject of this document. (42 U.S.C. 6292(a)(6)) EPCA authorizes DOE to establish technologically feasible, economically justified energy conservation standards for covered products that would be likely to result in significant national energy savings. (42 U.S.C. 6295(o)(2)(B)(i)(I)–(VII))

The current energy conservation standards for 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[c]), recommended specific energy conservation standards for 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 dishwasher efficiency levels, including those suggested in the Joint Petition. In a direct final rule published on May 30, 2012 (May 2012 Direct Final Rule), DOE prescribed energy conservation standards and water use standards consistent with the levels submitted in the Joint Petition. 77 FR 31918. Compliance with the standards established in the May 2012 Direct Final Rule was required beginning May 30, 2013. *Id.*

DOE subsequently published a final determination on December 13, 2016 (December 2016 Final Determination), in which it concluded that amended energy conservation standards would not be economically justified at any level above the standards established in the May 2012 Direct Final Rule, and therefore determined not to amend the standards. 81 FR 90072.

EPCA requires that, not later than three years after the issuance of a final determination not to amend standards, DOE must publish either a notice of determination that standards for the

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[a] All references to EPCA in this document refer to the statute as amended through the Energy Act of 2020, Public Law 116-260 (Dec. 27, 2020).

[b] For editorial reasons, upon codification in the U.S. Code, Part B was redesignated Part A.

[c] Available at: https://www.regulations.gov/document/EERE-2011-BT-STD-0060-0001

product do not need to be amended, or a notice of proposed rulemaking (NOPR) including new proposed energy conservation standards (proceeding to a final rule, as appropriate). (42 U.S.C. 6295(m)(3)(B)) DOE must make the analysis on which a determination is based publicly available and provide an opportunity for written comment. (42 U.S.C. 6295(m)(2)) DOE has initiated this rulemaking and is issuing this preliminary analysis notice and associated preliminary TSD, pursuant to the requirements of 42 U.S.C. 6295(m)(3)(B).

1.3 PROCESS FOR SETTING ENERGY CONSERVATION STANDARDS

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

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

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

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

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

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

6) the need for national energy conservation; and

7) other factors the Secretary considers relevant.

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

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

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

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

On October 14, 2020, DOE published an RFI (October 2020 RFI), which solicited information from the public to help DOE determine whether amended standards for dishwashers would result in a significant amount of additional energy savings and whether those standards would be technologically feasible and economically justified. The October 2020 RFI is available at https://www.regulations.gov/document/EERE-2019-BT-STD-0039-0001.

In response to the publication of the October 2020 RFI, interested parties commented on numerous issues related to the analyses listed in Table 1.3.1. DOE attempted to address these issues in this preliminary analysis and summarized the comments and DOE's responses in chapter 2 of the preliminary TSD.

Table 1.3.1 Analyses Under the Process Rule

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

DOE developed spreadsheets for the life-cycle cost (LCC), payback period (PBP), and national impact analyses (NIA) for dishwashers. DOE developed an LCC spreadsheet that calculates the LCC and PBP at various energy efficiency levels. DOE also developed an NIA spreadsheet that calculates the national energy savings (NES) and national net present values (NPVs) at various energy efficiency levels. This spreadsheet includes a model that forecasts the impacts of potential amended energy conservation standards at various levels on product shipments. All of these spreadsheets are available on the DOE website for dishwashers at: https://www1.eere.energy.gov/buildings/appliance_standards/standards.aspx?productid=38&action=viewlive.

1.4 STRUCTURE OF THE DOCUMENT

This preliminary TSD outlines the analytical approaches used in the preliminary analysis. The TSD consists of 17 chapters and supporting appendices.

Chapter 1 Introduction: Provides an overview of the appliance standards program and how it applies to this preliminary analysis, describes the purpose of the TSD, and outlines the structure of the document.

Chapter 2 Analytical Framework, Comments from Interested Parties, and DOE Responses: Describes the general rulemaking process and issues for the preliminary analysis.

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, and presents results of the preliminary analysis.
Chapter 5	Engineering Analysis: Describes the methods used for developing the relationship between increased efficiency and increased manufacturing cost and presents results of the preliminary analysis.
Chapter 6	Markups Analysis: Describes the methods used for establishing markups for converting manufacturing cost to customer purchase price and presents results of the preliminary analysis.
Chapter 7	Energy and Water Use Analysis: Describes the sources and methods used for generating energy- and water-use estimates for the considered products as a function of efficiency levels and presents results of the preliminary analysis.
Chapter 8	Life-Cycle Cost and Payback Period Analysis: Describes the methods used for analyzing the economic effects of new or amended efficiency standards on individual customers and users of the products with respect to LCC savings and PBP of higher efficiency levels of the considered products and presents results of the preliminary analysis.
Chapter 9	Shipments Analysis: Describes the methods used for forecasting shipments with and without higher efficiency standards and presents results of the preliminary analysis.
Chapter 10	National Impact Analysis: Describes the methods used for estimating the national energy savings and national economic benefit to consumers of potential standards, and presents the preliminary results of the analysis.
Chapter 11	Consumer Subgroup Analysis: Describes the methods to be used for analyzing the effects of potential standards on a subgroup of consumers compared to all consumers.
Chapter 12	Preliminary Manufacturer Impact Analysis: Describes the methods used for analyzing the effects of energy conservation standards on the finances and profitability of the considered product manufacturers and presents results of the preliminary analysis.
Chapter 13	Emissions Analysis: Describes the methods to be used to analyze the impact of potential standards on sulfur dioxide, nitrogen oxides, and

	mercury, as well as on carbon dioxide and other greenhouse gas emissions.
Chapter 14	Monetization of Emission Reductions Benefits: Describes the methods to be used for estimating the monetary benefits likely to result from reduced emissions expected to result from potential standards.
Chapter 15	Utility Impact Analysis: Describes the methods to be used for analyzing key impacts of potential standards on electric utilities.
Chapter 16	Employment Impact Analysis: Describes the methods to be used for analyzing the impact of potential standards on national employment.
Chapter 17	Regulatory Impact Analysis: Describes the methods to be used for analyzing the impact of non-regulatory alternatives to energy conservation standards compared to standards.
Appendix 6A	Incremental Markups: Theory and Evidence
Appendix 8A	User Instructions for Life-Cycle Cost Analysis Spreadsheet Model
Appendix 8B	Uncertainty and Variability in LCC Analysis
Appendix 8C	Energy Price Calculations for Dishwashers
Appendix 8D	Water and Wastewater Price Determinations
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CHAPTER 2. ANALYTICAL FRAMEWORK, COMMENTS FROM INTERESTED PARTIES, AND DOE RESPONSES

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CHAPTER 2. ANALYTICAL FRAMEWORK, COMMENTS FROM INTERESTED PARTIES, AND DOE RESPONSES

2.1 INTRODUCTION

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

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

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[a] All references to EPCA in this document refer to the statute as amended through the Energy Act of 2020, Public Law 116-260 (Dec. 27, 2020).

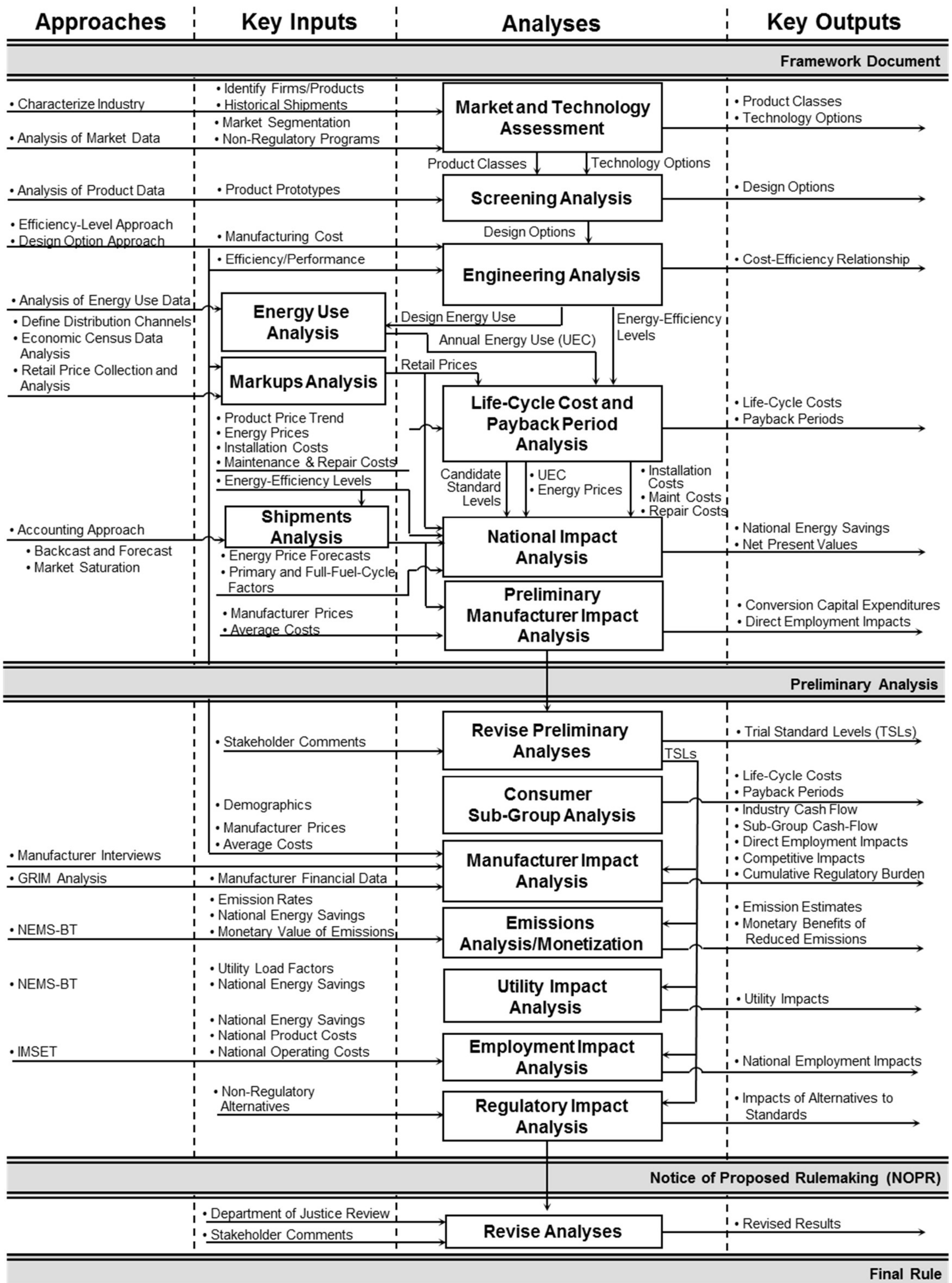

Figure 2.1.1 Flow Diagram of Analyses for the Rulemaking Process

The analyses performed as part of the preliminary analysis stage and reported in this preliminary 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 and determine if it is technologically feasible; is practical to manufacture, install, and service; would adversely affect product utility or product availability; or would have adverse impacts on health and safety.
- An engineering analysis to develop cost-efficiency relationships that show the manufacturer's cost of achieving increased efficiency.
- An analysis of markups for determining product price; markups throughout the distribution channel relate the manufacturer production cost (MPC) to the retail cost paid by the consumer.
- An energy and water use analysis to determine the annual energy and water use of the considered product for a representative set of users.
- A life-cycle cost (LCC) and payback period (PBP) analysis to calculate the savings in operating costs the consumer will realize throughout the life of the covered product compared to any increase in installed product cost likely to result directly from imposition of a standard.
- A shipments analysis to forecast product shipments, which then are used to calculate the national impacts of potential standards on energy consumption, 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 product, as measured by the NPV of total consumer economic impacts and the national energy savings (NES).
- A preliminary manufacturer impact analysis (MIA) to assess the potential impacts of energy conservation standards on manufacturers, such as impacts on capital conversion expenditures, marketing costs, shipments, and research and development costs.

The analyses DOE will perform in any subsequent notice of proposed rulemaking (NOPR) stage include those listed below. In addition, DOE will revise the analyses it performed in the preliminary analysis stage based on comments and new information received on topics including, but not limited, to those listed below.

- An LCC subgroup analysis to evaluate variations in customer characteristics that might cause a standard to affect particular consumer sub-populations, such as low-income households, differently than the overall population.
- An MIA to estimate the financial impact of standards on manufacturers and to calculate impacts on competition, employment, and manufacturing capacity.

- A utility impact analysis to estimate the effects of proposed standards on electric utilities.
- An employment impact analysis to assess the aggregate impacts of amended energy conservation standards on national employment.
- An environmental impact analysis to provide estimates of the effects of amended energy conservation standards on emissions of carbon dioxide (CO_2), sulfur dioxide (SO_2), nitrogen oxides (NO_X), and mercury (Hg).
- A regulatory impact analysis to present major alternatives to proposed amended energy conservation standards that could achieve substantially the same regulatory goal at a lower cost.

For each rulemaking, if DOE determines it is appropriate to proceed with a rulemaking, DOE will develop a framework document that describes the approaches and methods DOE will use in evaluating the need for new or amended standards. 10 CFR Part 430, subpart C, appendix A section 6(a)(2). As outlined in the notice, DOE is deviating from this requirement as provided by section 3(a) of 10 CFR Part 430, subpart C, appendix A. DOE initially published a request for information (RFI) in the *Federal Register* on October 14, 2020 (hereinafter, the October 2020 RFI) that sought input from interested parties that would help DOE determine whether to amend the current energy conservation standards for dishwashers. 85 FR 64981. The comment period deadline for the October 2020 RFI was December 28, 2020. The October 2020 RFI is available at document ID EERE-2019-BT-STD-0039-0001 on *https://www.regulations.gov*.

In response to the October 2020 RFI, DOE received comments regarding DOE's analytical approach from the interested parties listed in Table 2.1.1. A parenthetical reference at the end of a comment quotation or paraphrase provides the location of the item in the public record.[b]

[b] The parenthetical reference provides a reference for information located in Docket No. EERE-2019-BT-STD-0039, which is maintained at *http://www.regulations.gov*). The references are arranged as follows: (commenter name, comment docket ID number, page of that document).

Table 2.1.1 Commenters to the October 2020 RFI

Commenter(s)	Reference in this Document	Commenter Type
Appliance Standards Awareness Project (ASAP), National Consumer Law Center on behalf of its low-income clients (NCLC), and Natural Resources Defense Council (NRDC)	Joint Commenters	Efficiency Organization
Association of Home Appliance Manufacturers	AHAM	Trade Association
The Pacific Gas and Electric Company (PG&E), San Diego Gas & Electric (SDG&E), and Southern California Edison (SCE), collectively referred to as the California Investor-Owned Utilities	CA IOUs	Utility Association
The People's Republic of China	P. R. China	International Government
GE Appliances, a Haier Company	GEA	Manufacturer
Northwest Energy Efficiency Alliance	NEEA	Efficiency Organization
Samsung Electronics America, Inc.	Samsung	Manufacturer
Whirlpool Corporation	Whirlpool	Manufacturer
Anonymous	Anonymous	Individual
Alic	--	Individual
Hague	--	Individual

General comments are summarized below. In the remainder of this chapter, DOE: (1) summarizes all relevant comments received from interested parties and describes DOE's responses to those comments, and (2) explains in further detail each of the issues for which DOE seeks public comment in the executive summary. This preliminary TSD contains details of the preliminary analyses conducted for dishwashers.

Relevant Rulemaking History

The current standards for dishwashers were prescribed in a direct final rule published on May 30, 2012 (hereinafter, May 2012 Direct Final Rule). 77 FR 31918. On December 13, 2016, DOE published a final determination (hereinafter, December 2016 Final Determination) to not amend the standards because it concluded that amended energy conservation standards would not be economically justified at any level above the standards established in the May 2012 Direct Final Rule. 81 FR 90072. The current standards are presented in Table 2.2.1 in section 2.2 of this chapter, and the standards for energy consumption are based on 215 annual dishwasher cycles, which is the number of cycles specified in the current dishwasher test procedure at Appendix C1 to Subpart B of Title 10 of the Code of Federal Regulations (CFR) (hereinafter, Appendix C1). However, in the dishwasher test procedure NOPR published on December 22, 2021 (December 2021 NOPR), DOE proposed to adopt a new dishwasher test procedure, Appendix C2, which would be applicable upon the compliance date of any future amended conservation standards. 86 FR 72738. Appendix C2 proposes to update the annual dishwasher cycles to 184 cycles/year, which would require a proportional adjustment to the standards for energy consumption. 86 FR 72748-49.

On October 30, 2020, DOE published a final rule (October 2020 Final Rule) establishing a separate product class for standard-size dishwashers with a cycle time for the "normal" cycle of less than one hour (*i.e.*, 60 minutes) from washing through drying. 85 FR 68723. On August 11, 2021, DOE published a NOPR (August 2021 NOPR) proposing to revoke the final rule that established the new product class for dishwashers. 86 FR 43970. Subsequently, on January 11, 2022, DOE issued a final rule (January 2022 Pre-Publication Final Rule) revoking the final rule that established a new product class for dishwashers.[c] Accordingly, potential standards for the new product class of dishwashers are not addressed in the present process.

Additionally, in April 2015, the U.S. Environmental Protection Agency (EPA) published the ENERGY STAR Product Specification for Residential Dishwashers, Version 6.0 (hereinafter, ENERGY STAR V. 6.0) with qualification criteria for standard-size dishwashers of annual energy use of 270 kilowatt hours per year (kWh/year), based on 215 cycles/year, and per-cycle water use of 3.5 gallons/cycle (gal/cycle).[1] In March 2020, EPA published the ENERGY STAR Draft 1 Version 7.0 Residential Dishwashers Specification (hereinafter, ENERGY STAR Draft 1 V. 7.0) with proposed qualification criteria for standard-size dishwashers of annual energy use of 240 kWh/year, based on 215 cycles/year, and per-cycle water use of 3.2 gal/cycle.[2] These proposed criteria are the same as those specified for the ENERGY STAR Most-Efficient requirements.[3] In January 2022, EPA published the ENERGY STAR Draft 2 V. 7.0 specification in which it retained the proposed qualification criteria of 240 kWh/year (based on 215 cycles/year) and 3.2 gal/cycle for standard-size dishwashers.

General Comments and Responses

In response to the October 2020 RFI, AHAM commented that DOE's authority to establish standards is restricted if the new standards are likely to result in the unavailability of products with performance characteristics, features, and capacities, that are substantially the same as those generally available in the United States at the time of the Secretary's finding. AHAM commented that energy and water savings potential of current dishwashers would be more likely to be achieved at the expense of performance and features than in previous years, as dishwashers have already been subject to several rounds of more stringent energy conservation standards. (AHAM, No. 6 at p. 3)

NEEA urged DOE to update the energy conservation standards for dishwashers. NEEA calculated site energy savings using the rated energy consumption of one of the most efficient dishwashers available in the market and determined the 30-year site energy savings to be 0.5 quads and a 13-percent savings in current site energy use. NEEA asserted that, since this value

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[c] https://www.energy.gov/sites/default/files/2022-01/short-cycle-product-class-fr.pdf

exceeds both Process Rule[d] requirements of a 10-percent reduction in energy use and 0.3-quads energy savings, updated energy conservation standards for dishwashers were justified. (NEEA, No. 12 at pp. 1–2) The CA IOUs commented that they analyzed the potential energy savings using the NIA data from the December 2016 Final Determination to assess the potential savings if dishwasher standards were established at the ENERGY STAR Draft 1 V. 7.0 qualification criteria, and found that such standards could meet the significant savings threshold(s) of 0.3-quads site energy savings and 10-percent or more site energy savings. (CA IOUs, No. 8 at pp. 2–3)

AHAM stated that energy conservation standards beyond ENERGY STAR V. 6.0 are not justified under EPCA and reiterated that it has submitted comments to EPA to sunset the ENERGY STAR program for dishwashers. (AHAM, No. 6 at p. 11) GEA and Whirlpool both support AHAM's comments and submitted additional comments on specific topics. (GEA, No. 9 at p. 1; Whirlpool, No. 7 at p. 1)

GEA commented that at the current ENERGY STAR V. 6.0 qualification criteria, which is the level at which a majority of dishwashers are rated, most dishwashers use significantly less energy and water compared to handwashing or rinsing the load. GEA asserted that if DOE were to set more stringent standards, the energy and water must be sufficient for a high-performing dishwasher. GEA further commented that energy and water standards more stringent than the ENERGY STAR V. 6.0 qualification criteria would significantly impact dishwasher performance, as demonstrated in the December 2016 Final Determination. (GEA, No. 9 at p. 2)

Whirlpool commented that amended energy conservation standards more stringent than the current ENERGY STAR V. 6.0 qualification criteria would not be technologically feasible or economically justified and would have significant negative performance impacts. (Whirlpool, No. 7 at p. 1) Samsung commented that DOE should consider amending the dishwasher minimum standards to ENERGY STAR V. 6.0, due to high (90 percent) market penetration of standard-size qualified dishwashers, and further opportunity for innovation to improve energy efficiency beyond the ENERGY STAR V. 6.0 levels. (Samsung, No. 10 at p. 2)

The Joint Commenters noted that many dishwasher models meet or exceed the current ENERGY STAR V. 6.0 qualification criteria, which they suggested indicates that there is an opportunity for more stringent dishwasher standards. They referred to EPA's analysis, which put forth that the ENERGY STAR Most Efficient criteria is cost-effective and has a payback period

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[d] On February 14, 2020, DOE published an update to its procedures, interpretations, and policies for consideration in new or revised energy conservation standards and test procedure, *i.e.,* "Procedures, Interpretations, and Policies for Consideration of New or Revised Energy Conservation Standards and Test Procedures for Consumer Products and Certain Commercial/Industrial Equipment" (see 10 CFR part 430, subpart C, appendix A ("Process Rule,")). 85 FR 8626. In the updated Process Rule, DOE adopted a numerical threshold for significant conservation of energy. *Id.* at 8670. Specifically, the threshold requires that an energy conservation standard result in a 0.30-quad reduction in site energy use over a 30-year analysis period or a 10-percent reduction in site energy use over that same period. *Id*. This threshold was subsequently eliminated in a final rule published on December 13, 2021 (86 FR 70892, 70901).

of less than 4 years. The Joint Commenters cited data from EPA's investigation of consumer satisfaction, based on ratings from Consumer Reports and web-scraped data, across five criteria: cleaning performance, drying performance, noise, cycle time, and overall consumer satisfaction. and stated that based on these data, dishwashers that are rated at ENERGY STAR Most Efficient or higher, provide similar, or better, consumer satisfaction as all other dishwashers. (Joint Commenters, No. 11 at pp. 1–2, 4)

An individual commented that since U.S. dishwashers consistently use more energy than European ones, the ENERGY STAR qualification criteria should be made more stringent to match these overseas counterparts, to help produce energy savings across the U.S. (Anonymous, No. 4 at p. 1) Another individual commented in support of amending standards if possible, to make certain cuts and conserve energy. (Alic, No. 2 at p. 1) Another individual commented in favor of amending standards if it is possible to lower the energy consumption of dishwashers and the technology is available. (Hague, No. 3 at p. 1)

GEA commented that more stringent standards risk causing changes in consumer behavior, such as increased hand washing or pre-rinsing, that would outweigh savings from more stringent standards. (GEA, No. 9 at p. 2) AHAM commented that additional cost-effective efficiency gains are not available beyond the current ENERGY STAR V. 6.0 criteria without sacrificing performance and product functionality, because dishwashers are nearing maximum efficiency under available technology. AHAM commented that energy conservation standards that exceed the ENERGY STAR V. 6.0 criteria would likely result in limited energy savings compared to the significant cost increase to consumers and manufacturers, degraded cleaning and drying performance, and increased cycle length. AHAM further stated that standards beyond ENERGY STAR V. 6.0 would likely increase energy and water use and undercut projected savings due to undesirable consumer behavior such as pre-rinsing and selection of cycles other than the normal cycle. (AHAM, No. 6 at pp. 2–3)

AHAM and Whirlpool noted that approximately 90 percent of dishwashers shipped in the United States in 2019 were ENERGY STAR-certified, and claimed that this is because, although ENERGY STAR is a voluntary program, manufacturers consider it mandatory to provide ENERGY STAR-certified models across nearly their entire model line-up to remain competitive in the market. (AHAM, No. 6 at p. 2; Whirlpool, No. 7 at p. 10) Whirlpool further commented that DOE should not use the high penetration rate of ENERGY STAR-certified dishwashers as impetus to amend the DOE energy conservation standards. Whirlpool asserted that it is not technologically feasible or economically justified to go beyond the current ENERGY STAR V. 6.0 qualification criteria and noted evidence of diminishing return in product performance issues, lower consumer satisfaction, and compensating consumer behaviors. Additionally, Whirlpool commented that DOE should consider how a possible sunset of the ENERGY STAR Dishwashers Program, as recommended to EPA by Whirlpool and AHAM, may impact any amended standards. (Whirlpool, No. 7 at pp. 10–11)

AHAM further commented that, given the relatively limited savings available beyond ENERGY STAR V. 6.0 and that these savings may be outweighed by performance concerns and increased costs, DOE should focus its efforts on achieving energy and water savings through non-regulatory means in collaboration with AHAM, its members, and others such as detergent manufacturers and efficiency advocates. AHAM recommended non-regulatory options to achieve additional energy and water savings, such as establishing dishwasher market penetration targets to increase dishwasher ownership and educating consumers on proper dishwasher use to reduce handwashing and pre-rinsing. (AHAM, No. 6 at p. 11) In particular, AHAM suggested that DOE should establish market penetration targets for dishwashers to realize energy and water savings over handwashing, since only 67 percent of U.S. households have a dishwasher. AHAM further recommended educating consumers on increased and proper dishwasher use to discourage pre-rinsing and to select the proper cycle. AHAM asserted that a 1-percent increase in dishwasher ownership and a 3-percent decrease in pre-rinsing would yield greater energy and water savings than standards above the ENERGY STAR V. 6.0 criteria. (AHAM, No. 6 at pp. 11–12)

GEA commented that it would support, and Whirlpool reiterated its interest in, partnering with the government, AHAM, and other stakeholders to educate consumers about the importance of dishwasher ownership and proper usage. (GEA, No. 9 at pp. 2–3; Whirlpool, No. 7 at pp. 10–11) Whirlpool further estimates that the potential savings obtained from all households in the U.S. owning and optimally using a dishwasher are about 160 billion gallons of water per year, which far outweigh the savings from a revision to ENERGY STAR or DOE standards, and would benefit detergent and dishwasher manufacturers, EPA, DOE, consumers, retailers, and many other stakeholders. (Whirlpool, No. 7 at pp. 10–11)

DOE notes that, under EPCA, it is required to publish either a notice of determination that standards for dishwashers do not need to be amended, or a NOPR including new proposed energy conservation standards, within three years after the issuance of a final determination not to amend standards. (42 U.S.C. 6295(m)(3)(B)) Since DOE published the December 2016 Final Determination not to amend dishwasher standards, it has initiated this current process to evaluate whether amended standards are economically justified and technologically feasible, warranting a NOPR, or a determination that standards for dishwashers do not need to be amended. At this time, DOE is gathering information through this preliminary analysis and conducting its analyses to determine if amended standards for dishwashers are justified. For this analysis, DOE is evaluating many efficiency levels for both standard-size and compact dishwashers, including the ENERGY STAR V. 6.0 qualification criteria, ENERGY STAR Most-Efficient qualification criteria (for standard-size dishwashers), and the max-tech level. If the analyses indicate that amended standards are justified, any standards that DOE proposes would be after performing all the analyses as prescribed by EPCA and additional opportunity for public comment.

2.2 ENERGY AND WATER USE METRIC

Currently, manufacturers are required to demonstrate compliance with the energy and water conservation standards for dishwashers found at section 430.32(f) to Subpart C of Title 10 of the CFR, which are based on the annual energy use in kWh/year, and per-cycle water use in gal/cycle. These standards are as shown in Table 2.2.1.

Table 2.2.1 Federal Energy Conservation Standards for Dishwashers

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

*Using 215 annual cycles.

DOE received comments from Samsung and the CA IOUs regarding current standards for dishwashers. Samsung urged DOE to consider requiring cleaning performance testing and establish a minimum level of cleaning performance to increase consumer satisfaction with the functionality of the dishwasher in the tested mode and decrease the likelihood that consumers will opt for other modes with increased energy consumption. (Samsung, No. 10 at p. 2) The CA IOUs supported the inclusion of cleaning performance as part of the dishwasher regulation and specified that the requirement should be based on the weighted-average cleaning score at the heavy, medium, and light soil loads. (CA IOUs, No. 8 at p. 7) According to Samsung, DOE should consider recognizing the benefits of soil-sensing technologies through a field use factor, as soil-sensing dishwashers adapt to varying real-world use conditions, thereby optimizing energy usage, water usage and cycle time. (Samsung, No. 10 at p. 3)

In addition to supporting a minimum cleaning performance standard and field use factor, Samsung commented that the soil loads in the current DOE test procedure are low and are designed with the assumption that consumers pre-rinse the load prior to loading them in the dishwasher. Samsung recommended that the DOE test procedure should include an extra-heavy soil load per the American National Standards Institute (ANSI)/AHAM standard, ANSI/AHAM DW-1-2010.[4] Such a load, Samsung contended, would ensure that dishwashers clean effectively without pre-rinsing, and thus encourage consumers to avoid pre-rinsing. (Samsung, No. 10 at pp. 2–3)

EPCA requires consideration of any lessening of the utility or the performance of the covered product likely to result from the imposition of new or amended standards. (42 U.S.C. 6295(o)(2)(b)(i)(IV)) Accordingly, DOE will evaluate the impact of decreasing energy and water use on cleaning performance as part of its engineering analysis, as discussed in chapter 5 of this preliminary TSD. Additionally, soil-sensing technology is a design option that DOE intends to analyze, as discussed in chapter 3 of this preliminary TSD. DOE welcomes data that show the quantity and type of soil loads that consumers typically load in the dishwasher for consideration as part of the test procedure rulemaking process. Further, as noted in the December 2021 NOPR, DOE is proposing to include a minimum cleaning index threshold of 65 in the dishwasher test procedure as a condition for a test cycle to be considered valid. 86 FR 72758-59.

2.3 MARKET AND TECHNOLOGY ASSESSMENT

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

2.3.1 Market Assessment

When analyzing potential energy conservation standards, DOE initially develops information that provides an overall picture of the market for the products analyzed, including the nature of the products, the industry structure, and market characteristics for the products. This activity consists of both quantitative and qualitative efforts based primarily on publicly available information. In the context of the present preliminary analysis, the subjects addressed in the market assessment for dishwashers include manufacturers, trade associations, and the quantities and types of products sold and offered for sale. DOE examined both large and small and foreign and domestic manufacturers. Finally, DOE reviewed other energy efficiency programs from utilities, individual States, and other organizations.

DOE reviewed relevant literature to develop an overall picture of the dishwasher industry in the United States. Industry publications, government agencies, and trade organizations provided the bulk of the information, including (1) major and minor manufacturers, (2) shipments estimates, and (3) industry trends. The analysis developed as part of the market and technology assessment is described in chapter 3 of the preliminary TSD.

2.3.1.1 Product Definition

As discussed previously, EPCA gives DOE the authority to regulate "consumer products" other than those solely used in automobiles. (42 U.S.C 6291(1)) Dishwashers are listed as one of the covered products that are subject to DOE's energy conservation standard regulations. (42 U.S.C. 6292(a)(6)) At 10 CFR 430.2, DOE defines dishwashers as follows:

Dishwasher means 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.

2.3.1.2 Product Classes

When evaluating and establishing energy conservation standards, DOE generally divides covered products into product classes by the type of energy used or by capacity or other performance-related features that affect efficiency. Different energy conservation standards may apply to different product classes. (42 U.S.C. 6295(q))

DOE has currently established dishwasher standards for two product classes that are based on the capacity of the unit (as specified in ANSI/AHAM DW-1-2010). Table 2.3.1 shows these two product classes.

Table 2.3.1 Current Dishwasher Product Classes

Standard Product Class	Capacity equal to or greater than eight place settings plus six serving pieces
Compact Product Class	Capacity less than eight place settings plus six serving pieces

Additionally, in the October 2020 Final Rule, DOE established a new product class for dishwashers that includes standard-size dishwashers with a "normal cycle"[e] of 60 minutes or less, that are not currently subject to energy or water conservation standards. 85 FR 68723. Subsequently, DOE published the August 2021 NOPR proposing to revoke the final rule that established the new product class for dishwashers. 86 FR 43970. Thereafter, DOE issued the January 2022 Pre-Publication Final Rule which revoked the final rule that established the new product class for dishwashers.

In response to the October 2020 RFI (and prior to the publication of the August 2021 NOPR), DOE received several comments regarding the new product class. The Joint Commenters commented that DOE should eliminate the October 2020 Final Rule, claiming it is unlawful. The Joint Commenters further contended that if DOE proceeds with establishing standards for this new product class, it would be illegal to set standards that are less stringent than the existing standards for standard-size dishwashers. (Joint Commenters, No. 11 at p. 5) P. R. China commented that DOE should maintain the current energy consumption standards for the new, short-cycle product class because there isn't a major difference in the technology options used for the short cycle compared to the normal cycle. (P. R. China, No. 5 at p. 3) AHAM commented that DOE should withdraw the newly adopted product class for dishwashers with cycle times of 60 minutes or less, which would also eliminate the need to consider standards for the new product class. AHAM further commented that it would petition DOE to withdraw the October 2020 Final Rule and expects that litigation would challenge the final rule. (AHAM, No. 6 at p. 12)

NEEA opposed separate standards for short-cycle dishwashers because it claimed there is no unique utility associated with having a fast cycle be the normal cycle. NEEA reviewed available dishwasher models on retail websites and found that consumers already have access to fast wash cycles on current standard-size models. NEEA also opined that, given the 215 annual cycles assumed in the dishwasher test procedure for the calculation of EAEU, consumers are unlikely to require a short cycle regularly. Furthermore, based on the NEEA-PG&E market study, NEEA found that on average, more efficient dishwashers have a shorter cycle time. (NEEA, at pp. 5-6) NEEA asserted that DOE's proposal for the short-cycle product class violates two EPCA provisions: (1) the anti-backsliding provision in EPCA (42 U.S.C. 6295(o)(1)), and (2) EPCA's provision which prescribes test procedure and standards requirements for

[e] Normal cycle is the cycle type, including washing and drying temperature options, recommended in the manufacturer's instructions for daily, regular, or typical use to completely wash a full load of normally soiled dishes including the power-dry feature. Section 1.12 of Appendix C1.

dishwashers of all cycle lengths (42 U.S.C. 6295(g)(9)), which would not allow short-cycle dishwashers without applicable standards. NEEA stated that DOE should eliminate the short-cycle product class, or if that is not feasible, initiate a rulemaking to consider identical updated standards for the short-cycle and standard-size product classes. (NEEA, No. 12 at p. 6)

The CA IOUs commented that it does not support the short-cycle product class for dishwashers. The CA IOUs stated that the 2018 short-cycle product class petition was unsupported by the data put forth by the Competitive Enterprise Institute,[5] and the subsequent NOPR and October 2020 Final Rule failed to address critical issues that could impact the standards rulemaking. The CA IOUs further commented that since there are no energy conservation standards for short-cycle products, and no test procedure to allow certification to this new product class, the potential savings of the current rulemaking could be significantly impacted due to the uncertainty in the number of products that would fall under the existing dishwasher standard and would therefore be subject to more stringent standards. According to the CA IOUs, the current absence of energy conservation standards for the short-cycle product class would likely constitute backsliding under EPCA, as amended. Therefore, the CA IOUs stated that DOE should conduct a rulemaking to withdraw the short-cycle product class for dishwashers. (CA IOUs, No. 8 at p. 6)

The CA IOUs also commented that the findings presented in the notice of data availability (NODA) test data (hereinafter, the NODA test data),[6] which was posted on the rulemaking docket along with the October 2020 Final Rule, do not support any significant industry effort to develop a dishwasher with a normal cycle that has a cycle time less than 60 minutes, as 23 percent (7 out of 31) of the models tested would only need to update product literature to define the short-cycle as a normal cycle before entering the market. The CA IOUs cited the October 2020 Final Rule, in which DOE stated there were no eligible short-cycle products with cycle times of 60 minutes or less for a cycle that is recommended by the manufacturer for a full load of normally soiled dishes that also obtain a cleaning index of 70 or greater at all soil levels. The CA IOUs stated that the cleaning index threshold of 70 was not necessary, since it is not required under existing regulation and, of the data presented by DOE, only 11 of the 31 models met this threshold for the normal cycle. (CA IOUs, No. 8 at pp. 6–7)

The CA IOUs further commented that if the dishwashers selected by DOE represent a general distribution of dishwasher operation for the entire market, then 23 percent of the dishwashers on the market could move to an unregulated short-cycle product class by implementing minor changes to the manufacturer literature, which would be a potentially substantial disruption to the product class distribution and would pose questions on previous DOE evaluations of dishwasher trial standard levels (TSLs). Therefore, the CA IOUs recommended that, if the short-cycle product class is not withdrawn, DOE implement energy conservation standards for the short-cycle product class at the same levels as the current standards for standard-size dishwashers. (CA IOUs, No. 8 at p. 7)

An individual commented in support of the new short-cycle product class, stating it could help further reduce the amount of energy used per year. The individual suggested that a potential way to realize energy savings from the short cycle would be to provide a "certification" to units that offer a short cycle. The individual further recommended a short-cycle ENERGY STAR rating to encourage manufacturers to include such a feature to further reduce dishwasher energy usage. (Individual, No. 4 at p. 1)

As noted, DOE is not addressing potential energy conservation standards for the new product class as part of the present evaluation because DOE issued the January 2022 Pre-Publication Final Rule revoking the final rule that established the new product class for dishwashers.

P. R. China also commented that DOE should further improve the classification of dishwashers and provide corresponding testing procedures, asserting that the classification of dishwashers by DOE can no longer cover all types of dishwashers on the market, such as in-sink dishwashers. (P. R. China, No. 5 at p. 3) DOE notes that the December 2021 NOPR includes proposed test requirements for compact in-sink dishwashers. 86 FR 72738, 72746. Based on DOE's initial review of compact in-sink dishwashers available on the market, a separate product class would not be warranted for these products at this time since these products meet the definition of compact dishwashers.

2.3.2 Technology Assessment

DOE typically uses information relating to existing and past technology options and working 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 dishwashers through review of previous rulemakings for dishwashers, product literature, technical papers, market assessment, and product teardowns.

In the October 2020 RFI, DOE sought comments on any changes to these technology options that could affect whether DOE could again propose a "no-new-standards" determination, such as an insignificant increase in the range of efficiencies and performance characteristics of these technology options. 85 FR 64981, 64982–3 (Oct. 14, 2020). AHAM commented that there are few available additional technology options for improving energy efficiency in dishwashers. Manufacturers have selected virtually all of the viable technology options across their product lines. (AHAM, No. 6 at pp. 6–7) NEEA commented that DOE should consider the 13 technology options listed in the 2014 NOPR TSD,[7] many of which are likely employed in current models, that are available to improve dishwasher efficiency and update the standard accordingly. NEEA further commented that DOE should consider technology options to reduce heating energy in the household water heater and/or the dishwasher itself, which include (i) reduced use of heated drying, (ii) wastewater heat recovery, (iii) thermal energy storage using materials that absorb water vapor, (iv) reduced inlet water temperature, and (v) heat pump water heating instead of the electric resistance heating element. (NEEA, No. 12 at pp. 2–3)

Whirlpool commented that there are no new technologies that would save energy and water without impacting performance or cycle time. Whirlpool commented that all available technologies that are technologically feasible and cost-effective are already being used and maximized in today's dishwashers. (Whirlpool, No. 7 at p. 9)

As mentioned previously, DOE determined the available dishwasher technology options for this preliminary analysis through review of the previous dishwasher rulemaking, product literature, and technical papers. Additionally, these technology options include those that reduce water heating energy as discussed in more detail in chapter 3 of the preliminary TSD. DOE evaluated technology options that improve the energy and water consumption of a dishwasher. Technology options to reduce heating energy in the household water heater are not considered, since these do not directly impact the calculated estimated annual energy use of a dishwasher. Additionally, any technology options that negatively impact dishwasher performance would be screened out in the screening analysis as discussed in section 2.4 of this chapter.

Chapter 3 of this preliminary TSD includes the detailed list of all technology options identified for potential efficiency improvements in dishwashers.

2.4 SCREENING ANALYSIS

The screening analysis examines various technologies to determine whether they: (1) are technologically feasible; (2) are practicable to manufacture, install, and service; (3) have an adverse impact on product utility or availability; (4) have adverse impacts on health and safety; and (5) utilize proprietary technology that represents a unique pathway to achieving a given efficiency level. 10 CFR part 430, subpart C, appendix A, 6(b)(3) and 7(b). 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 October 2020 RFI, DOE also requested comment on whether any of these technologies may impact product features or consumer utility. 85 FR 64982, 64983 (Oct. 14, 2020). Whirlpool commented that technologies to improve drying performance, such as door opening systems, have potential negative implications and would need to be investigated further before being considered a technology option. Whirlpool also commented that a water re-use tank is another possible technology option to save water, but has a high customer cost, which would make it impractical to use on most dishwashers, and such technology has an increased possibility of leaks, which would be a quality impact for manufacturers and consumers. (Whirlpool, No. 7 at p. 9)

DOE will evaluate door opening to improve drying performance as a technology option, including any potential negative implications of such an option. While DOE is aware of a single dishwasher model that utilizes a water re-use tank as a design option,[f] that model is listed as discontinued and unavailable to consumers on retail sites. Additionally, leaking and contamination from a water holding tank could potentially present a safety hazard in addition to possible consumer utility impacts. For these reasons, DOE did not consider this technology option when analyzing dishwasher efficiency.

In the engineering analysis, DOE further considered efficiency enhancement options that it did not screen out in the screening analysis. Chapter 4 of this preliminary TSD contains details on the screening analysis for dishwashers.

2.5 ENGINEERING ANALYSIS

The purpose of the engineering analysis is to establish the relationship between the efficiency and cost of dishwashers. There are two elements to consider in the engineering analysis; the selection of efficiency levels to analyze (*i.e.*, the efficiency analysis) and the determination of product cost at each efficiency level (*i.e.*, the cost analysis). In determining the performance of higher-efficiency products/equipment, DOE considers technologies and design option combinations not eliminated by the screening analysis. For each product class, DOE estimates the baseline cost, as well as the incremental cost for the product at efficiency levels above the baseline. The output of the engineering analysis is a set of cost-efficiency "curves" that are used in downstream analyses (*i.e.*, the LCC and PBP analyses and the NIA).
Chapter 5 of this preliminary TSD discusses the product classes DOE analyzed, the representative baseline units, the incremental efficiency levels, the methodology DOE used to develop MPCs, the cost-efficiency curves, and the impact of efficiency improvements on the considered products.

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[f] DOE granted a test procedure waiver to Whirlpool for a KitchenAid brand basic model KDTE554C++# equipped with a "water use system" in November 2013. Docket available here: *https://www.regulations.gov/docket/EERE-2013-BT-WAV-0042*

DOE typically uses one of two approaches to develop efficiency levels for the engineering analysis: (1) relying on observed efficiency levels in the market (*i.e.*, the efficiency-level approach), or (2) determining the incremental efficiency improvements associated with incorporating specific design options to a baseline model (*i.e.*, the design-option approach). Using the efficiency-level approach, the efficiency levels established for the analysis are determined based on the market distribution of existing products (in other words, based on the range of efficiencies and efficiency level "clusters" that already exist on the market). Using the design option approach, the efficiency levels established for the analysis are determined through detailed engineering calculations and/or computer simulations of the efficiency improvements from implementing specific design options that have been identified in the technology assessment. DOE may also rely on a combination of these two approaches. For example, the efficiency-level approach (based on actual products on the market) may be extended using the design option approach to interpolate to define "gap fill" levels (to bridge large gaps between other identified efficiency levels) and/or to extrapolate to the max-tech level (particularly in cases where the max-tech level exceeds the maximum efficiency level currently available on the market).

For this preliminary analysis, DOE used a combination of these engineering approaches. This approach involved physically disassembling commercially available products, reviewing publicly available cost information, and modeling equipment cost. From this information, DOE estimated the MPCs for a range of products currently available on the market. DOE then considered the incremental steps manufacturers may take to reach higher efficiency levels. 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. DOE also provides further discussion on the design options and efficiency improvements in chapter 5 of this preliminary TSD.

In response to the October 2020 RFI, AHAM commented that energy efficiency improvements involve either additional or more expensive components. AHAM further commented that DOE must assess the incremental cost to achieve lower energy use within a product platform, while accounting for any associated changes in the chassis size and weight, which could result in expensive retooling and may change the fundamental product manufacturing approach. AHAM asserted that in order to go beyond ENERGY STAR V. 6.0 levels for the energy conservation standard, manufacturers would need to redesign and retool virtually all product platforms across the entire dishwasher industry. (AHAM, No. 6 at pp. 7–8)

DOE does take into consideration the costs associated with a platform change, if it determines that a given efficiency level cannot be reached without changing the manufacturing platform. For dishwashers, however, product teardowns initially indicated that improved efficiency could be achieved without a platform change up to the max-tech efficiency level for standard-size dishwashers, at which point DOE estimates a change in platform. For compact dishwashers, product teardowns initially indicated that a platform change would not be required at any efficiency level.

AHAM commented that there may be a limited number of dishwasher models that can achieve efficiency at levels higher than ENERGY STAR V. 6.0 while maintaining product performance, but such models may be costlier to consumers and these higher efficiency levels may not be achievable by a broad range of products and platforms. AHAM reiterated its comments, as well as results from testing conducted in support of the December 2016 Final Determination, to state that any standard that is more stringent than the ENERGY STAR V. 6.0 levels would negatively impact performance. AHAM commented that manufacturers report and consumer feedback indicated that consumers are dissatisfied at levels that are less stringent than the ENERGY STAR V. 6.0 levels. For these reasons, AHAM would oppose standards beyond ENERGY STAR V. 6.0. (AHAM, No. 6 at pp. 4–5)

Whirlpool reiterated the results from its 2015 investigative testing, which it had previously submitted as comments in response to the December 2016 Final Determination as well as to EPA in response to ENERGY STAR Draft 1 V. 7.0, wherein Whirlpool concluded that the only cost-effective and technologically-feasible option for lowering energy and water consumption to meet the ENERGY STAR Draft 1 V. 7.0 proposed levels would be to exchange that efficiency improvement for reduced performance. Whirlpool conducted this testing on three dishwashers that were identical except for varying wash/rinse temperatures, cycle times, and estimated annual energy and water consumption. Based on consumer feedback and evaluation of water samples, Whirlpool concluded that the ENERGY STAR V. 6.0 criteria may already be beyond the ability to offer consumer-acceptable cleaning performance using an optimal loading pattern and, according to Whirlpool, this would be exacerbated by more stringent standards. Whirlpool stated that lower energy and water levels would force lower wash and rinse temperatures, and fewer water exchanges, which would impede the ability to effectively clean dishes. (Whirlpool, No. 7 at pp. 5–7)

AHAM commented that several aspects of dishwasher performance, such as cleaning performance, cycle time, drying performance, and noise level, would be impacted at levels beyond the ENERGY STAR V. 6.0 qualification criteria. (AHAM, No. 6 at p. 4) Whirlpool also identified cleaning performance, drying performance, and cycle time as potential issues. Whirlpool further commented that DOE should evaluate the implications of updated standards on performance, consumer satisfaction, and any consumer behavioral changes. Whirlpool commented that cleaning performance would degrade with more stringent standards unless the issues with water filtration technology and poor water dilution (*i.e.,* if water use is too low, there may not be enough water exchanges to dilute the leftover soils to get the final rinse water clean) are addressed. (Whirlpool, No. 7 at pp. 6-7) Whirlpool commented that while there may be some limited examples of improved dishwasher efficiency in recent years, its internal testing and consumer satisfaction surveys indicate that this improvement in dishwasher energy and water efficiency occurs at the expense of cleaning and drying performance and cycle time increases. Whirlpool cautioned that some stakeholders may assert that its lab testing indicates that performance has been maintained or improved, but this testing does not closely replicate testing using the DOE test procedure, so is not "consumer representative." Additionally, Whirlpool commented that some performance improvement is due to the improvement in dishwasher detergent efficacy since the phosphate ban in 2010. (Whirlpool, No. 7 at pp. 9–10)

The CA IOUs commented that in the December 2016 Final Determination, DOE did not adopt a more efficient TSL due to concerns raised by stakeholders regarding the cleaning performance of efficient models. To mitigate these concerns, the CA IOUs recommended using the Consumer Reports scoring method, which provided a mean score of 4.2 out of 5 to dishwashers that are rated at or above the ENERGY STAR Draft 1 V. 7.0 levels. (CA IOUs, No. 8 at p. 8) Further, the CA IOUs and the Joint Commenters evaluated the NODA test data and commented that they found no correlation between cleaning performance and product efficiency. Units with energy consumption as low as 200 kWh/year achieved a weighted-average cleaning score of 70, whereas a unit near 300 kWh/year produced a weighted-average cleaning score less than 70. (CA IOUs, No. 8 at pp. 8–10; Joint Commenters, No. 11 at pp. 2–3) The CA IOUs commented that over 70 percent of the tested units had a weighted-average cleaning score of 70 or higher for water consumption between 3.1 and 3.5 gal/cycle. (CA IOUs, No. 8 at p. 9) The CA IOUs asserted that since there is no correlation between cleaning scores and water and energy consumption, and the many dishwasher models met or exceeded a weighted average cleaning score of 70 at various efficiency levels, more stringent standards up to the ENERGY STAR Draft 1 V. 7.0 levels would be justified. (CA IOUs, No. 8 at pp. 8–10)

NEEA commented that its review of Consumer Reports rating data revealed that more than 80 percent of the models with the highest energy rating have good customer satisfaction ratings, and the 2020 NEEA-PG&E Market Research Study also found high consumer satisfaction with efficient dishwashers based on reviews from retailer websites. NEEA commented that high consumer satisfaction for more efficient dishwashers indicated that a standards update to include more efficient dishwasher technologies was justified. (NEEA, No. 12 at p. 4) AHAM commented that Consumer Reports uses different, non-public test procedures and cycles to evaluate dishwasher performance and that DOE must understand the basis and comparability of performance statements. (AHAM, No. 6 at p. 5) AHAM and Whirlpool opined that consumers would not accept poor performance and would engage in compensatory behaviors that would cause additional energy and water usage, such as running the dishwasher more than once, using heavier cycles, pre-rinsing, and hand-washing. (AHAM, No. 6 at p. 6; Whirlpool, No. 7 at p. 6) AHAM further commented that if performance of the normal cycle is affected by standards that are too stringent, consumers might be more likely to select other cycles that are not tested under the DOE test procedure, which could use more energy and/or water and thus impact the projected energy savings. (AHAM, No. 6 at p. 6)

DOE notes that the Consumer Reports scoring methodology is not publicly available. Additionally, DOE evaluated cleaning performance of dishwashers on the same cycles that measure energy and water consumption for soil-sensing dishwashers and using the same test methodology for non-soil-sensing dishwashers as specified in the DOE test procedure at 10 CFR 430, Appendix C1. This approach allows direct evaluation of cleaning performance to energy and water consumption. Further, as discussed in more detail in chapter 5 of this preliminary TSD, DOE determined that a cleaning index of 65 can be maintained up to, and including, the ENERGY STAR Most-Efficient levels. DOE reiterates that when evaluating potential energy and water consumption standards, impact on performance is one of several aspects that DOE analyzes.

AHAM commented that water heating is the biggest contributor to the energy use of a dishwasher and if manufacturers must further reduce water heating energy, it could lead to lengthening cycle times to maintain cleaning performance. AHAM stated that this is because wash temperature must be maintained at 120–140 degrees Fahrenheit (°F) to break up surface oils and fats to avoid leaving residual film buildup. AHAM commented that in order to reduce energy and water use and maintain cleaning performance, it is likely that cycle time will reach a level unacceptable to consumers. AHAM commented that the shipment-weighted average normal cycle time has increased from 1.76 hours in 2015 to 2.02 hours in 2019, which is a 14.8 percent increase. AHAM commented that if DOE were to amend standards to levels more stringent than ENERGY STAR V. 6.0 levels, cycle time could increase to 3 or more hours. (AHAM, No. 6 at pp. 3, 5–6) Whirlpool commented that dishwasher cycle durations could increase 20–40 minutes if more stringent standards are established to compensate for lower water levels and temperatures. According to Whirlpool, longer cycle durations could also impact the drying performance of the dishwasher, if consumers cannot unload the dishwasher soon after a cycle ends (within an hour after the end of a cycle) due to the moisture from the dishwasher's ambient air condensing back onto the dish items as they cool. (Whirlpool, No. 7 at p. 7)

AHAM also commented that counting the number of models in DOE's Compliance Certification Database (CCD) as a means of determining the availability of technologies would overstate the number of actual products. AHAM stated that many higher efficiency models listed in the CCD are discontinued or no longer widely available through retail channels, indicating that these products did not meet either, or both, consumer acceptance and competitive cost levels. (AHAM, No. 6 at p. 7) AHAM further commented that DOE should review the key assumptions in its consumer economic analysis. In particular, AHAM commented that DOE should review the technology options necessary to achieve reduced energy and water consumption when evaluating the consumer cost impacts. (AHAM, No. 6 at p. 9) NEEA commented that strong consumer demand for high-efficiency dishwashers, as evidenced by the high sales volume of ENERGY STAR dishwashers, and other efficiency innovations in European markets and the ENERGY STAR Most Efficient qualification have allowed costs of efficient technologies to decline substantially since DOE's last rulemaking. NEEA asserted that these factors would make many technology options that were previously expensive, cost effective. (NEEA, No. 12 at pp. 4–5)

When determining the efficiency levels to analyze for this preliminary analysis, particularly the max-tech efficiency level, DOE screened out all models from the CCD that were discontinued or not available through retail channels. DOE also screened out max-tech efficiency models if they utilized technology options that DOE screened out from its analysis. DOE's approach for the selection of each of the efficiency levels is discussed in more detail in chapter 5 of this preliminary TSD. DOE also determined costs of efficient technologies through a combination of product teardowns and review of publicly available cost information. Chapter 5 of this preliminary TSD describes the methodology and results of the analysis used to derive the cost-efficiency relationships.

2.6 MARKUPS ANALYSIS

DOE analyzed product markups to convert the MPCs, estimated in the engineering analysis, to consumer prices, which then are used in analyzing the LCC and PBP and manufacturer impacts. To develop markups, DOE identified how dishwashers are distributed from the manufacturer to the consumer. After identifying 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 products pass from the manufacturer to the consumer. The manufacturer markup converts MPC to manufacturer selling price (MSP). DOE developed an average manufacturer markup by examining the annual Securities and Exchange Commission (SEC) 10-K reports filed by publicly traded manufacturers primarily engaged in appliance manufacturing. DOE calculated markups for baseline products (baseline markups) and for more efficient products (incremental markups). The incremental markup relates the change in the manufacturer sales price of higher-efficiency models (the incremental cost increase) to the change in the retailer or distributor sales price.

AHAM raised concerns about key assumptions regarding DOE's use of average consumer cost of capital in its consumer financial discount rate and the use of incremental markups for retailers. AHAM commented that DOE should not proceed with any analyses of LCCs or other metrics until the study conducted by The National Academies of Sciences, Engineering and Medicine (NAS) has been completed, including its review of the assumptions used in the 2016 rulemaking. (AHAM, No. 6 at p. 10)

The NAS began meeting for its review of the Methods for Setting Building and Equipment Performance Standards program on November 19, 2019 and had its latest meeting on February 3, 2021. The NAS recently published its final report and DOE is reviewing the NAS report recommendations. However, DOE is under statutory requirements to complete its rulemaking analyses and will proceed with its rulemaking obligations.

The concept of DOE's incremental markup approach is based on a simple notion that an increase in profitability, which is implied by keeping a fixed markup when the product price goes up, is not likely to be viable over time in a business that is reasonably competitive. DOE's analysis necessarily considers a very simplified version of the world of appliance retailing: namely, a situation in which nothing changes except for those changes in appliance offerings that occur in response to amended standards.

DOE recognizes that retailers are likely to seek to maintain the same markup on appliances if the price they pay goes up as a result of appliance standards, but it believes that over time adjustment is likely to occur due to competitive pressures. Other retailers may find that they can gain sales by reducing the markup and maintaining the same per-unit operating profit. Additionally, DOE contends that retail pricing is more complicated than a simple fixed profit margin.

DOE acknowledges that its approach to estimating retailer markup practices after amended standards take effect is an approximation of real-world practices that are both complex and varying with business conditions. However, DOE continues to maintain that its assumption that standards do not facilitate a sustainable increase in profitability is reasonable.

Chapter 6 of the preliminary analysis TSD provides details on DOE's development of markups for residential dishwashers.

2.7 ENERGY AND WATER USE ANALYSIS

To conduct the LCC and PBP analyses described in section 2.8, DOE must determine the operating cost savings to consumers from using more efficient products. The goal of the energy and water use analysis is to determine the annual energy and water consumption of dishwashers for use in the LCC and PBP analyses. Energy use characterization generates a range of use values that reflect real-world dishwasher use in American homes. By incorporating data on how dishwashers are used by U.S. consumers, DOE can estimate the energy that would be consumed (or potentially saved) by units having various efficiency levels.

Per-cycle water use is taken from the engineering analysis. To establish a reasonable range of energy consumption in the field for dishwashers, DOE primarily used data from the U.S. Energy Information Administration's (EIA's) 2015 *Residential Energy Consumption Survey* (*RECS 2015*).[8] *RECS* is a national sample survey of housing units that collects statistical information on the consumption of and expenditures for energy in housing units along with data on energy-related characteristics of the housing units and occupants. *RECS 2015* has a sample size of 5,686 housing units and was constructed by EIA to be a national representation of the household population in the United States. DOE's assumptions for establishing a dishwasher sample included the following considerations: (1) the household had a dishwasher and (2) the dishwasher use was greater than zero.

AHAM commented that DOE should update its estimate of 215 annual cycles and use 184 cycles per year based on the recently published AHAM DW-1-2020. (AHAM, No. 6 at pp. 9–10)

The energy use analysis requires DOE to establish a range of total annual usage or number of cycles in order to estimate annual energy consumption by a dishwasher. DOE estimated the number of dishwasher cycles per year for each sample household using data given by *RECS 2015* on the number of dishwasher cycles per week. DOE determined a range of annual energy and per-cycle water consumption of residential 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 found in *RECS 2015*. These data yielded a weighted average usage of 185 cycles per year.

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 residential dishwasher cycles per year. DOE used data regarding cycle duration provided by AHAM in response to the August 2019 Test Procedure RFI . Average cycles are assumed to have a duration of 122.6 minutes for standard-size dishwashers and 95.4 minutes for compact sized dishwashers.

DOE analyzed per-cycle energy consumption based on two components: (1) water-heating energy, and (2) machine (motor) and drying energy. Values for the two components are drawn from the engineering analysis. See section 2.4 for more information. The following equation for total annual energy use from the DOE test procedure demonstrates how per-cycle dishwasher energy use is determined for use in the LCC and PBP analysis.

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

Where:

DW_{ANNUAL} = total annual dishwasher energy consumption,
DW_{CYCLE} = per-cycle dishwasher energy consumption,
N = representative annual dishwasher use,
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 from the engineering analysis and from AHAM data, the per-cycle dishwasher energy consumption is found by:

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

AHAM and Whirlpool commented that DOE should consider the amount of water and energy used to rinse or pre-clean dishes before loading into dishwashers or use of more energy intensive cycles to achieve the desire level of cleaning. (AHAM, No. 6 at p. 8; Whirlpool, No. 7 at p. 7)

Testing conducted in support of the October 2020 Final Rule[g] indicated that a cleaning index of 65, which is the cleaning index threshold that DOE is proposing in the December 2021 NOPR as a condition for a test cycle to be considered valid (86 FR 72756-59), was achievable at all efficiency levels except the highest efficiency level, at which point cleaning performance was uncertain (Chapter 5 of this preliminary TSD discusses cleaning performance in more detail). DOE considers pre-rinsing dishes a practice driven by consumer behavior, and therefore believes that it will occur in both the no-new-standards case and in the standards-case. As a result, the amount of water and energy used for pre-rinsing in the no-new-standards case and standards-case is expected to be the same.

Chapter 7 of the preliminary analysis TSD provides more detail about DOE's approach for characterizing energy and water use of residential dishwashers.

2.8 LIFE-CYCLE COST AND PAYBACK PERIOD ANALYSIS

In determining whether an energy conservation standard is economically justified, DOE considers the economic impacts of efficiency levels on consumers. Energy conservation standards produce a change in consumer operating costs—usually a decrease—and a change in product purchase price—usually an increase. DOE used the following two metrics to measure potential impacts on consumers.

- LCC is the total consumer cost of an appliance or product, generally over the life of the product. The LCC calculation includes total installed cost (product MSP, markups through the distribution channel, sales tax, and any installation costs), operating costs (energy, repair, and maintenance costs), product 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 measures the amount of time required for consumers to recover the assumed higher purchase price of a more energy efficient product through reduced operating costs. Inputs to the calculation of PBP include the installed cost to the consumer and first-year operating costs. DOE's analysis produces a simple PBP based on using single-point average values to estimate the purchase price and undiscounted first-year operating cost.

DOE analyzed the net effect on consumers of potential standards for dishwashers by calculating the LCC and PBP using the engineering performance data, energy and water use data, and markups. Other inputs included retail prices and installation costs, energy and water prices, discount rates, and product lifetimes. DOE examined installation, maintenance, and repair costs for the efficiency levels considered in this preliminary analysis.

As described in section 2.7, DOE developed samples of individual households that use dishwashers. By developing such samples, DOE was able to calculate the LCC to account for the variability in energy consumption and electricity price among users of dishwashers. DOE used probability distributions to characterize discount rates and product lifetimes. To estimate the percentage of consumers who would be affected by a standard at each efficiency level, the LCC analysis considered the projected distribution of efficiencies for dishwashers purchased under the no-new-standards case.

DOE used Monte Carlo simulations and probability distributions to model both the uncertainty and variability in inputs to the LCC and PBP analysis. DOE developed LCC and PBP spreadsheet models that incorporate the results of Monte Carlo simulations sampling from probability distributions. Because certain key inputs to the analysis consist of probability distributions rather than single-point values, the analysis produces a range of LCC and PBP results that enables DOE to identify the percentage of consumers who will achieve LCC savings or incur net cost at each considered efficiency level.

In performing an iteration of the Monte Carlo simulation for a given consumer, product efficiency is chosen based on its probability. If the chosen product efficiency is greater than or equal to the efficiency level under consideration, the LCC and PBP calculation reveals that a consumer is not affected by the efficiency level. By accounting for consumers who already purchase more efficient products, DOE avoids overstating the potential benefits from increasing product efficiency.

2.8.1 Total Installed Cost Inputs

The total installed dishwasher cost equals the consumer product price plus the installation cost. DOE used cost data from a reverse engineering analysis and manufacturer interviews to develop manufacturer cost increases associated with increases in standard levels for residential dishwashers. Refer to section 2.4, Engineering Analysis, for details. Markups are used to convert the manufacturer cost to a consumer product price and have been described in section 2.5.

AHAM commented that there is variability in retail pricing and that it may not always provide a complete picture of actual costs for future products, which could also impact the consumer economic analysis. (AHAM, No. 6 at p. 9)

DOE used the historic producer price index (PPI) for "other miscellaneous household appliances excluding room air conditioners" to project a price trend for dishwashers. DOE understands that the category "other miscellaneous household appliances" encompasses 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.

2.8.2 Operating Cost Inputs

Operating costs include costs of operating a dishwasher over its lifetime. Dishwasher energy and water consumption form the basis of cost amounts and have been described in section 2.7, Energy and Water Use. Other inputs for operating costs include energy and water prices, lifetime, and discount rates.

Product Energy and Water Prices

For electricity and natural gas prices, DOE used marginal and average prices which vary by season and region. DOE estimated regional monthly electricity prices for 2020 using data from Form 861-M.[9] For natural gas prices, DOE obtained 2020 data for calculating regional monthly prices of natural gas from the EIA publication, *Natural Gas Navigator*.[10] EIA provides historical monthly natural gas consumption and expenditures by state. These data were used to determine 10-year average summer and winter marginal prices factors for the *RECS 2015* geographical areas, which are then used to convert average monthly energy prices into marginal monthly energy prices. For liquid petroleum gas (LPG) and distillate oil, DOE collected 2019 average LPG and distillate oil prices from EIA's State Energy Consumption, Price, and Expenditures Estimates.[11] DOE assigned an average price to all sampled households based on each household's location and its baseline energy consumption. For sampled households who were assigned a product efficiency that is greater than or equal to the efficiency of the considered efficiency level, DOE assigned a marginal price to each household based on its location and the reduction in energy consumption. DOE then used projections of the prices from EIA's *Annual Energy Outlook* (*AEO) 2021*[12] to estimate future electricity, natural gas, LPG, and distillate oil prices.

DOE obtained the most recent, complete dataset on public supply water and wastewater prices from the *2016 Water and Wastewater Rate Survey* conducted by Raftelis Financial Consultants and the American Water Works Association.[13] The survey covers approximately 263 water utilities and 181 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 price average would lead to a slightly higher water price. For wastewater utilities, the data format is similar to the water utility data, except that the price represents the cost to treat a given volume of wastewater. A sample of 263 or 181 utilities is too small to calculate regional prices for all U.S. Census divisions. (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).

In response to the October 2020 RFI, AHAM commented that the weighted average cost of water should account for the percentage of households with well water and/or off sewer systems. (AHAM, No. 6 at p. 9)

For this dishwasher rulemaking, DOE also developed water prices for consumers who rely on private well water systems for their water needs rather than the public supply system. The *American Housing Survey* (*AHS*) collects data on the primary source of water and type of sewage system for U.S. households. In its 2019 survey, *AHS* estimated that 13.8 million households used individual wells, about 11 percent of all households.[14] In the same survey, *AHS* estimated that 20.5 million households were not on a public sewer system, about 17 percent of all households. In 2009, the National Groundwater Association estimated that the annual economic value of the water pumped privately by individual households is $3.3 billion, and the value of the installed well/pump infrastructure is $64.3 billion.[15] Based on the historic trend of national water price index (U.S. city average),[16] DOE extrapolated the appropriate water costs - (either public system or private) in 2027 and applied the projected representative share of U.S. consumers relying on that water source to derive weighted average regional water prices.

Product Lifetime

DOE used probability distributions to characterize 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 *AHS*,[17] which surveys all housing including vacant and second homes, enabled DOE to adjust the *RECS* data to reflect some appliances use outside of primary residences. By combining the results of both surveys with the known history of appliance shipments (collected from *Appliance* magazine and 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 estimates of appliance lifetime, as well as the appliance failure rate for all ages in the possible age range.

AHAM commented that DOE's estimate of mean dishwasher lifetime of 15.4 years from 2016 was higher than the estimate of 12.6 years found in Navigant's 2010 study for ACEEE and AHAM's estimate of 13 years. (AHAM, No. 6 at pp. 9–10)

Using the historical shipments data combined with *RECS 2015* and *AHS 2019*, which are the most current publicly available nationally representative information, DOE calculated the average lifetime for both product classes at 15.2 years using the method described above.

Discount Rates

DOE used probability distributions to characterize discount rates. DOE developed discount rates for consumers that purchase dishwashers. DOE developed discount rates from estimates of the interest rate, or finance cost, applied to purchases of consumer products. Following accepted principles of financial theory, the finance cost of raising funds to purchase products can be interpreted as (1) the financial cost of any debt incurred by the purchase, principally interest charges on debt; or (2) the opportunity cost of any equity used for the purchase, principally forfeited interest earnings on household equity.

AHAM raised concerns about key assumptions regarding DOE's use of average consumer cost of capital in its consumer financial discount rate (AHAM, No. 6 at p. 10)

With respect to the issue of DOE's use of average consumer cost of capital in its consumer financial discount rate, DOE maintains that the LCC is not predicting a purchase decision; rather, it is estimating the net present value of the financial impact of a given standard level over the lifetime of the product (*i.e.*, 30 years) assuming the standard-compliant product has already been installed. It is applied to future-year energy costs and non-energy operations and maintenance costs in order to calculate the net present value of the appliance to a household at the time of installation. The consumer discount rate reflects the opportunity cost of receiving energy cost savings in the future, rather than at the time of purchase and installation. The opportunity cost of receiving operating cost savings in future years, rather than in the first year of the modeled period, is dependent on the rate of return that could be earned if invested into an interest-bearing asset or the interest cost accrual avoided by paying down debt. Consumers generally hold a variety of assets (*e.g.*, certificates of deposit, stocks, bonds) and debts (*e.g.*, mortgage, credit cards, vehicle loan), which vary in amount over time as consumers allocate their earnings, make new investments, *etc.* Thus, the consumer discount rate is estimated as a weighted average of the rates and proportions of the various types of assets and debts held by households, as reported by the Survey of Consumer Finances. An average, rather than marginal, rate is appropriate in this context because the LCC: 1) does not model the purchase decision, in which an implicit discount rate or the interest rate of the purchase method would be relevant, and

2) spans a long enough time frame that a marginal rate is not appropriate because consumers will naturally shift their holdings of assets and debts to achieve their preferred balance of risk and liquidity.

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

2.9 SHIPMENTS ANALYSIS

DOE needs projections of product shipments to calculate the national impacts of potential standards on energy use, NPV, and future manufacturer cash flows. DOE projected shipments based on an analysis of key market drivers for dishwashers. DOE estimated future shipments of dishwashers to two market segments: (1) replacements; and (2) homeowners that previously had no dishwashers, including new construction ("first-time owners").

To project shipments of replacement units, DOE used the 15.2-year estimated lifetime and a retirement function obtained based on *RECS* and *AHS* historical data for dishwashers. DOE applied that retirement function to the current stock of products. DOE's shipments model, which takes a stock accounting approach, uses historical product shipment data as inputs to estimate the age distribution of in-service product stocks for all years. The age distribution of 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.

To estimate shipments to first-time owners, DOE used projections of housing starts coupled with dishwashers' saturation data. To calibrate estimated shipments with the historical data, DOE introduced into the model a non-replacement market function.

DOE also accounted for the impacts on shipments from changes in product purchase price and operating costs associated with higher energy efficiency levels. DOE implemented purchase price elasticity in the shipments model to capture any impact of a price increase due to potential proposed standards on the consumer's decision to install a dishwasher in the new construction market. In the replacement market, DOE assumed that, in response to an increased product price, some consumers will choose to repair their old dishwasher and extend its lifetime instead of replacing it immediately. DOE estimated the magnitude of such impact through a purchase price elasticity of demand. The estimated price elasticity of -0.45 is based on data for dishwashers.

AHAM commented that DOE needs to develop a more robust shipments model that explicitly accounts for likely consumer behavior and must not assume only a deferral relationship between price and shipments because dishwashers are not a consumer necessity given that about 67 percent of households own a dishwasher according to *RECS 2015*. (AHAM, No. 6 at p. 8)

DOE believes that its shipments model accounts for consumer behavior regarding dishwasher purchase. The importance of dishwashers to consumers is highlighted by the fact that dishwasher ownership has increased over time; *AHS 2019* showed 73.9 percent of households owning a dishwasher.[h] Given the increasing presence of dishwashers in households over time, it is probable that a dishwasher that reaches the end of its lifetime would be replaced. However, higher dishwasher prices could cause some homeowners or landlords to undertake repair of an existing unit deferring replacement. DOE's use of a price elasticity of demand provides a reasonable accounting of this behavior. For new homes, it is unlikely that a small increase in dishwasher price would cause home builders to omit a dishwasher if it was part of their kitchen design, as is very common.

Stratton, *et al*. showed that based on a 2019 consumer survey of national scale, consumer behavior does indicate that that price is the most important consideration for consumer purchasing decisions, followed by sound when in use, dishwasher style, and brand. In a list of 18 options, energy efficiency ranked fifth most important, and energy bill cost savings ranked as the sixth.[18]

Chapter 9 of the preliminary analysis TSD provides additional details on the shipments analysis.

2.10 NATIONAL IMPACT ANALYSIS

The NIA assesses the NPV, to the nation, of total consumer LCC and 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.

Several of the inputs for determining NES and NPV depend on the forecast trends in product energy efficiency. Analyzing impacts of potential energy conservation standards for dishwashers requires comparing projections of U.S. energy consumption with energy conservation standards against projections of energy consumption without standards. The analysis includes projections of annual product shipments, the annual energy consumption of new products, and the purchase price of new products.

[h] American Housing Survey, 2019. *https://www.census.gov/programs-surveys/ahs.html*

For its determination of standards case projected efficiencies, DOE assumed a "roll-up" scenario to establish the efficiency distribution under different candidate standard levels. Product efficiencies in the no-new-standards case that do not meet the standard under consideration would "roll up" to meet the new standard level. All efficiency shares in the no-new-standards case that were above the standard under consideration would not be affected.

2.10.1 National Energy Savings

DOE calculated annual NES as the difference between national energy consumption in the no-new-standards case and under each efficiency level considered. The inputs for determining the NES are: (1) annual energy consumption per unit, (2) shipments, (3) product stock, (4) national energy consumption, and (5) site-to-primary and full-fuel-cycle (FFC) conversion factors for energy. DOE calculated national energy consumption by multiplying the number of units, or stock (by vintage, or age), by the unit energy consumption (also by vintage). DOE estimated energy consumption and savings based on site energy consumption, which it then converted to primary and FFC energy using annual conversion factors derived from the most recent version of the NEMS. Cumulative energy savings are the sum of the NES for each year throughout the forecast period.

2.10.2 Net Present Value of Consumer Benefit

DOE calculated net monetary savings for consumers in each year after potential standards take effect for the base case and each standards-case. The inputs for determining the NPV of the total costs and savings experienced by consumers are (1) total annual installed cost, (2) total annual savings in operating costs, and (3) a discount factor to calculate the present value of costs and savings. DOE calculated savings throughout the lifetime of products shipped in 2027–2056, accounting for differences in yearly energy prices. DOE used the most recent edition of EIA's *AEO* as the default source of projections for future energy prices and total housing stock. In the NOPR stage, DOE also will calculate the NPV assuming energy price scenarios that are higher and lower than the *AEO* reference case.

DOE projected future dishwasher prices by extrapolating the PPI trend described in section 2.8.1. In the NOPR stage, DOE also will calculate the NPV assuming product price trends that are higher and lower than the default product price.

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. DOE calculated NPV as the difference between the present value of operating cost savings and the present value of total installed costs. DOE applied real discount rates of both 3 percent and 7 percent to discount future costs and savings to present values. DOE uses 3-percent and 7-percent real discount rates in accordance with guidance provided by the Office of Management and Budget (OMB) to Federal agencies on the development of regulatory analysis. (OMB Circular A-4 (Sept. 17, 2003), section E, "Identifying and Measuring Benefits and Costs")

Chapter 10 of this preliminary TSD provides additional details regarding the NIA.

2.11 CONSUMER SUBGROUP ANALYSIS

During the preliminary analysis, DOE has identified consumer subgroups that it believes may be affected disproportionately by new or revised energy conservation standards – low-income consumers and senior-only households. In support of a subsequent NOPR, should one be issued, DOE will conduct an LCC subgroup analysis. A consumer subgroup comprises a subset of the population that may be affected disproportionately by new or revised energy conservation standards (*e.g.*, low-income consumers, senior-only households). The purpose of a subgroup analysis is to determine the extent of any such disproportional impacts.

Chapter 11 of this preliminary TSD provides additional details regarding the consumer subgroup analysis.

2.12 MANUFACTURER IMPACT ANALYSIS

In the NOPR phase of analysis, should DOE proceed to a NOPR, DOE will perform an MIA to estimate the impact of potential energy conservation standards on dishwasher manufacturers. The MIA has both quantitative and qualitative aspects. The quantitative parts of the MIA rely on the government regulatory impact model (GRIM), an industry-cash flow model customized for the dishwasher industry. The GRIM inputs are information on the industry cost structure, shipments, and revenues. This includes information from many of the analyses described above, such as manufacturing costs from the engineering analysis and the shipments forecasts. The key GRIM output is the industry net present value (INPV). Different sets of input assumptions (scenarios) will produce different results. The qualitative parts of the MIA addresses factors such as product characteristics, manufacturer characteristics, and market and product trends, and the impacts of standards on manufacturer subgroups. Chapter 12 of the preliminary TSD describes the MIA in further detail.

DOE conducts each MIA in three phases. In Phase I, DOE creates an industry profile to characterize the industry and identify important issues that require consideration. DOE performed preliminary manufacturer interviews for the preliminary analysis as part of its Phase I activities. In Phase II, DOE prepares an industry cash-flow model and interview questionnaire to guide subsequent discussions. In Phase III, DOE interviews manufacturers and assesses the impacts of standards quantitatively and qualitatively. DOE assesses industry and subgroup cash flow and INPV using the GRIM. DOE then assesses impacts on competition, manufacturing capacity, employment, and regulatory burden based on manufacturer interview feedback and discussions.

In response to October 2020 RFI, interested parties commented on the potential magnitude of conversion costs if standards are amended. The CA IOUs noted that 91 percent of shipments today meet ENERGY STAR V. 6.0 and suggested that the redesign costs for industry to meet amended standards at that ENERGY STAR level would be minimal. (CA IOUs, No. 8 at p. 5) AHAM noted that standards that limit energy and water use beyond ENERGY STAR V. 6.0 levels would likely require platform redesigns rather than incremental component changes. AHAM estimated the capital conversion costs to meet standards above the ENERGY STAR V. 6.0 levels would exceed $1 billion. (AHAM, No. 6 at pp. 7, 10)

DOE will investigate conversion costs as part of the MIA conducted during the NOPR phase of analysis, should DOE proceed to a NOPR. Details of the types of conversion costs DOE considers are presented in chapter 12 of this preliminary TSD.

2.13 EMISSIONS IMPACT ANALYSIS

An emissions impact analysis is conducted during the NOPR phase of analysis, should DOE proceed to a NOPR. The emissions analysis consists of two components. The first component estimates the effect of potential energy conservation standards on power sector and site (where applicable) combustion emissions of CO_2, NO_X, SO_2, and Hg. The second component estimates the impacts of potential standards on emissions of two additional greenhouse gases, methane (CH_4) and nitrous oxide (N_2O), as well as the reductions to emissions of all species due to "upstream" activities in the fuel production chain. These upstream activities comprise extraction, processing, and transporting fuels to the site of combustion. The associated emissions are referred to as upstream emissions.

The analysis of power sector emissions uses marginal emissions factors that will be derived from data in the *AEO*.

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

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i Available at: *http://www2.epa.gov/climateleadership/center-corporate-climate-leadership-ghg-emission-factors-hub*

The emissions intensity factors are expressed in terms of physical units per megawatt-hour (MWh) or MMBtu of site energy savings. Total emissions reductions will be estimated using the energy savings calculated in the NIA.

The *AEO* incorporates the projected impacts of existing air quality regulations on emissions. *AEO* generally represents current legislation and environmental regulations, including recent government actions, for which implementing regulations were available as of the time of its preparation. The methodology is described in more detail in chapter 13 of the preliminary analysis TSD.

2.14 MONETIZATION OF EMISSIONS REDUCTION BENEFITS

DOE considers the estimated monetary benefits likely to result from the reduced emissions of CO_2, CH_4, N_2O, sulfur dioxide (SO_2), and NO_X that are projected to result from each of the potential standard levels considered.

For the greenhouse gases CO_2, CH_4, and N_2O, DOE estimates the monetized benefits of the reductions in emissions by using a measure of the social cost (SC) of each pollutant. These estimates represent the monetary value of the net harm to society associated with a marginal increase in emissions of these pollutants in a given year, or the benefit of avoiding that increase. These estimates are intended to include (but are not limited to) climate-change-related changes in net agricultural productivity, human health, property damages from increased flood risk, disruption of energy systems, risk of conflict, environmental migration, and the value of ecosystem services.

DOE uses the estimates for the social cost of greenhouse gases (SC-GHG) from the most recent update of the Interagency Working Group on Social Cost of Greenhouse Gases, United States Government (IWG) working group, from "Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide Interim Estimates under Executive Order 13990." (February 2021 TSD). DOE has determined that the estimates from the February 2021 TSD, as described in more detail below, are based upon sound analysis, and provide well founded estimates for DOE's analysis of the impacts of related to the reductions of emissions anticipated from the proposed rule.

The SC-GHG estimates in the February 2021 TSD are interim values developed under Executive Order (E.O.) 13990 for use until an improved estimate of the impacts of climate change can be developed based on the best available science and economics. The SC-GHG estimates used in this analysis were developed over many years, using a transparent process, peer-reviewed methodologies, the best science available at the time of that process, and with input from the public. Specifically, an interagency working group (IWG) that included DOE, the EPA and other executive branch agencies and offices used three integrated assessment models (IAMs) to develop the SC-CO2 estimates and recommended four global values for use in regulatory analyses. Those estimates were subject to public comment in the context of dozens of proposed rulemakings as well as in a dedicated public comment period in 2013.

The SC-CO2 estimates were first released in February 2010 and updated in 2013 using new versions of each IAM. In 2015, as part of the response to public comments received to a 2013 solicitation for comments on the SC-CO2 estimates, the IWG announced a National Academies of Sciences, Engineering, and Medicine review of the SC-CO2 estimates to offer advice on how to approach future updates to ensure that the estimates continue to reflect the best available science and methodologies. In January 2017, the National Academies released their final report, Valuing Climate Damages: Updating Estimation of the Social Cost of Carbon Dioxide, and recommended specific criteria for future updates to the SC-CO2 estimates, a modeling framework to satisfy the specified criteria, and both near-term updates and longer-term research needs pertaining to various components of the estimation process (National Academies 2017). On January 20, 2021, President Biden issued Executive Order 13990, which directed the IWG to ensure that the U.S. Government's (USG) estimates of the SC-CO2 social cost of carbon and other greenhouse gases reflect the best available science and the recommendations of the National Academies (2017). The IWG was tasked with first reviewing the estimates currently used by the USG and publishing interim estimates within 30 days of E.O. 13990 that reflect the full impact of GHG emissions, including taking global damages into account, which resulted in the issuance of the February 2021 TSD. More information on the basis for the IWG's interim values may be found in the IWG's Technical Support Document.[j]

To estimate the monetary value of reduced NO_X and SO_2 emissions from electricity generation attributable to the standard levels it considers, DOE uses benefit-per-ton estimates derived from analysis conducted by the EPA. For NO_X and SO_2 emissions from combustion at the site of product use, DOE uses another set of benefit-per-ton estimates published by the EPA. The methodology is described in more detail in chapter 14 of the preliminary analysis TSD.

2.15 UTILITY IMPACT ANALYSIS

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

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[j] See Interagency Working Group on Social Cost of Greenhouse Gases, Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide. Interim Estimates Under Executive Order 13990, Washington, D.C., February 2021.
https://www.whitehouse.gov/wpcontent/uploads/2021/02/TechnicalSupportDocument_SocialCostofCarbonMethaneNitrousOxide.pdf?source=email

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

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

2.16 EMPLOYMENT IMPACT ANALYSIS

An employment impact analysis is conducted during the NOPR phase of analysis, should DOE proceed to a NOPR. 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.

The indirect employment impacts are investigated in the employment impact analysis using the Pacific Northwest National Laboratory's "Impact of Sector Energy Technologies" (ImSET) model.[19] The ImSET model was developed for DOE's Office of Planning, Budget, and Analysis to estimate the employment and income effects of energy-saving technologies in buildings, industry, and transportation. Compared with simple economic multiplier approaches, ImSET allows for more complete and automated analysis of the economic impacts of energy conservation investments. The methodology is described in more detail in chapter 16 of the preliminary analysis TSD.

2.17 REGULATORY IMPACT ANALYSIS

In the NOPR stage, if conducted, DOE prepares an analysis that evaluates potential non-regulatory policy alternatives, comparing the costs and benefits of each to those of the proposed standards. DOE recognizes that non-regulatory policy alternatives can substantially affect energy efficiency or reduce energy consumption. DOE bases its assessment on the actual impacts of any such initiatives to date, but also considers information presented by interested parties regarding the potential future impacts of current initiatives. The methodology is described in more detail in chapter 17 of the preliminary analysis TSD.

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CHAPTER 3. MARKET AND TECHNOLOGY ASSESSMENT

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CHAPTER 3. MARKET AND TECHNOLOGY ASSESSMENT

3.1 INTRODUCTION

This chapter provides a profile of the 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 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 dishwashers, the size of the unit impacts the energy consumed. Because standard 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 unit (as specified in American National Standards Institute (ANSI)/Association of Home Appliance Manufacturers (AHAM) Standard DW-1-2010, Household Electric Dishwashers, using the test load specified in the DOE test procedure for dishwashers in appendix C1 to subpart B of Title 10 of the Code of Federal Regulations (CFR) (Appendix C1)):

- 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).

The current dishwasher product classes have existed since the first rulemaking for dishwashers was published in May 1991. However, standard and compact dishwashers were initially distinguished based on the exterior width of the dishwasher; in a test procedure rulemaking published in 2001, DOE changed the definitions to be based on capacity as defined by the number of place settings. In a final determination published on December 13, 2016

(December 2016 Final Determination), DOE maintained the standard and compact product class distinction for dishwashers. 81 FR 90072, 90075. Currently, there are 64 compact dishwasher models and 1094 standard dishwasher models in DOE's Compliance Certification Database (CCD). For standard dishwashers, DOE is aware of products available on the market with capacities up to 16 place settings.

On October 30, 2020, DOE published a final rule establishing a separate product class for standard-size dishwashers with a cycle time for the "normal" cycle of less than one hour (*i.e.,* 60 minutes) from washing through drying. 85 FR 68723. DOE initiated the rulemaking in response to a petition submitted by the Competitive Enterprise Institute and established the new product class following an evaluation of testing and analysis conducted by DOE and comments received from stakeholders. *Id.* at 68724. To date, the short-cycle product class is not subject to energy conservation standards and no product relies on the short-cycle product classification. On January 11, 2022, DOE issued a final rule revoking the final rule that established a new product class for dishwashers.[a] Accordingly, DOE addressed only the two current product classes for dishwashers as part of the present evaluation.

3.4 PRODUCT TEST PROCEDURES

DOE's test procedure for dishwashers is found in Appendix C1. DOE originally established its test procedure for 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, 65095–65097 (Dec. 18, 2001).

In 2003, DOE again revised the test procedure to more accurately measure 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, 51899–51903 (Aug. 29, 2003).

In 2012, DOE established a new test procedure at Appendix C1 for 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 units 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, 65982–65987 (Oct. 31, 2012). The current test procedure requirements at 10 CFR 430.23(c) include provisions for determining annual energy

[a] https://www.energy.gov/sites/default/files/2022-01/short-cycle-product-class-fr.pdf

use expressed in kilowatt-hours (kWh) per year, water consumption expressed in gallons per cycle, and estimated annual operating cost.

In the December 2016 Final Determination, DOE deleted an obsolete version of the dishwasher test procedure, codified at 10 CFR part 430, subpart B, appendix C. 81 FR 90072, 90076 (Dec. 13, 2016).

In 2019, DOE began a new rulemaking for dishwasher test procedures. Per EPCA, at least once every 7 years, DOE is required to evaluate test procedures for each type of covered product, including dishwashers, to determine whether amended test procedures would more accurately or fully comply with the requirements for the test procedures to not be unduly burdensome to conduct and be reasonably designed to produce test results that reflect energy efficiency, energy use, and estimated operating costs during a representative average use cycle or period of use. (42 U.S.C. 6293(b)(1)(A)). On August 20, 2019, DOE began a rulemaking process pursuant to the mandated 7-year lookback review by publishing a Federal Register notice initiating a data collection process through a request for information (RFI) pertaining to test procedures for dishwashers. 84 FR 43071. In the 2019 RFI, DOE sought to address issues concerning dishwasher consumer usage, appropriate testing conditions and methods, and performance metrics.

In the subsequent test procedure NOPR published on December 22, 2021, DOE proposed to reference the newly published AHAM DW-1-2020 standard, *Uniform Test Method for Measuring the Energy Consumption of Dishwashers*, which is consistent with the existing DOE test procedure in Appendix C1 with some updates to include requirements for water hardness, relative humidity, ambient temperature, detergent dosage, and standby power measurement. 86 FR 72738. DOE additionally proposed a minimum cleaning index threshold as a condition for a test cycle to be considered valid. *Id.* at 72756—59. DOE also proposed to adopt a new test procedure, Appendix C2, which would be applicable upon the compliance date of any future amended energy conservation standards. 86 FR 72748—49. Appendix C2 would include all the updates proposed in Appendix C1 and additionally specify an update to the annual number of cycles and low-power mode hours for the calculation of energy consumption. The annual number of cycles would be reduced from 215 to 184 cycles, while the estimated low-power mode hours would be updated from the fixed 8,465 annual hours to a value that is dependent on the "normal" cycle duration of a unit. *Id.* These updates are based on the specifications in AHAM DW-1-2020. The proposed cleaning performance requirements are based on the recently published AHAM standard, DW-2-2020, which is an update to the ANSI/AHAM DW-1-2010 standard, *Household Electric Dishwashers*.

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[b], formed in 1967, aims to enhance the value of the home appliance industry through leadership, public education, and advocacy. AHAM provides services to its members including government relations; certification programs for a range of residential appliances; an active communications program; and technical services and research. 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 December 2016 Final Determination for this market assessment.

3.6.1 Manufacturers and Market Shares

DOE typically uses publicly available data sources to estimate the domestic market shares for dishwasher original equipment manufacturers (OEMs). In the absence of publicly available market share resources, DOE will use the Compliance Certification Database (CCD) to estimate model share by OEM. The DOE CCD houses certification reports and compliance statements submitted by manufacturers for covered products and equipment subject to Federal energy conservation standards. However, the DOE CCD lists dishwashers by brand name, not OEM. Many manufacturers 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. To determine model share by OEM, DOE first determined each unique OEM and mapped each brand or subsidiary company to its corresponding OEM.

For dishwashers, DOE estimates that there are approximately 14 OEMs supplying the domestic market. Five of these OEMs have established domestic manufacturing facilities: BSH Home Appliances Corporation (BSH), Haier Group Corporation (Haier), LG Electronics, Inc. (LG), SubZero Group, and Whirlpool. The remainder of the market comprises companies including: Arcelik A.S. (Arcelik), Guangdong Canbo Electric Co., Ltd. (Guangdong Canbo), Hisense Group (Hisense), Midea Group (Midea), Miele, Inc. (Miele), Mondragon Corporation (Mondragon), Samsung Electronics, Inc. (Samsung), Smeg S.p.A. (Smeg), and Zhongshan Galanz Consumer Electric Appliances Co., Ltd. (Zhongshan Galanz).

Figure 3.6.1 and Figure 3.6.2 provide a breakdown of the total number of standard and compact dishwasher models, respectively, available on the market by OEM, based on data

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

available from the DOE CCD as of April 2021. This is not an explicit breakdown of market share, but rather, a representation of the number of dishwasher models available by each manufacturer.

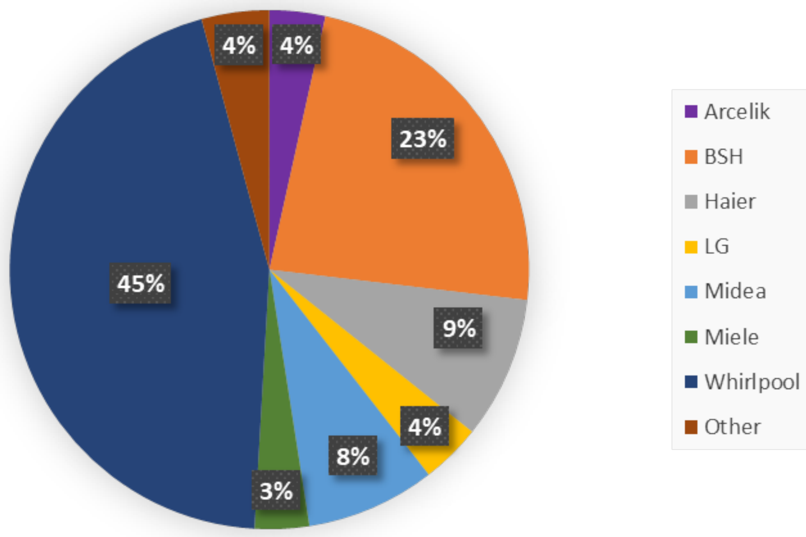


Figure 3.6.1 DOE CCD Standard Dishwasher Individual Model Breakdown by Manufacturer

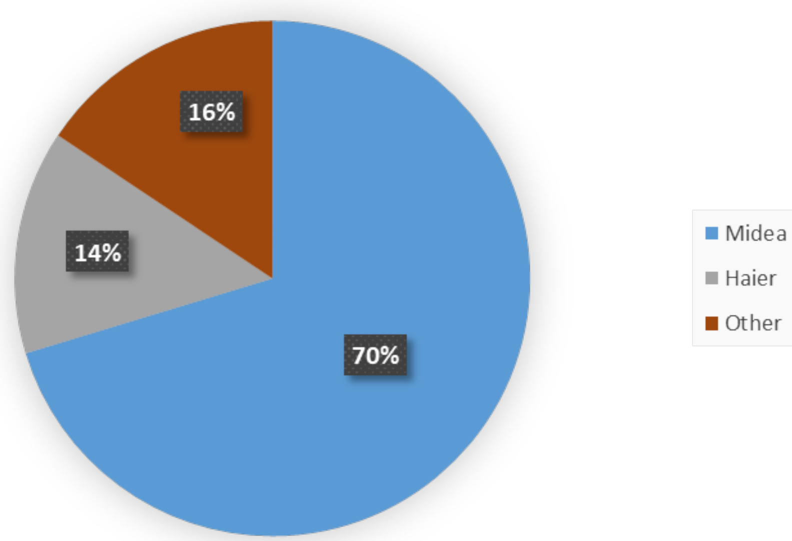


Figure 3.6.2 DOE CCD Compact Dishwasher Individual Model Breakdown by Manufacturer

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.

In 2012, the Middleby Corporation acquired Viking Range Corporation for $380 million.[1]

In 2012, Haier Group completed the acquisition of New Zealand appliance manufacturer Fisher & Paykel Appliances Holdings in a deal valued at $766 million.[2]

In 2016, Samsung Electronics America acquired Dacor for a reported $150 million.[3]

In 2016, Qingdao Haier Co. (Haier) acquired of GE's appliance division from GE for $5.6 billion. Haier will have the rights to use the GE brand for 40 years.[4]

In 2018, Hisense Luxembourg Home Appliance Holding, a member of Hisense Group, acquired a 95% majority in Gorenje Group, the parent company of Asko Appliances.[5]

In 2019, The Legacy Companies acquired Avanti Products, a producer of consumer appliances.[6]

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 1,500 employees or fewer,[7] who produce dishwashers and who therefore would be impacted by a minimum efficiency standard. See chapter 12 of this preliminary TSD for more detail on small business impacts.

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 equipment, 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 TWICE *2017 Top 50 Major Appliance Retailers Report* estimated that home improvement stores claim nearly one out of every two dollars spent on appliances.[8]

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 dishwashers. The National Appliance Energy Conservation Act of 1987 (NAECA), Public Law 100-12 (Mar. 17, 1989), 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 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))

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 dishwashers. In response to the Consensus Agreement, DOE conducted a rulemaking analysis based on the recommended levels for dishwashers. On May 30, 2012, DOE published a direct final rule (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.

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

Table 3.7.1 Current Federal Energy Conservation Standards for Dishwashers

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

Subsequently, and pursuant to the six-year review requirement, in the December 2016 Final Determination, DOE concluded to not amend the standards established in the May 2012 Direct Final Rule. 81 FR 90072. DOE determined that amended standards for dishwashers are not economically justified and that the benefits of energy savings, positive net present value of consumer benefits, and emission reductions of more-stringent standards are outweighed by the economic burden on over half of dishwasher consumers. Furthermore, the impacts on manufacturers, including the conversion costs and profit margin impacts, could result in a large reduction in industry net present value.

3.7.2 Canadian Energy Conservation Standards

Canada's Energy Efficiency Regulations (Regulations) have had energy conservation standards in place for dishwashers since February 3, 1995. The current Canadian Regulations include maximum energy and water use requirements consistent with DOE standards. The Regulations set a maximum annual energy use of 307 kWh/year for standard dishwashers and 222 kWh/year for compact dishwashers. The Regulations also specify a maximum water consumption of 5 gallons/cycle for standard dishwashers and 3.5 gallons/cycle for compact dishwashers. These standards apply to dishwashers manufactured after May 30, 2013. Canadian Regulations have the same definitions for compact and standard dishwashers as currently in place for the United States.

3.7.3 International Energy Performance Standards for Dishwashers

According to the Collaborative Labeling and Appliance Standards Program (CLASP), seven other countries outside of North America have mandatory minimum energy performance standards for dishwashers in effect or being developed.[9] These standards, whether mandatory or voluntary, may be accompanied by a label. A mandatory label must include a dishwasher's energy consumption as determined under a specified test standard. Some countries require that manufacturers affix a performance label without requiring that they adhere to a minimum energy performance standard. Voluntary labels also exist for programs such as the ENERGY STAR program in Canada. Table 3.7.2 notes the presence of mandatory or voluntary performance standards and labeling programs where applicable.

Table 3.7.2 International Energy Efficiency Standards and Labels for Dishwashers[10]

Country	Minimum Energy Performance		Label	
	Mandatory	Voluntary	Mandatory	Voluntary
Algeria				X*
Argentina			X	
Barbados			X	
Canada	X		X	X
Chile			X	
China	X*			
Egypt			X	
European Union		X		X
Germany				X*
Iran	X			
Jordan	X		X	
Korea (ROK)	X		X	
New Zealand			X	
Russia		X		X
Singapore				X
South Africa	X		X	
Sweden				X
Switzerland	X		X	
Thailand				X
Turkey		X		X
Ukraine				X*
United Arab Emirates	X		X	
United States	X	X		X

**Policy pending implementation*

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 dishwashers.

On April 29, 2015, ENERGY STAR finalized the Version 6.0 specification for dishwashers (ENERGY STAR V. 6.0), which took effect on January 29, 2016, and set maximum annual energy consumption and maximum per-cycle water consumption levels for standard and compact dishwashers. The specification provides a 5-percent energy consumption allowance for standard dishwashers meeting the ENERGY STAR connected criteria.[e] The current ENERGY STAR criteria for dishwashers are listed in Table 3.8.1.

Table 3.8.1 ENERGY STAR V. 6.0 Qualifying Criteria for Dishwashers

	Current Criteria Levels	
Dishwasher Classification	**Maximum Annual Energy Use *(kWh/year)***	**Maximum Water Consumption *(gallons/cycle)***
Standard dishwasher	270	3.5
Compact dishwasher	203	3.1

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 the ENERGY STAR V. 6.0 specification, ENERGY STAR provides the option of reporting cleaning performance for its qualified products; however, the current DOE test procedure does not include any measure of cleaning performance. Accordingly, DOE developed an ENERGY STAR Test Method for Determining Dishwasher Cleaning Performance (Rev. Feb-2014) (the "Cleaning Performance Test Method"). This Cleaning Performance Test Method is based on the DOE test procedure in Appendix C1 with added requirements for scoring test load items at the end of a test cycle and calculations to determine a per-cycle cleaning index. The scoring requirements and cleaning index calculations are based on the methods included in ANSI/AHAM DW-1-2010.

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

[e] There is currently no finalized ENERGY STAR Test Method for Dishwashers to Validate Demand Response.

Per the ENERGY STAR website, 12 dishwasher manufacturers participate in the ENERGY STAR program, representing 70 brands and covering 804 total base models. According to 2019 shipment estimates, the market penetration for ENERGY STAR dishwasher products was roughly 91%. The significantly high market penetration of dishwashers led ENERGY STAR to review its specifications for its labeling program. On March 10, 2020, ENERGY STAR released Draft 1 of its Dishwasher Specification Version 7.0 for dishwashers and on January 6, 2022, ENERGY STAR released Draft 2 of the Version 7.0 Dishwashers Specification. The new proposed criteria would reduce annual energy consumption to 240 kWh/yr and water use to 3.2 gal/cycle and would also include a cleaning performance criterion. Dishwashers would need to score a cleaning index of 65 for all tested cycles in the aforementioned Cleaning Performance Test Method to qualify for ENERGY STAR. Version 7.0 of the ENERGY STAR specification for dishwashers is currently under review.

Beyond its labeling program, ENERGY STAR has established Most Efficient product criteria for many household appliances, including standard dishwashers. The current Most Efficient criteria is consistent with the ENERGY STAR Draft 2 Version 7.0 Dishwasher Specification, with maximum annual energy consumption levels at 240 kWh/year and water consumption at 3.2 gallons/cycle. Additionally, products meeting the Most Efficient criteria must have a per-cycle cleaning index of at least 70 for each of the three soil loads tested under the Cleaning Performance Test Method. At the time of the preliminary analysis, 80 basic models qualify for ENERGY STAR Most Efficient criteria.[f]

3.8.2 Consortium for Energy Efficiency

CEE[g] 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 dishwashers. Table 3.8.2 presents the dishwasher efficiency specifications, effective January 29, 2016, under its Super-Efficient Home Appliances Initiative.

Table 3.8.2 CEE Criteria for Dishwashers

Level	**Maximum Annual Energy Use *(kWh/year)***	**Maximum Water Consumption *(gallons/cycle)***
Standard CEE Tier 1	270	3.5
Compact CEE Tier 1	203	3.1

[f] For more information, please visit https://www.energystar.gov/index.cfm?c=most_efficient.me_dishwashers.

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

The annual energy use and water consumption CEE Tier 1 criteria for both standard-size and compact dishwashers are identical to the Version 6.0 criteria for the ENERGY STAR program.

3.8.3 Federal Energy Management Program

DOE's FEMP[h] 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 dishwashers.

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.

3.8.4 Rebates for Highly Energy-Efficient Products

Electric utilities and other organizations promote the purchase of highly energy-efficient dishwashers through consumer rebates. Typically, these programs offer rebates for products meeting the ENERGY STAR qualification criteria. DOE identified rebates listed in Table 3.8.3 that were offered in 2021 through ENERGY STAR's Rebate Finder.[11] Some utilities also offer incentives to retire older (and typically less efficient) appliances.

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

Table 3.8.3 Rebates Offered for Highly Energy-Efficient Dishwashers in 2020[12]

Utility/ Organization	Rebate Level
Austin Utilities (Minnesota)	$25-$40
Black Hills Energy	$20
Blooming Prairie Public Utilities	$25-$40
City of Tallahassee (Florida)	$40
Dominion Energy	$50
Fairmont Public Utilities	$25-40
Glendale Water & Power	$30-40
Grand Marais Public Utilities	$25-40
Gunnison County Electric Association, Inc.	$35
Heartland Consumers Power District	$50
La Plata Electric Association	$20
Lake City Utilities	$25-$40
Lansing Board of Water & Light	$25
Litchfield Public Utilities	$25-$40
Marshall Municipal Utilities	$50
Mora Municipal Utilities	$25-$40
Nebraska Energy Office	Low Interest Loan
New Prague Utilities Commission	$25-$40
North Branch Municipal Water and Light	$25-$40
Owatonna Public Utilities	$25-$40
Pasadena Water and Power	$30
Preston Public Utilities	$25-$40
Princeton Public Utilities	$25-$40
Public Service Company of New Mexico (PNM)	$50
Public Works Commission of the City of Fayetteville	$30
Redwood Falls Public Utilities	$25-$40
Riverside Public Utilities	$50
Rochester Public Utilities	$25-$40
Saint Peter Municipal Utilities	$25-$40
Spring Valley Public Utilities	$25-$40
UGI Utilities	$25
Waseca Utilities	$25-$40
Wells Public Utilities	$25-$40

Note: The table includes a survey of a limited number of rebate programs. Additional programs may exist.

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 dishwasher shipment trends and the value of these shipments. Knowledge of such trends will be used during the shipments analysis (chapter 9 of this preliminary TSD).

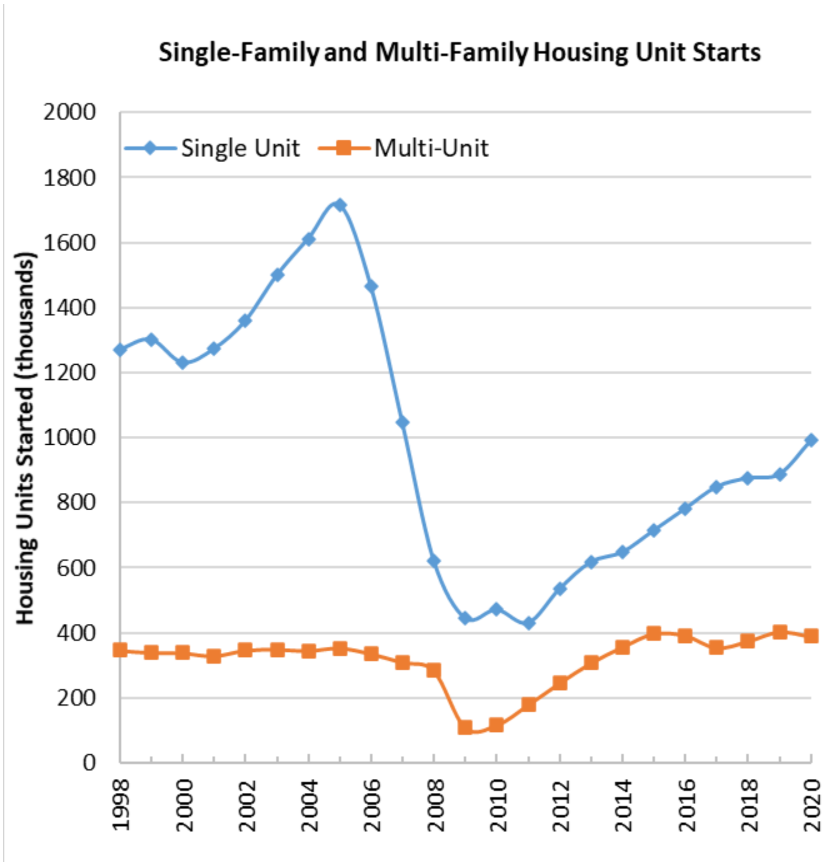
3.9.1 New Home Starts

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 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 1998–2020. 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 2010–2020, multi-family units have rebounded to 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 1998–2020 (Thousands)[13]

Year	Single Unit	Multi-Unit
2020	991	389
2019	888	403
2018	876	374
2017	849	354
2016	782	392
2015	715	397
2014	648	356
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



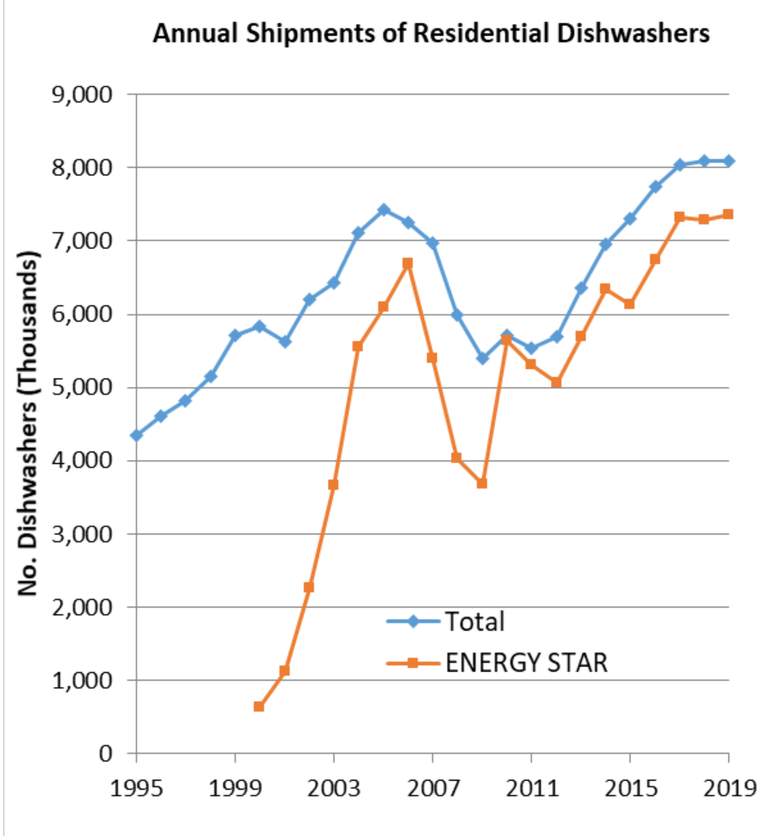
3.9.2 Unit Shipments

AHAM's *2005 Fact Book* provides annual unit shipments for 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. ENERGY STAR also provides shipment data and market share for qualified dishwashers from 2000 to 2019.

Table 3.9.2 presents the breakdown of ENERGY STAR versus non-ENERGY STAR shipments for dishwashers from 2000 to 2019.

Table 3.9.2 Dishwasher Shipments and ENERGY STAR Market Share (Domestic and Import) [14, 15, 16, 17, 18]

Shipments *(Thousands)*			
Year	% ENERGY STAR	Total	ENERGY STAR
2019	91.0%	8,088	7,360
2018	90.0%	8,094	7,285
2017	91.0%	8,049	7,325
2017	87.0%	7,746	6,739
2015[a]	84.0%	7,301	6,133
2014	92.0%	6,911	6,346
2013	92.0%	6,346	5,838
2012[b]	89.2%	5,689	5,072
2011	95.9%	5,535	5,309
2010	98.9%	5,708	5,644
2009[c]	68.0%	5,404	3,672
2008	67.2%	5,995	4,030
2007[d]	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[e]	10.9%	5,827	632
1999	N/A	5,712	N/A
1998	N/A	5,144	N/A
1997	N/A	4,826	N/A
1996	N/A	4,606	N/A
1995	N/A	4,346	N/A



[a] ENERGY STAR criteria effective April 29, 2015: Standard ≤ 270 kWh/year, 3.5 gal/cycle; Compact ≤ 203 kWh/year, 3.1 gal/cycle
[b] ENERGY STAR criteria effective January 20, 2012: Standard ≤ 295 kWh/year, 4.25 gal/cycle; Compact ≤ 222 kWh/year, 3.5 gal/cycle
[c] ENERGY STAR criteria effective August 11, 2009: Standard ≤ 324 kWh/year, 5.8 gal/cycle; Compact ≤ 234 kWh/year, 4.0 gal/cycle
[d] ENERGY STAR criteria effective January 1, 2007: Standard – EF ≥ 0.65, Compact – EF ≥ 0.88
[e] ENERGY STAR criteria: Standard – EF ≥ 0.46, Compact – EF ≥ 0.62

3.9.3 Value of Shipments

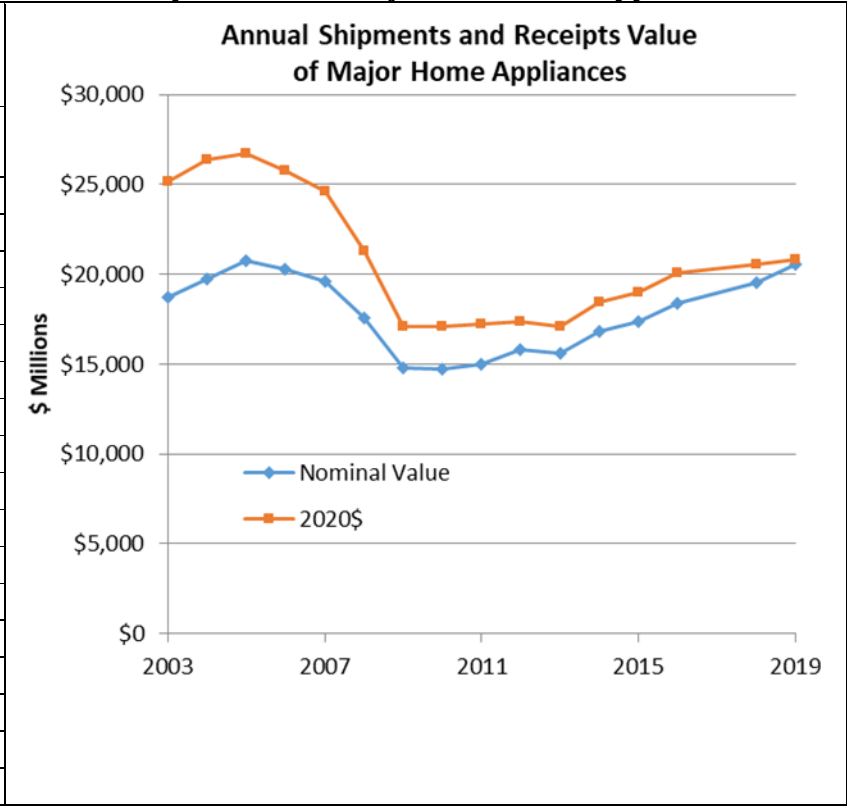
Table 3.9.3 provides the value of shipments and receipts for the manufacturers in the North American Industry Classification System (NAICS) category of major household appliances (product class code 33522) from 2003 to 2019. The values are based on data from the U.S. Census Bureau's *Annual Survey of Manufactures*[i] (*ASM*). This NAICS category includes companies primarily engaged in manufacturing household appliances such as cooking

[i] Available online at www.census.gov/manufacturing/asm/index.html

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.*, 2017 data are expressed in 2017 dollars and 2016 data are expressed in 2016 dollars. Using the Producer Price Index (PPI) published by the U.S. Bureau of Labor Statistics (BLS)[j] DOE converted each year's value of shipments to 2020 dollars.

Table 3.9.3 Annual Shipments and Receipts Value of Major Household Appliances[19]

Annual Shipments and Receipts Value (*$ millions)*		
Year	**Nominal Dollars**	**2020 Dollars**
2019	20,516	20,810
2018	19,511	20,576
2017	-	-
2016	18,370	20,081
2015	17,386	18,968
2014	16,820	18,425
2013	15,577	17,077
2011	15,834	17,373
2010	15,005	17,209
2009	14,727	17,095
2008	14,776	17,092
2007	17,584	21,313
2006	19,575	24,615
2005	20,255	25,760
2004	20,730	26,719
2003	19,747	26,363
2002	18,722	25,143



Note: No data available for 2017.

Table 3.9.4 provides the annual total shipment and receipts 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 2002 to 2016 based on data from the U.S. Census Bureau's *ASM*. Also included in Table 3.9.4 are dishwasher shipment values from 2006 to 2010—the only years that dishwashers are reported separately in the U.S. Census Bureau's *Current Industrial Reports*[k] (*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 shipments and receipts values are expressed in nominal dollars. DOE used the PPI to convert each year's value to 2020 dollars.

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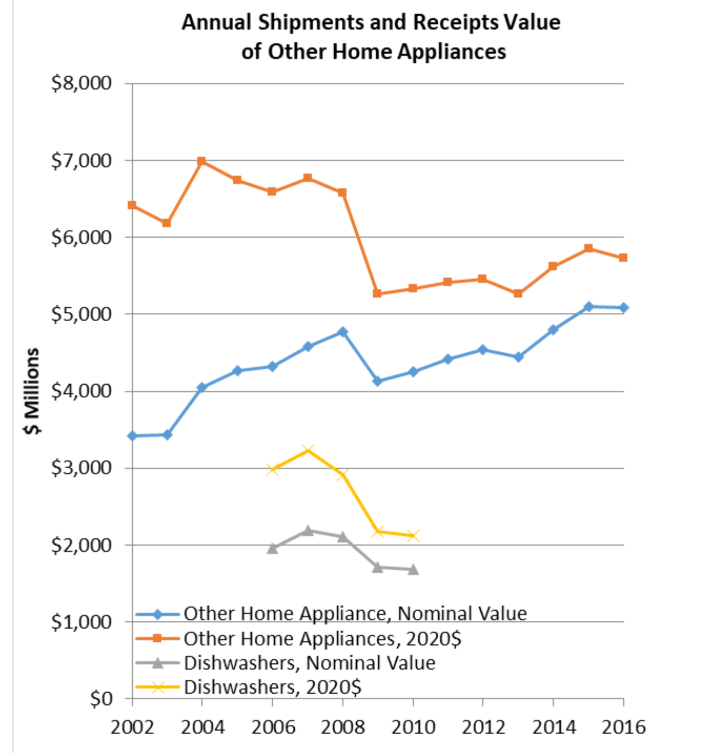
[j] Available online at www.bls.gov/ppi/

[k] Available online at www.census.gov/manufacturing/cir/index.html

Table 3.9.4 Annual Shipment Value of Other Major Household Appliances[20, 21, 22, 23, 24]

Annual Total Shipments and Receipts Value *($ millions)*				
	Other Home Appliances		Dishwashers	
Year	Nominal Dollars	2020 Dollars	Nominal Dollars	2020 Dollars
2016	5082	5724	N/A	N/A
2015	5099	5846	N/A	N/A
2014	4,798	5616	N/A	N/A
2013	4,402	5266	N/A	N/A
2012	4,547	5457	N/A	N/A
2011	4,164	5412	N/A	N/A
2010	4,058	5339	1,690	2,122.9
2009	3,990	5271	1,709	2,182.2
2008	4,711	6574	2,114	2,911.6
2007	4,582	6770	2,189	3,234.6
2006	4,319	6588	1,954	2,981.1
2005	4,264	6742	N/A	N/A
2004	4,259	6990	N/A	N/A
2003	4,043	6175	N/A	N/A
2002	3,428	6409	N/A	N/A

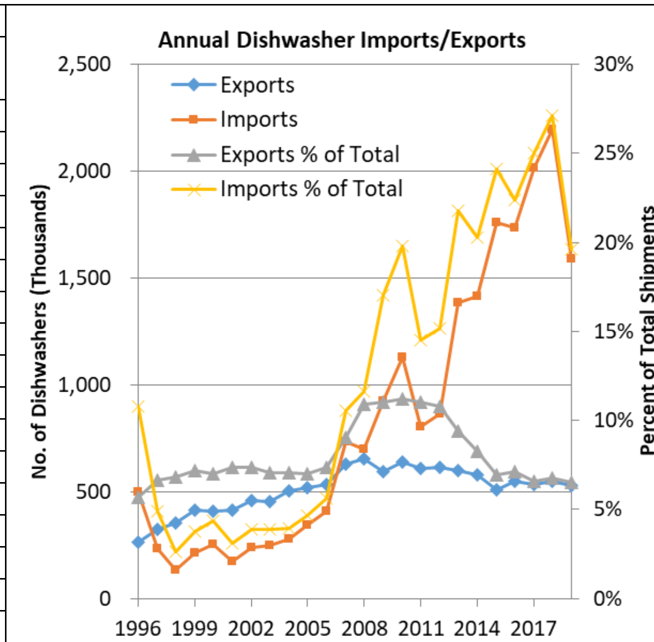


3.9.4 Imports and Exports

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 3.9.5 shows ITC's import/export data for Harmonized Tariff Schedule (HTS) 8422110000, *Dishwashing Machines, Household Type*, for 1996–2015. Beginning in 2006, both imports and exports rose as a share of total shipments, with imports in particular increasing substantially from 2006 to 2018. 2019 featured a significant drop in dishwasher imports, with import quantities reaching 2014 levels. Prior to 2007, the United States generally exported more dishwashers than it imported. Since that time, imports have exceeded exports.

Table 3.9.5 Annual Dishwasher Imports/Exports[25]

Year	Imports		Exports	
	Units *(1,000)*	% of Total Shipments	Units *(1,000)*	% of Total Shipments
2019	1,588	19.6%	528	6.5%
2018	2,196	27.1%	547	6.8%
2017	2,014	25.0%	532	6.6%
2016	1,734	22.4%	552	7.1%
2015	1,760	24.1%	509	7.0%
2014	1,414	20.5%	577	8.3%
2013	1,383	21.8%	598	9.4%
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%

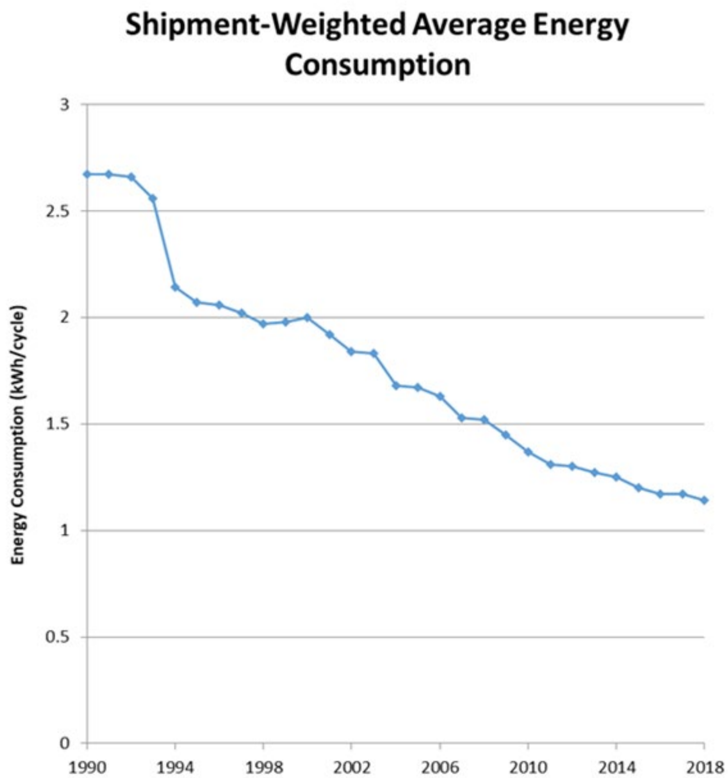


3.10 HISTORICAL EFFICIENCIES

The average efficiency of new 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 2018, the average energy consumption per cycle decreased by over 56 percent. DOE does not have shipment-weighted efficiency information for the market since 2014.

Table 3.10.1 Annual Shipment-Weighted Per-Cycle Dishwasher Energy Consumption[26, 27, 28]

Year	Energy Consumption *(kWh/cycle)*	% Change vs. 1990
2018	1.14	-57.3%
2017	1.17	-56.1%
2016	1.17	-56.1%
2015	1.20	-55.1%
2014	1.25	-53.2%
2013	1.27	-52.4%
2012	1.30	-51.3%
2011	1.31	-50.9%
2010[a]	1.37	-48.7%
2009	1.45	-45.7%
2008	1.52	-43.1%
2007	1.53	-39.0%
2006	1.63	-37.5%
2005	1.67	-37.1%
2004	1.68	-37.1%
2003	1.83	-31.5%
2002	1.84	-31.1%
2001	1.92	-28.1%
2000	2.00	-25.1%
1999	1.98	-25.8%
1998	1.97	-26.2%
1997	2.02	-24.3%
1996	2.06	-22.8%
1995	2.07	-22.5%
1994[b]	2.14	-19.9%
1993	2.56	-4.1%
1992	2.66	-0.4%
1991	2.67	0.0%
1990	2.67	-



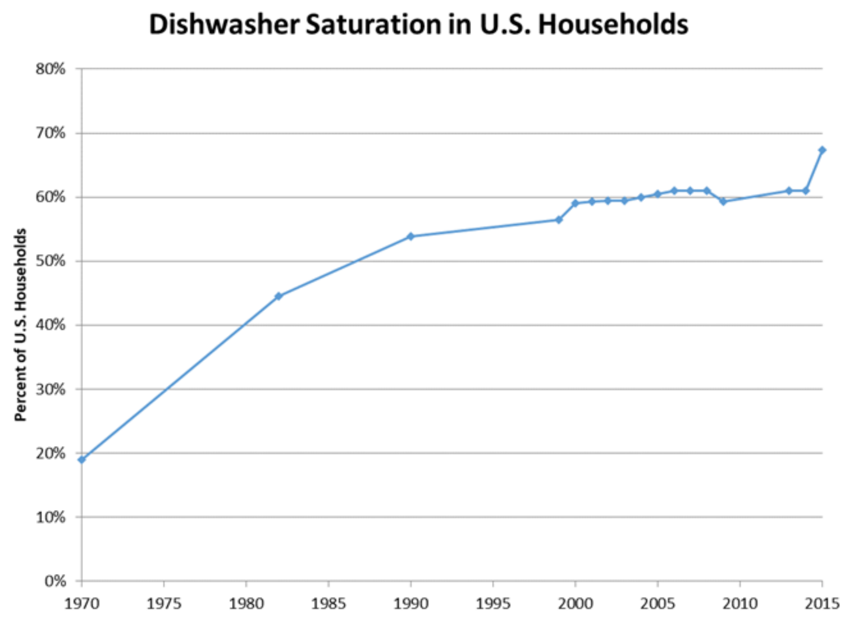
[a] DOE energy conservation standards for annual energy use took effect on January 1, 2010.
[b] DOE energy conservation standards for EF took effect on May 14, 1994.

3.11 MARKET SATURATION

AHAM's *2005 Fact Book*, Appliance Magazine's *Market Research Reports* and U.S. Energy Information Administration's Residential Energy Consumption Survey (RECS) present the market saturation for dishwashers. The market saturation of dishwashers has more than tripled since 1970. However, from 2001 through 2014, the market saturation only increased by 1.7 percent. For the 9 years from 2006 through 2014, the market saturation remained mostly constant at 61 percent with a slight downturn to 59.3% in 2009. In 2015, dishwasher market saturation rose 6.4%, the largest growth rate in consecutive years. Table 3.11.1 presents the percentage of U.S. households with dishwashers.

Table 3.11.1 Percentage of U.S. Households with Dishwashers[29, 30, 31,32]

Year	% of U.S. Households
2015	67.4
2014	61.0
2013	61.0
2009	59.3
2008	61.0
2007	61.0
2006	61.0
2005	60.5
2004	60.0
2003	59.5
2002	59.5
2001	59.3
2000	59.0
1999	56.5
1990	53.9
1982	44.5
1970	18.9



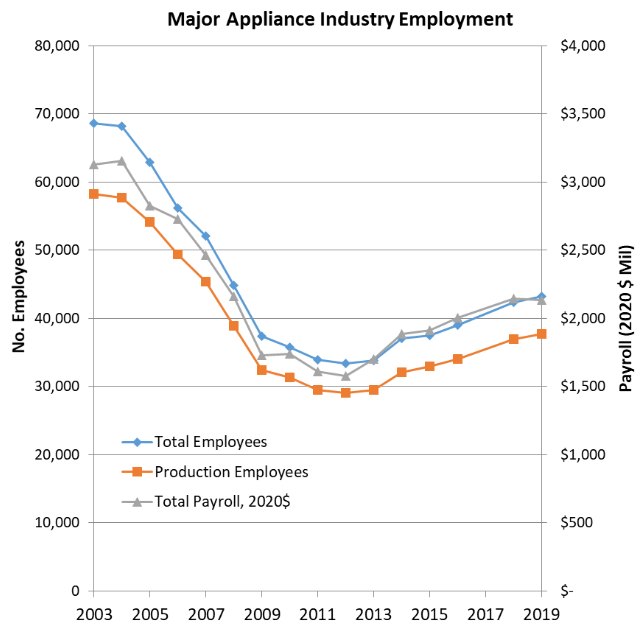
3.12 INDUSTRY COST STRUCTURE

DOE used information gathered in support of the December 2016 Final Determination, 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. Table 3.12.1 presents the major appliance manufacturing industry (NAICS code 33522) employment levels and earnings from 2003 through 2019. The statistics illustrate a steady decline in the number of production and non-production workers in the industry until 2013 where it has since rebounded to roughly 2008 levels.

DOE converted cost data to constant 2020 dollars using the PPI published by the U.S. Bureau of Labor Statistics. Table 3.12.1 shows that as industry employment levels decline, the industry payroll in constant 2020 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[33]

Year	Production Workers	All Employees	Payroll for All Employees *(2016 $ Mil)*
2019	37,669	43,170	2136
2018	36,956	42,395	2144
2017	-	-	-
2016	34,078	39,038	2006
2015	32,998	37,516	1912
2014	32,127	37,105	1887
2013	29,449	33,834	1703
2011	29,073	33,400	1579
2010	29,470	33,934	1610
2009	31,291	35,769	1741
2008	32,376	37,336	1727
2007	38,949	44,852	2160
2006	45,370	52,045	2462
2005	49,360	56,174	2727
2004	54,083	62,877	2828
2003	57,660	68,213	3154



Note: No data available for 2017

Table 3.12.2 presents the employment 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 decrease from 2002 to 2012, but the decrease is of a smaller magnitude than for the major appliance industry overall.

Table 3.12.2 Other Major Home Appliance Industry Employment and Earnings[34]

Year	Production Workers	All Employees	Payroll for All Employees *(2020 $ Mil)*
2016	8,516	10,288	613
2015	8,295	10,139	606
2014	8,017	9,851	547
2013	7,472	9,001	504
2012	7,195	8,772	479
2011	7,531	9,326	478
2010	7,525	9,272	491
2009	7,679	9,567	515
2008	9,081	11,432	632
2007	9,792	11,516	696
2006	10,281	11,974	741
2005	10,179	12,360	766
2004	10,304	12,672	830
2003	10,519	12,819	842
2002	10,118	12,671	856

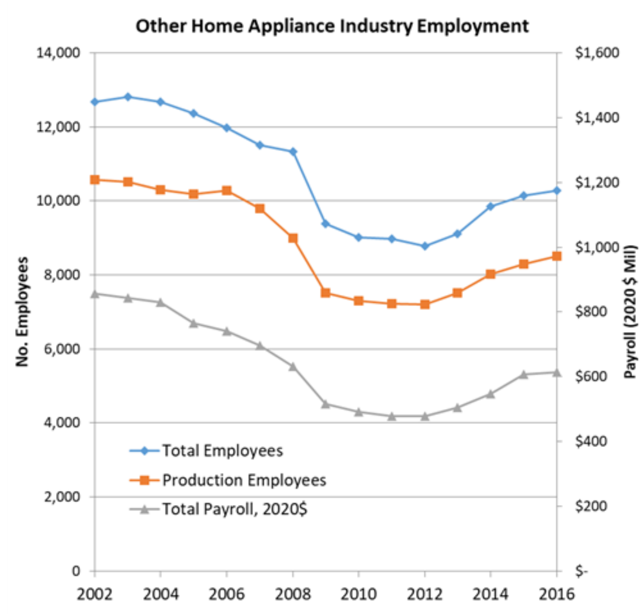
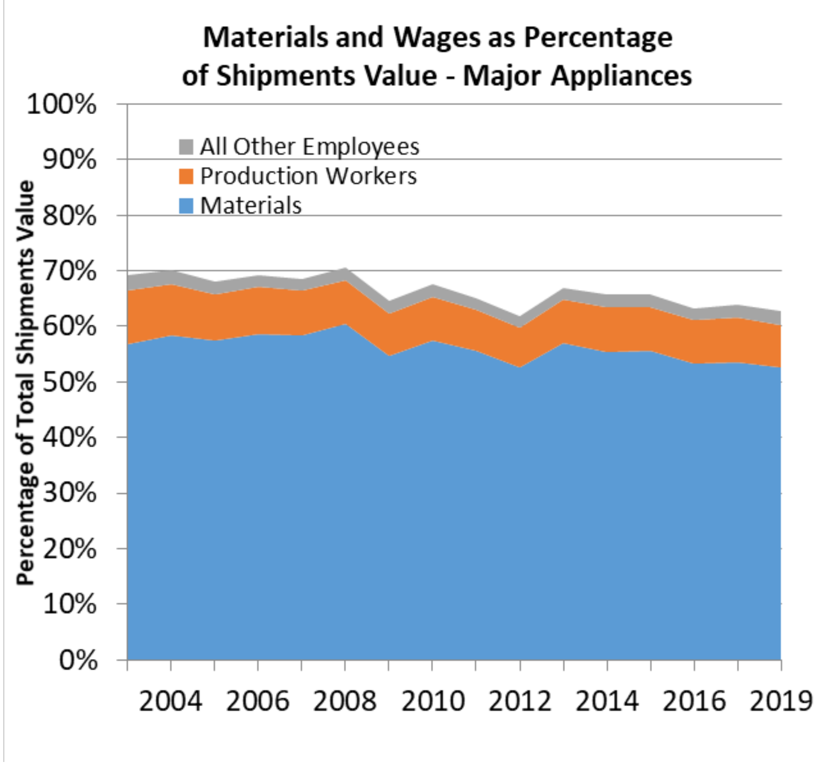


Table 3.12.3 presents the costs of materials and industry payroll as a percentage of value of shipments from 2003 to 2019 for the major appliance industry. The cost of materials as a percentage of value of shipments has remained relatively steady over the 11-year period, with small fluctuations. DOE 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 2003.

Table 3.12.3 Major Appliance Manufacturing Industry Materials and Wages Cost[35]

Cost as a Percentage of Value of Shipments *(%)*			
Year	**Materials**	**Payroll for Production Workers**	**Payroll for All Other Employees**
2019	52.6%	7.8%	2.5%
2018	53.5%	8.0%	2.4%
2017	N/A	N/A	N/A
2016	53.3%	7.8%	2.2%
2015	55.7%	7.8%	2.2%
2014	55.4%	8.0%	2.2%
2013	56.9%	7.8%	2.1%
2011	52.6%	7.1%	2.0%
2010	55.7%	7.2%	2.2%
2009	57.4%	7.9%	2.3%
2008	54.6%	7.8%	2.3%
2007	60.5%	7.9%	2.3%
2006	58.4%	8.0%	2.0%
2005	58.6%	8.5%	2.1%
2004	57.4%	8.3%	2.3%
2003	58.3%	9.3%	2.7%

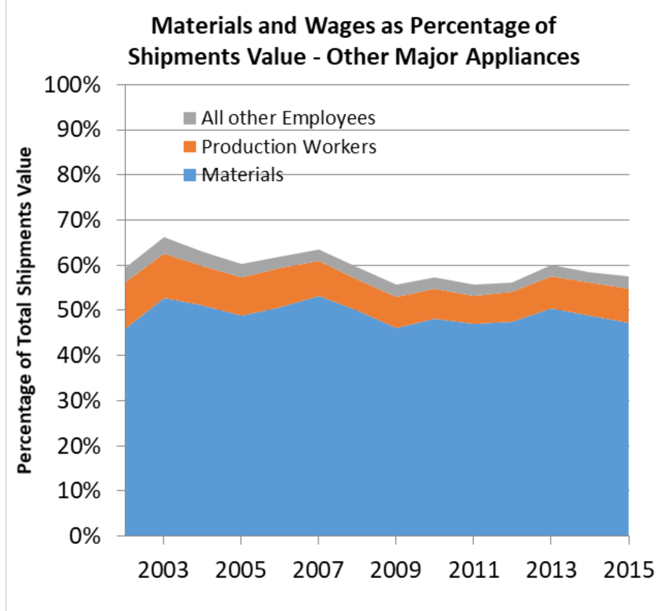


Note: No data available for 2017

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 2002 to 2016. 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[36]

Cost as a Percentage of Value of Shipments *(%)*			
Year	**Materials**	**Payroll for Production Workers**	**Payroll for All Other Employees**
2014	48.8%	7.3%	2.4%
2013	50.5%	7.2%	2.2%
2012	47.5%	6.5%	2.3%
2011	47.6%	6.8%	2.7%
2010	48.6%	7.1%	2.6%
2009	46.4%	7.2%	3.0%
2008	50.2%	6.9%	2.9%
2007	50.7%	7.9%	2.4%
2006	50.6%	8.7%	2.5%
2005	48.9%	8.4%	3.0%
2004	48.5%	8.3%	3.0%
2003	44.7%	8.5%	3.1%
2002	45.9%	10.1%	4.0%

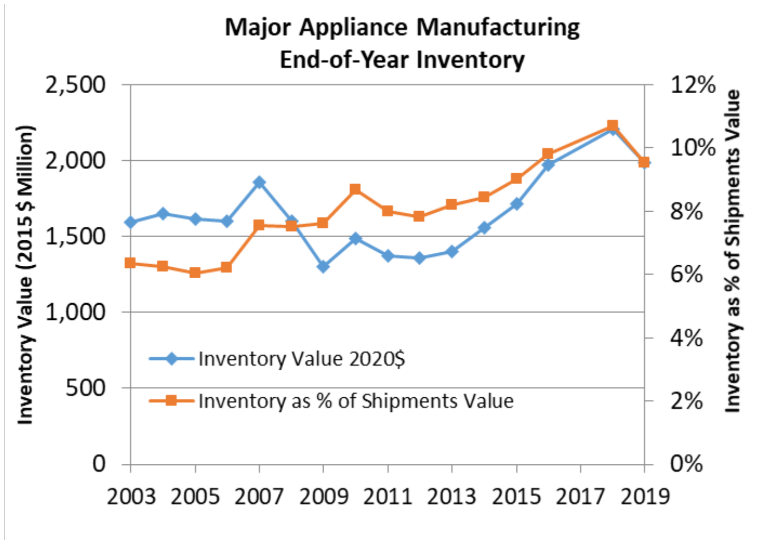


3.13 INVENTORY LEVELS AND CAPACITY UTILIZATION RATES

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*. Inventories of major appliance manufacturers decreased in value from 2002 to 2019, but inventories as a percentage of shipments values increased over that period. For other appliance manufacturers, inventories increased slightly in both value and as a percentage of shipments value from 2002 to 2016.

Table 3.13.1 Major Appliance Manufacturing Industry Inventory Levels[37]

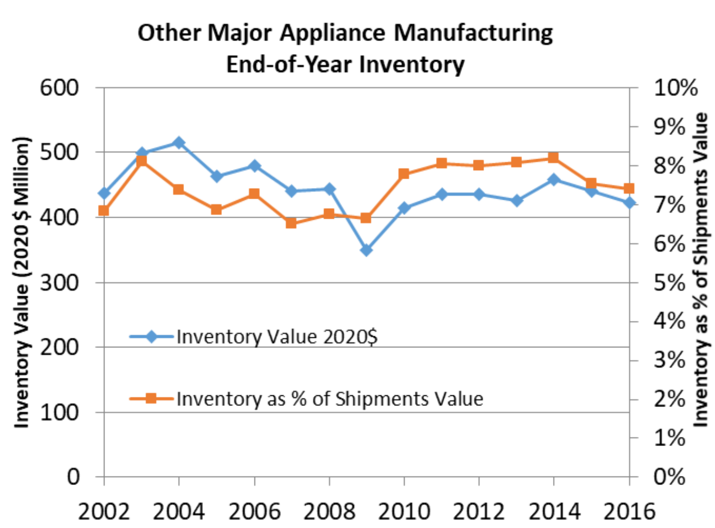
Year	End-of-Year Inventory *(2020 $ Mil)*	EOY Inventory as % of Shipments Value
2019	1,987.5	9.6%
2018	2,204.8	10.7%
2017	N/A	N/A
2016	1,969.3	9.8%
2015	1,714.0	9.0%
2014	1,557.8	8.5%
2013	1,402.0	8.2%
2011	1,362.2	7.8%
2010	1,373.3	8.0%
2009	1,485.4	8.7%
2008	1,304.0	7.6%
2007	1,600.0	7.5%
2006	1,856.5	7.5%
2005	1,603.2	6.2%
2004	1,616.6	6.1%
2003	1,650.0	6.3%
2002	1,594.0	7.1%



Note: No data available for 2017

Table 3.13.2 Other Major Appliance Manufacturing Industry Inventory Levels[38]

Year	End-of-Year Inventory *(2020 $ Mil)*	EOY Inventory as % of Shipments Value
2016	423.4	7.4%
2015	440.8	7.5%
2014	458.9	8.2%
2013	425.9	8.1%
2012	436.1	8.0%
2011	435.3	8.0%
2010	415.0	7.8%
2009	350.3	6.6%
2008	444.5	6.8%
2007	439.9	6.5%
2006	479.0	7.3%
2005	463.2	6.9%
2004	515.0	7.4%
2003	499.8	8.1%
2002	438.2	6.8%

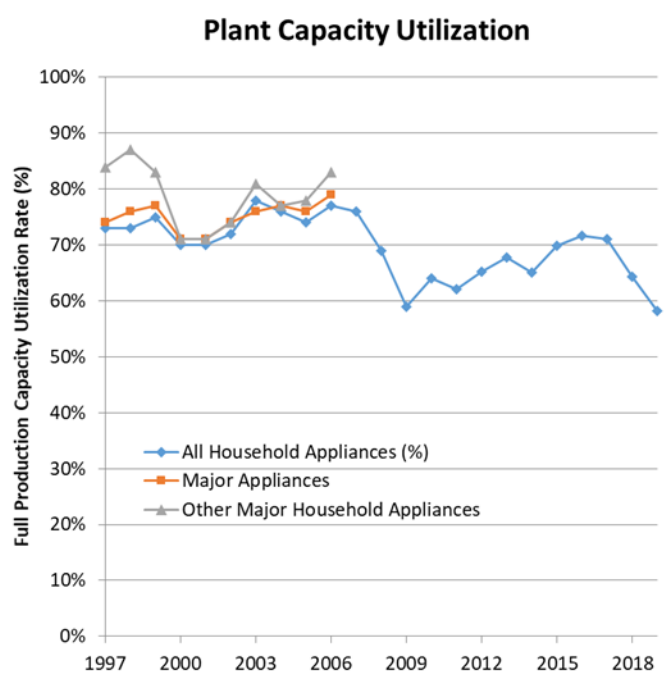


DOE obtained full production capacity utilization rates from the U.S. Census Bureau's *Survey of Plant Capacity* from 1997–2006. After 2006, the Census Bureau discontinued this survey, and began a new *Quarterly Survey of Plant Capacity Utilization*. However, this survey does not break down the utilization 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 2016, the utilization rate rebounded slightly from its low in 2009. Since 2016, the utilization rate has dropped significantly back down to its 2009 low. 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[39, 40]

Year	Plant Capacity Utilization Rates *(%)*		
	All Household Appliances	Major Appliances[a]	Other Major Home Appliances[a]
2019	58%	N/A	N/A
2018	64%	N/A	N/A
2017	71%	N/A	N/A
2016	72%	N/A	N/A
2015	70%	N/A	N/A
2014	65%	N/A	N/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 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 Dishwasher Operations and Components

Dishwashers 3are a product designed to clean dishes, utensils, and cookware by using a solution of detergent and heated water. Dishwashers spray this solution from rotating or translating 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.

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.

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 Dishwasher Technology Options

For dishwashers, DOE will consider previous and existing technologies in addressing the feasibility of potential new or amended conservation standards. DOE will consider technologies identified in the December 2016 Final Determination, as well as design data identified in manufacturer product offerings, and non-confidential information gathered during manufacturer interviews. Compared to the analysis conducted for the December 2016 Final Determination, DOE identified two additional technology option for dishwashers: thermoelectric heat pump systems and water re-use systems. The technology options identified for dishwashers in this final determination analysis are listed in Table 3.14.1.

Table 3.14.1 Technology Options for Dishwashers

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

3.14.2.1 Condensation Drying

This technology may reduce the amount of energy required to dry the dishes at the end of the wash cycle. Instead of using an exposed electric heating element within the tub 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.

3.14.2.2 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.

3.14.2.3 Desiccant Drying

Desiccant drying relies on a material such as zeolite to adsorb moisture to aid in the drying process and reduce drying energy consumption. Certain European dishwashers currently incorporate this technology option, and DOE is aware of dishwashers from one manufacturer available on the market in the United States that use desiccant drying. Additionally, multiple manufacturers hold patents on different implementations of this technology option.

3.14.2.4 Fan/Jet Drying

To reduce drying times, some 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.

3.14.2.5 Flow-Through Heating

As discussed in section 3.14.1, 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.

3.14.2.6 Improved Fill Control

Modifying the fill control to admit a lower volume of water can reduce hot water consumption and the associated water-heating 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.

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.

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 flow 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 precisely metering the water fills, 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.

3.14.2.7 Improved Food Filter

Improved food filters help prevent the re-deposition of food particles on dishes during the wash cycle, possibly leading to one less fill for rinsing. 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 total fill volume of the water system. Typical filter designs include a removable filter that traps soil particles and requires periodic cleaning. Others 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.

3.14.2.8 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% should be possible using a capacitor-type motor.

A 30% improvement in motor efficiency produces approximately a 2.5% 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%from the levels attainable with PSC motors.

3.14.2.9 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. Additionally, incorporating spray arms dedicated to certain portions of the load allows water to be sprayed more directly on the dishes (*e.g.*, separate spray arms for the top and bottom racks). Multiple spray arms also allow the water flow to be alternated between them, using a diverter valve, decreasing the total water system fill volume.

3.14.2.10 Increased Insulation

Some dishwashers incorporate 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.

3.14.2.11 Low-Standby-Loss Electronic Controls

Electronic controls may consume power even when the dishwasher is not actively washing or drying dishes. 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.

3.14.2.12 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.[39] 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.

3.14.2.13 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 present). 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.

3.14.2.14 Reduced Inlet-Water Temperature

This technology option uses a connection to the cold-water supply rather than the hot-water supply for inlet water. This allows the use of lower-temperature water for some portions of the wash cycle when hot water is not necessary (*e.g.*, certain rinse cycles). This would avoid the energy consumption associated with the use of hot water during the wash cycle. For the portions of cycle requiring hot water, the dishwasher would still consume energy to heat the cold-water supply. However, the dishwasher's internal water heater may also be more efficient than the household water heater. One potential drawback to this technology option is that 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.

3.14.2.15 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.[40] 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.

3.14.2.16 Thermoelectric Heat Pump System

This technology is undergoing testing and development at Oak Ridge National Laboratory as part of a DOE-funded project partnered with Samsung Electronics America. The thermoelectric heat pump system is a low-cost technology that aims to extract waste heat from drain water and recover heat normally lost during the drying process. The captured and saved heat is applied to the washing, rinsing, and drying phases, effectively saving energy. The technology targets 30% reduction in energy consumption, while improving drying performance and maintain cleaning performance. The technology is not commercially available yet as research and development is still underway. There are two related publications available for additional review of thermoelectric heat pump system design.[l,m]

3.14.2.17 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.[41] 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 and magnesium ions. 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.

3.14.2.18 Variable Washing Pressure and Flow Rates

Variable washing pressure and flow rates are being employed in some 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

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l Patel *et al*., 2016, "Experimental Evaluation and Thermodynamic System Modeling of Thermoelectric Heat Pump Clothes Dryer," 16th Int. Ref. & Air- Cond. Conf. at Purdue, West Lafayette, IN.
m Goodman *et al.*, 2017, "Thermoelectric Heat Pump Clothes Dryer Design Optimization," 12th IEA Heat Pump Conf., Rotterdam, The Netherlands.

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, as described previously. 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 at a time. 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.

3.14.2.19 Water Re-use System

Dishwashers equipped with a "water re-use system" save water from the final rinse of a given dishwasher cycle for use in a subsequent dishwasher cycle. A portion of the water fill volume comes from saved water fill instead of the house supply water fill. If not operated for a certain duration, the dishwasher will "drain out" the saved water. The dishwasher also performs a "clean out" periodically. Both "drain out" and "clean out" events consume additional water and energy during the subsequent cycle but overall, such dishwashers save water.

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 and Figure 3.14.2 display the distribution of standard and compact dishwasher individual models respectively, in DOE's CCD as of April 2021 as a function of estimated annual energy use, rounded down to 10 kWh/year intervals.[n]

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

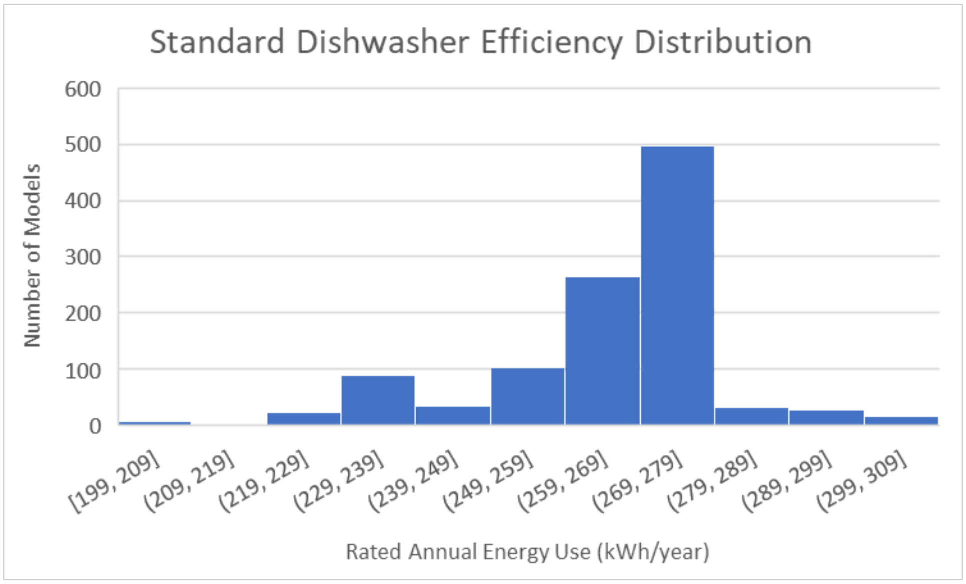

Figure 3.14.1 Standard Dishwashers in the DOE CCD[41]

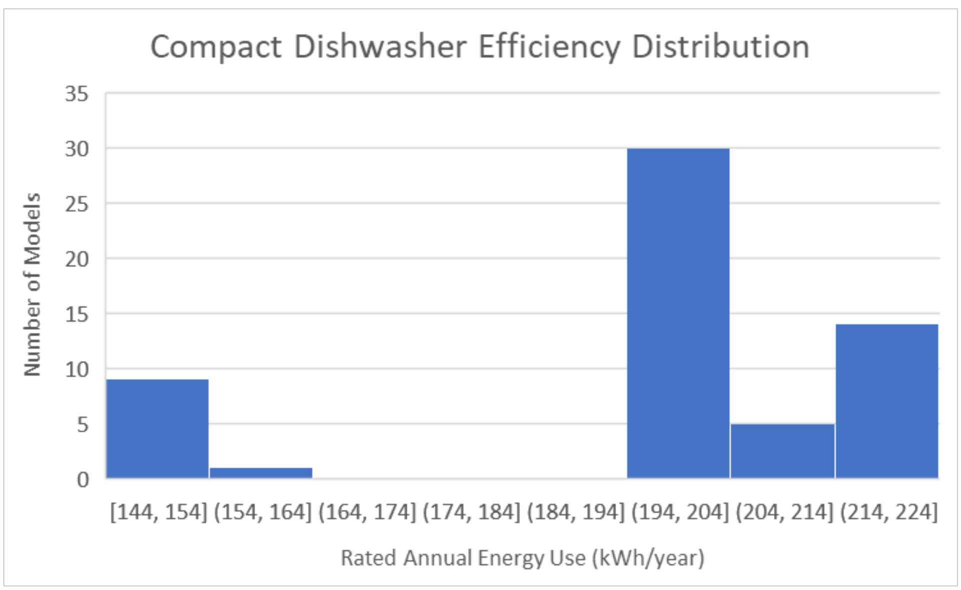

Figure 3.14.2 Compact Dishwashers in the DOE CCD[42]

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CHAPTER 4. SCREENING ANALYSIS

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CHAPTER 4. SCREENING ANALYSIS

4.1 INTRODUCTION

This chapter discusses the screening analysis conducted by the U.S. Department of Energy (DOE) of the technology options identified in the market and technology assessment fordishwashers (chapter 3 of this preliminary 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 dishwashers. The goal of the screening analysis is to identify any technology options that will be eliminated from further consideration in the rulemaking analyses.

The candidate technology options are assessed based on DOE analysis as well as inputs gathered from interested parties, including manufacturers, trade organizations, and energy efficiency advocates in support of both the final determination published on December 13, 2016, and the request for information published on October 14, 2020. Technology 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 preliminary TSD). Technology options that are not incorporated in commercial products or in working prototypes, or that fail to meet certain criteria as to practicability to manufacture, install and service; as to impacts on product utility or availability; as to health or safety; or as to proprietary technologies 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)) and *Energy Conservation Program for Appliance Standards: Procedures for Use in New orRevised Energy Conservation Standards and Test Procedures for Consumer Products and Commercial/Industrial Equipment*. (85 FR 8626, section 1(c) and 6(c)(3)). The rationale for either screening out or retaining each technology option is detailed in the following sections.

4.2 DISCUSSION OF TECHNOLOGY OPTIONS

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

4.2.1 Screened out Technology Options

The technologies identified in the market and technology assessment were evaluated pursuant to the criteria set out in The Energy Policy and Conservation Act, as amended (EPCAor 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.

(5) Unique-Pathway Proprietary Technologies. If a technology option utilizes proprietary technology that represents a unique pathway to achieving a given efficiency level, it will not be considered further.

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

4.2.1.1 Desiccant drying

Desiccant drying relies on a material such as zeolite to adsorb moisture to aid in the drying process and reduce drying energy consumption. DOE is aware of dishwashers from one manufacturer on the market in the United States that use desiccant drying.

DOE has screened out desiccant drying from further consideration because it would not be practicable to manufacture on the scale necessary for the dishwasher market.

Desiccant drying is a patented technology, and although multiple manufacturers hold patents for dishwasher designs with desiccant drying features, DOE is concerned that this technology optionis not available for all manufacturers.

4.2.1.2 Reduced inlet-water temperature

Reduced inlet-water temperature requires that dishwashers tap the cold-water line for their water supply. Because most dishwashers in the United States tap the hot water line, this technology option would require significant alteration of existing dishwasher installations in order to accommodate newly purchased units incorporating this technology 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.

4.2.1.3 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.

4.2.1.4 Ultrasonic washing

A 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 withdetergent 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 consumer dishwashers, it is impossible to assess whether this technology 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.

4.2.1.5 Thermoelectric heat pumps

The thermoelectric heat pump system aims to extract waste heat from drain water and recover heat normally lost during the drying process, and apply it to the washing, rinsing, and drying phases, effectively saving energy. The technology is not commercially available yet as research and development is still underway. Therefore, 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.

4.2.1.6 Water re-use system

This system saves water from the final rinse of a given dishwasher cycle for use in a subsequent dishwasher cycle. A water re-use system dishwasher also performs “drain out” and “clean out” cycles if the dishwasher is not operated for a certain period of time. Both “drain out” and “clean out” events consume additional water and energy during the subsequent cycle, even though such a system saves water and energy consumption overall.

DOE has screened out this technology option as it believes that leaking and contamination from a water holding tank could potentially present a safety hazard in addition to possible consumer utility impacts.

4.2.2 Remaining Design Options

For 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 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

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CHAPTER 5. ENGINEERING ANALYSIS

5.1 INTRODUCTION

The engineering analysis performed by the U.S. Department of Energy (DOE) establishes the relationship between the manufacturing product cost (MPC) and the efficiency of dishwashers. The purpose of the analysis is to estimate the incremental MPCs for a product that would result from increasing efficiency levels above the baseline model. These relationships serve as the basis for calculating costs and benefits of modified product designs for consumers, manufacturers, and the Nation. The engineering analysis considers technologies not eliminated in the screening analysis, designated as "design options," associated with each higher efficiency level. This chapter 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 preliminary 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, teardown analysis, and information compiled from previous rulemakings. The primary output of the engineering analysis is a relationship comparing increases in 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 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 an MPC estimate, while removing the costs associated with non-efficiency-related components or features.

5.2 PRODUCT CLASSES ANALYZED

When evaluating and establishing energy conservation standards, DOE may divide covered products into 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. Different energy conservation standards may apply to different product classes. (42 U.S.C. 6295(q))

For dishwashers, the size of the unit impacts the energy consumed. Because standard 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*, and the DOE test procedure for dishwashers in appendix C1 to subpart B of Title 10 of the Code of Federal Regulations (CFR) (Appendix C1)). Table 5.1 lists the current two product classes for dishwashers.

Table 5.1 Current Dishwasher Product Classes

Product Class	
Standard	Capacity equal to or greater than eight place settings plus six serving pieces as specified in ANSI/AHAM DW-1 using the test load specified in section 2.7 of Appendix C1 in subpart B
Compact	Capacity less than eight place settings plus six serving pieces as specified in ANSI/AHAM DW-1 using the test load specified in section 2.7 of Appendix C1 in subpart B

On October 30, 2020, DOE published a final rule establishing a separate product class for standard-size dishwashers with a cycle time for the "normal" cycle of less than one hour (*i.e.*, 60 minutes) from washing through drying. 85 FR 68723. DOE initiated the rulemaking in response to a petition submitted by the Competitive Enterprise Institute and established the new product class following an evaluation of testing and analysis conducted by DOE and comments received from stakeholders. *Id*. at 68724. To date, the short-cycle product class is not subject to energy conservation standards and no product relies on the short-cycle product classification. On January 11, 2022, DOE issued a final rule revoking the final rule that established a new product class for dishwashers.[a] Accordingly, DOE addressed only the two current product classes for dishwashers as part of the present evaluation.

5.3 EFFICIENCY LEVELS

For dishwashers, energy conservation standard levels are currently defined by two factors determined in accordance with Appendix C1 and 10 CFR 430.23 (c)(2)–(3): estimated annual energy use (EAEU), in terms of kilowatt-hours per year (kWh/year), and per-cycle water consumption, in terms of gallons per cycle (gal/cycle). The EAEU 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 Efficiency Levels

DOE selected baseline efficiency levels to represent the basic design characteristics of dishwashers. Typically, a baseline unit is a unit that just meets current energy conservation standards and provides basic consumer utility. To determine energy savings and changes in price associated with higher efficiency levels, DOE compared design options at each efficiency level with those identified in 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 current energy and water conservation standards for dishwashers manufactured on or after May 30, 2013. 77 FR 31918. In a final determination published on December 13, 2016 (December 2016 Final Determination), DOE decided not to amend the standards because it concluded that amended energy conservation standards would not be economically justified at any level above the standards established in the May 2012 Direct Final Rule. 81 FR 90072. The current standards are presented in Table 5.2 below.

[a] https://www.energy.gov/sites/default/files/2022-01/short-cycle-product-class-fr.pdf

Table 5.2 Current Federal Energy Conservation Standards for Dishwashers

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

The current annual energy consumption standards are based on the specifications defined in the current dishwasher test procedure at Appendix C1. However, in the test procedure notice of proposed rulemaking published on December 22, 2021, DOE proposed to adopt a new test procedure, Appendix C2, which would be applicable upon the compliance date of any future amended energy conservation standards. 86 FR 72738. DOE proposes to update to the annual number of cycles and low-power mode hours for the calculation of energy consumption in Appendix C2. The annual number of cycles would be reduced from 215 to 184 cycles, while the estimated low-power mode hours would be updated from the fixed 8,465 annual hours to a value that is dependent on the "normal" cycle duration of a unit. These updates are based on the specifications in the most recent industry standard, AHAM's *Uniform Test Method for Measuring the Energy Consumption of Dishwashers* (AHAM DW-1-2020).

Both the annual number of cycles and annual low-power mode hours are factors used in the calculation of EAEU. Since the proposed Appendix C2 would be applicable upon the compliance date of any future amended energy conservation standards, DOE evaluated baseline efficiency levels by proportionately scaling the current energy conservation standards to reflect the updates proposed in the new proposed Appendix C2. Baseline water consumption levels used in the preliminary analysis are those in the current standards, since per-cycle values are not affected by the number of annual cycles or annual low-power mode hours. The analyzed baseline efficiency levels are shown in Table 5.3 below.

Table 5.3 Preliminary Analysis Baseline Efficiency Levels

Dishwasher Classification	Maximum Annual Energy Use* *(kWh/year)*	Maximum Per-Cycle Water Consumption *(gallons/cycle)*
Standard Dishwasher	263	5.0
Compact Dishwasher	178	3.5

* Using 184 annual cycles.

5.3.2 Incremental Efficiency Levels

To determine the appropriate energy and water consumption levels above the baseline, DOE surveyed the products currently available on the market in the United States using DOE's Compliance Certification Database (CCD).[b] Since efficiency levels were identified using current data and information that are based on Appendix C1, DOE scaled the EAEU values to determine efficiency levels based on the criteria in the proposed Appendix C2.

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

5.3.2.1 Standard Product Class

DOE analyzed several efficiency levels for standard dishwashers, identified design options, and obtained incremental cost data at each of these levels. Table 5-4 includes the efficiency levels analyzed for this preliminary analysis and the reference source of each level for the standard product class. Table 5.4 includes energy use based on both the current Appendix C1 and scaled to the proposed Appendix C2 for the analysis.

Table 5.4 Preliminary Analysis Standard Dishwasher Incremental Efficiency Levels

Level	Efficiency Level Reference Source	Efficiency Level		
		EAEU (Appendix C1) ***(kWh/year)***	**Analyzed EAEU (Appendix C2)** ***(kWh/year)***	**Water Consumption** ***(gal/cycle)***
Baseline	DOE Standard	307	263	5.0
EL 1	ENERGY STAR V. 6.0	270	232	3.5
EL 2	Gap Fill	260	223	3.3
EL 3	ENERGY STAR Most Efficient 2021	240	206	3.2
EL 4	Maximum Available[a]	225	193	2.4

[a] *Source: DOE-certified dishwashers as of April 2021*

DOE analyzed four efficiency levels beyond the baseline for standard dishwashers in the engineering analysis. Intermediate efficiency levels were established based on energy and water use specifications in voluntary efficiency programs and by analyzing the distribution of rated dishwasher efficiencies and identifying efficiency "clusters" that exist in the market.

Figure 5.1 shows the distribution of standard dishwashers included in the DOE CCD at the time of this preliminary analysis. As previously noted, the data certified in the DOE CCD are based on Appendix C1, so the efficiency level overlays observed in Figure 5-1 are unscaled.

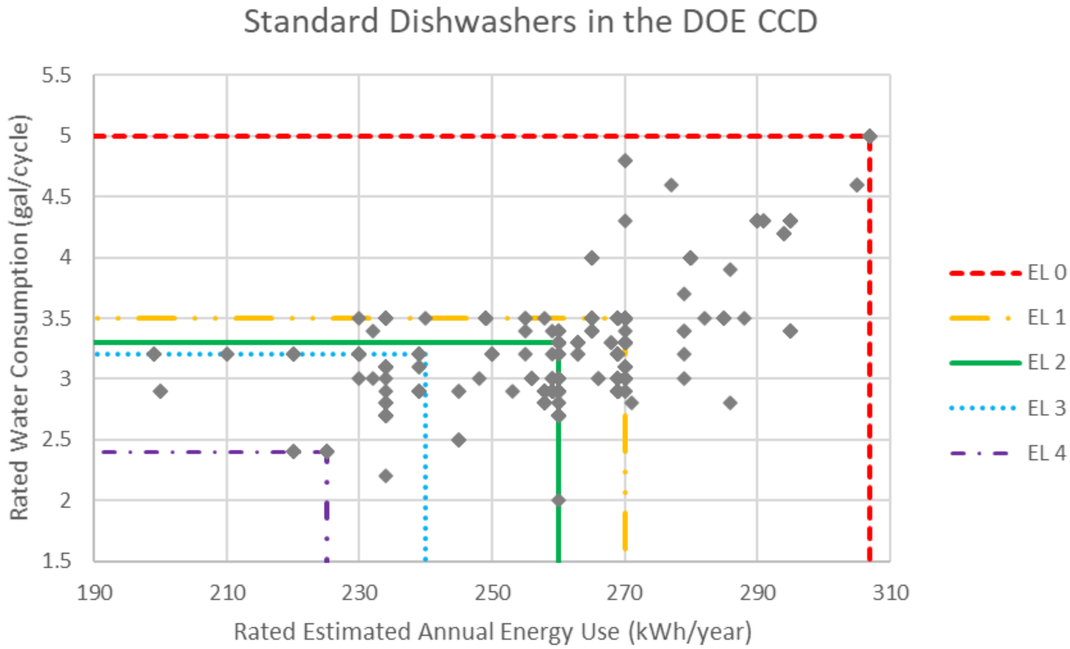

Figure 5.1 Market Availability of Standard Dishwashers as of April 2021

Efficiency Level (EL) 1 was selected to correspond to the current ENERGY STAR V. 6.0[c] qualification criteria for standard dishwashers. Nearly 61% of standard dishwasher basic models are rated at EL 1.

An intermediate level was considered between ENERGY STAR V. 6.0 and the baseline, but was determined to be unnecessary, since only approximately 12% of standard dishwasher basic models do not meet the water and energy use criteria of the ENERGY STAR V. 6.0 program. Therefore, further disaggregation of such a small portion of the market would not be warranted.

EL 3 is the level that corresponds to the energy and water qualifying criteria for the 2021 ENERGY STAR Most Efficient[d] dishwasher designation and 8% of dishwasher basic models meet the EL 3 criteria according to the DOE CCD.

EL 2 was established as a gap-fill level, developed by identifying product efficiency "clusters" when analyzing the range of efficiencies available on the market. The annual energy consumption and per-cycle water consumption values associated with a significant cluster between EL 1 and EL 3 served as the basis for selecting EL 2 and approximately 18% of basic models are at EL 2.

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[c] Information on the ENERGY STAR program can be found at www.energystar.gov. Version 6.0 effective January 29, 2016.

[d] https://www.energystar.gov/most-efficient/me-certified-dishwashers

Lastly, EL 4 represents the maximum technologically feasible (max-tech) efficiency level, which was determined to be the maximum available efficiency level identified on the market for a standard dishwasher at the time of this preliminary analysis. DOE selected a dishwasher model rated at 225 kWh/year and 2.4 gal/cycle as the representative unit for EL 4. DOE identified units on the market with lower energy or water consumption values, but these units were either not commercially available, were relatively low-capacity 8-place setting units that would not provide sufficient capacity for all consumers,[e] or were less efficient overall when considering both energy and water consumption. When scaling EL 4 to Appendix C2 specifications, the annual energy use for EL 4 is 193 kWh/year. Only 1% of the basic models on the DOE CCD are rated at EL 4.

5.3.2.2 Compact Product Class

Table 5-5 below shows the three efficiency levels DOE analyzed for the compact product class for this preliminary analysis. As explained in section 5.3.2.1, the existing standards and certified energy consumption data for all dishwashers, including compact dishwashers, are based on the current Appendix C1. Since DOE used existing product information to guide the selection of efficiency levels, but analyzed specific energy consumption values based on the proposed Appendix C2, DOE scaled its selected compact dishwasher efficiency levels to account for the proposed Appendix C2 specifications. Table 5.5 shows the incremental efficiency levels for this preliminary analysis, based on Appendix C1 and the new proposed Appendix C2.

Table 5.5 Preliminary Analysis Compact Dishwasher Incremental Efficiency Levels

Level	Efficiency Level Reference Source	EAEU (Appendix C1) *(kWh/year)*	Analyzed EAEU (Appendix C2) *(kWh/year)*	Water Consumption *(gal/cycle)*
Baseline	DOE Standard	222	178	3.50
EL 1	ENERGY STAR V. 6.0	203	174	3.10
EL 2	Maximum Available[a]	144	124	1.60
[a] *Source: DOE-certified dishwashers as of April 2021*				

DOE evaluated two incremental efficiency levels above the baseline for compact dishwashers. Table 5.5 provides the distribution of compact models in the market, based on the DOE CCD.

[e] 8 place setting-capacity dishwashers represent 10.7% of dishwasher models in the DOE CCD as of April 2021.

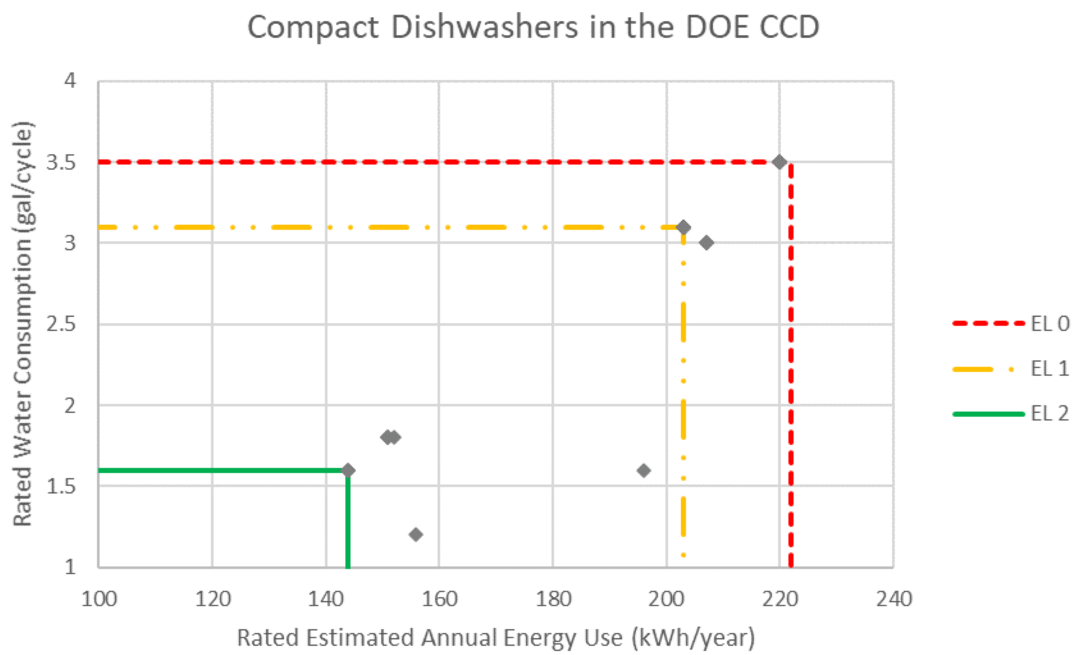


Figure 5.2 Market Availability of Compact Dishwashers as of April 2021

The first efficiency, EL 1, represented the same EAEU and per-cycle water consumption measured in accordance with Appendix C1 as the requirements in the current ENERGY STAR V. 6.0 specification for compact dishwashers. After eliminating from consideration any ultra-small capacity, 1- or 2-place setting compact dishwasher models that would not provide sufficient capacity for all consumers, 53% of basic compact dishwasher models in the DOE CCD are rated at the EL 1 level. With 33% of compact dishwasher basic models rated at the EL 0 level, basic models between the baseline and ENERGY STAR V. 6.0 account for roughly 87%% of the market. All compact models within this efficiency range are in the countertop configuration. No countertop units exist in the market beyond the ENERGY STAR V. 6.0 level.

DOE identified EL 2 as the max-tech efficiency level, defined by the maximum available technology that DOE identified on the market at the time of its analysis. As with EL 1, DOE removed ultra-small capacity dishwashers from consideration when identifying the max-tech level. DOE established the energy and water consumption levels for EL 2 from a basic model that was rated at 144 kWh/year based on the Appendix C1 test procedure, which was scaled to 124 kWh/year under the new proposed Appendix C2. Approximately 13% of basic models in the DOE CCD are rated at the EL 2 level.

5.4 METHODOLOGY OVERVIEW

DOE relied on multiple sources of information for the engineering analysis including a review of TSDs from previous rulemakings, internal product testing, and product teardowns. The following sections describe DOE's sources of information and methodology for product selection, 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 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 dishwashers was created in support of the December 2016 Final Determination.

5.4.2 Product Testing

Much of the analysis in this chapter relies on data from publicly available sources such as the DOE CCD and ENERGY STAR product databases. However, DOE also conducted its own limited performance testing according to Appendix C1 in conjunction with the ENERGY STAR Test Method for Determining Dishwasher Cleaning Performance (Cleaning Performance Test Method)[f] for the following purposes:

- To develop a better understanding of the design options and product features currently available on the market; and
- To characterize any 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. DOE performed physical teardown analysis on both standard and compact dishwashers based on the methodology outlined 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

[f] 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

- The selected products should have non-efficiency-related features that are the same as, or similar to, features of other products in the same class and at the same efficiency level.

5.4.3.2 Generation of Bill of Materials

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

Materials in the BOM are divided between raw materials that require conversion steps to be made ready for assembly, 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[g] (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 5.3 shows the three major steps in generating the manufacturing cost.

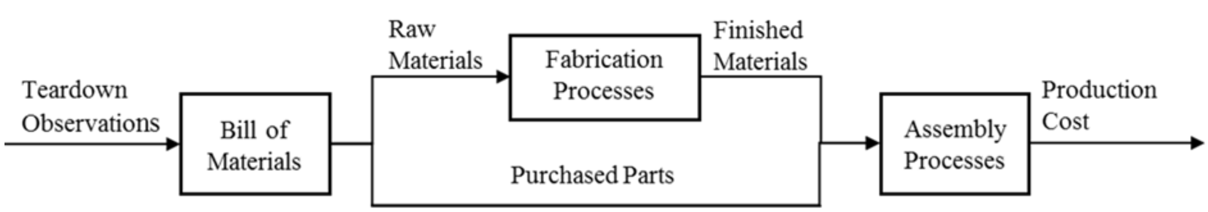


Figure 5.3 Manufacturing Cost Assessment Stages

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

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

dismantled, and each part was characterized according to weight, manufacturing processes used, dimensions, material, and quantity. The BOM incorporates all materials, components, and fasteners with estimates of raw material costs and purchased part costs. Assumptions on the sourcing of parts and in-house fabrication were based on industry experience, information in trade publications, and discussions with manufacturers. Interviews and plant visits were conducted previously 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 5.6.

Table 5.6 Major Manufacturing Processes

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

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

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

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

5.4.3.4 Cost Model and Definitions

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

- Materials: Purchased parts (*i.e.*, motors, valves, *etc*.), raw materials, (*i.e.*, cold rolled steel, copper tube, *etc*.), and indirect materials that are used for processing and fabrication.

- Labor: Fabrication, assembly, indirect, and supervisor labor. Fabrication and assembly labor cost are burdened with benefits and supervisory costs.
- Overhead: Equipment, tooling, and building depreciation, as well as utilities, equipment and tooling maintenance, insurance, and property taxes.

Cost Definitions

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

- Direct material: Purchased parts (out-sourced) plus manufactured parts (made in-house from raw materials).
- Indirect material: Material used during manufacturing (*e.g.*, welding rods, adhesives).
- Fabrication labor: Labor associated with in-house piece manufacturing.
- Assembly labor: Labor associated with final assembly.
- Supervisory labor: Labor associated with fabrication and assembly basis. Assigned on a span basis (x number of employees per supervisor) that depends on the industry.
- Indirect labor: Labor costs that scale with fabrication and assembly labor. These included the cost of technicians, manufacturing engineering support, stocking, *etc*. that are proportional to all other labor.
- Equipment depreciation: Money allocated to pay for initial equipment installation and replacement as the production equipment is amortized. All depreciation is assigned in a linear fashion and affected equipment life depends on the type of equipment.
- Tooling depreciation: Cost for initial tooling (including non-recurring engineering and debugging of the tools) and tooling replacement as it wears out or is rendered obsolete.
- Building depreciation: Money allocated to pay for the building space and the conveyors that feed and/or make up the assembly line.
- Utilities: Electricity, gas, telephones, *etc*.
- Maintenance: Annual money spent on maintaining tooling and equipment.
- Insurance: Appropriated as a function of unit cost.
- Property Tax: Appropriated as a function of unit cost.

5.4.3.5 Cost Model Assumptions

As discussed in the previous section, assumptions about manufacturer practices and cost structure played an important role in estimating the final product cost. In converting physical information about the product into cost information, DOE reconstructed manufacturing processes for each component using internal expertise and knowledge of the methods used by the industry. 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 to analyze the impact of key design options and product features on dishwasher efficiency and to characterize any relationship between energy and water consumption and cleaning performance. DOE selected over 30 standard dishwasher models and four compact dishwasher models that spanned the dishwasher market and encompassed various brands, features, and efficiencies. Each unit in the sample was tested according to the current test procedure at Appendix C1 in conjunction with the ENERGY STAR Cleaning Performance Test Method, which specifies a methodology to determine the per-cycle cleaning index for a test cycle. The cleaning performance results were compared with energy and water consumption data obtained from Appendix C1 for each tested standard dishwasher model as shown in Figure 5.4 through Figure 5.9. The results are divided by heavy, medium, and light soil loads. DOE compared the unitless per-cycle cleaning index for each soil type with the measured energy consumption per cycle (kWh/cycle) and measured water consumption (gal/cycle).

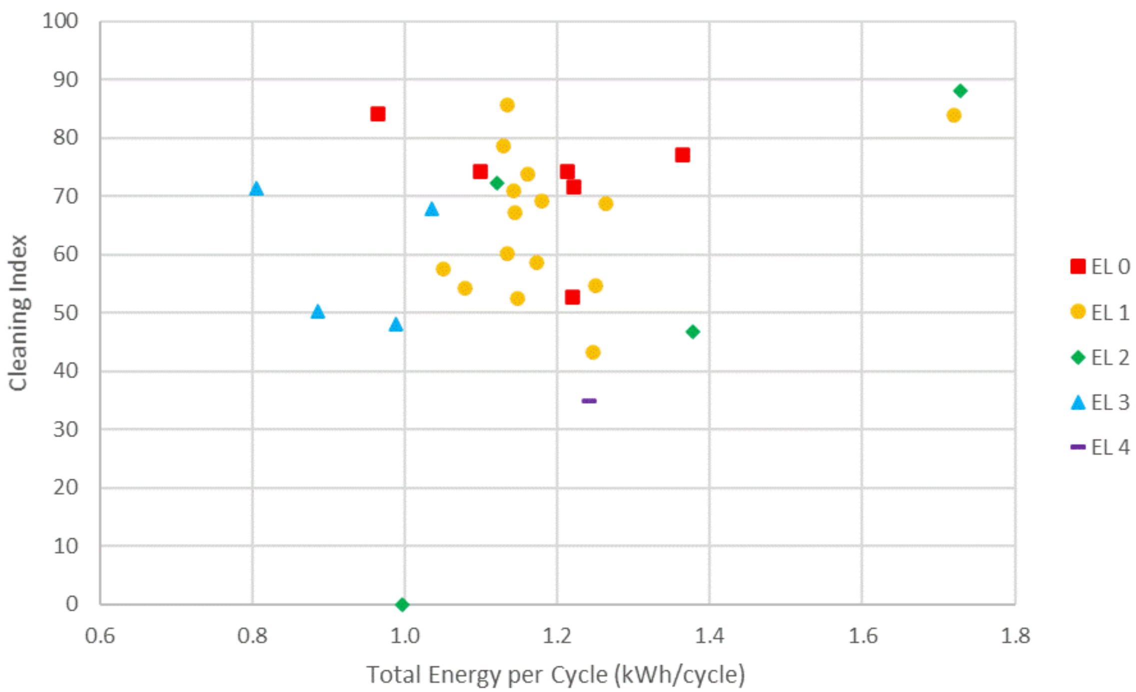


Figure 5.4 Standard Dishwasher Heavy Soil Load Cleaning Performance vs. Machine Energy Consumption

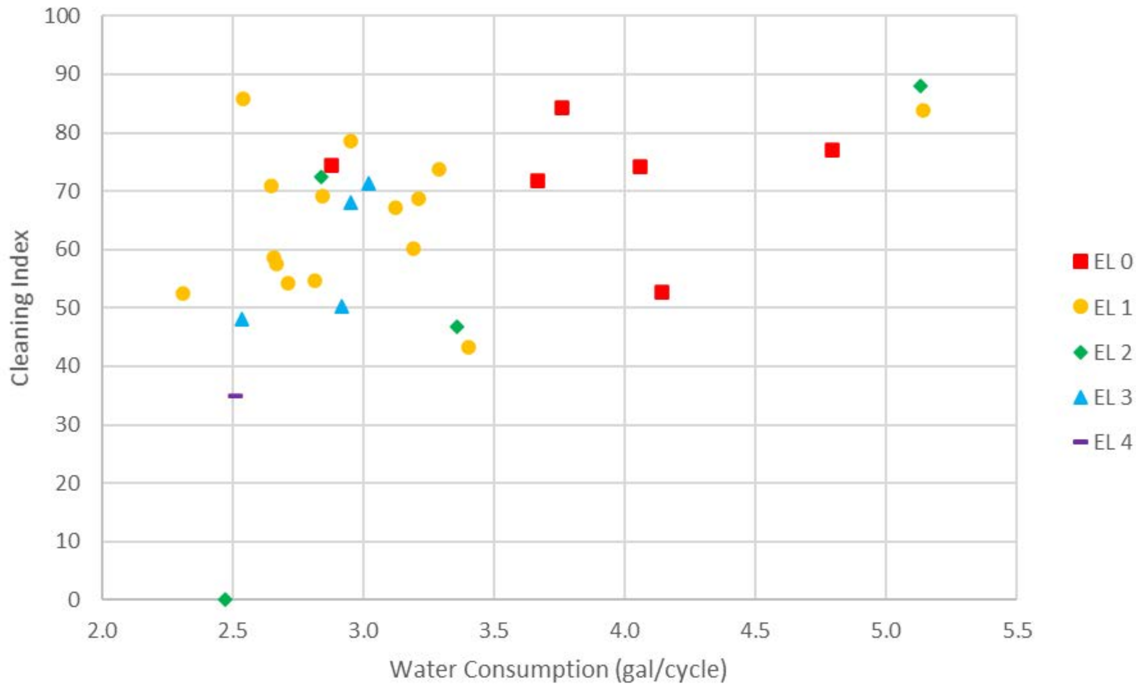


Figure 5.5 Standard Dishwasher Heavy Soil Load Cleaning Performance vs. Water Consumption

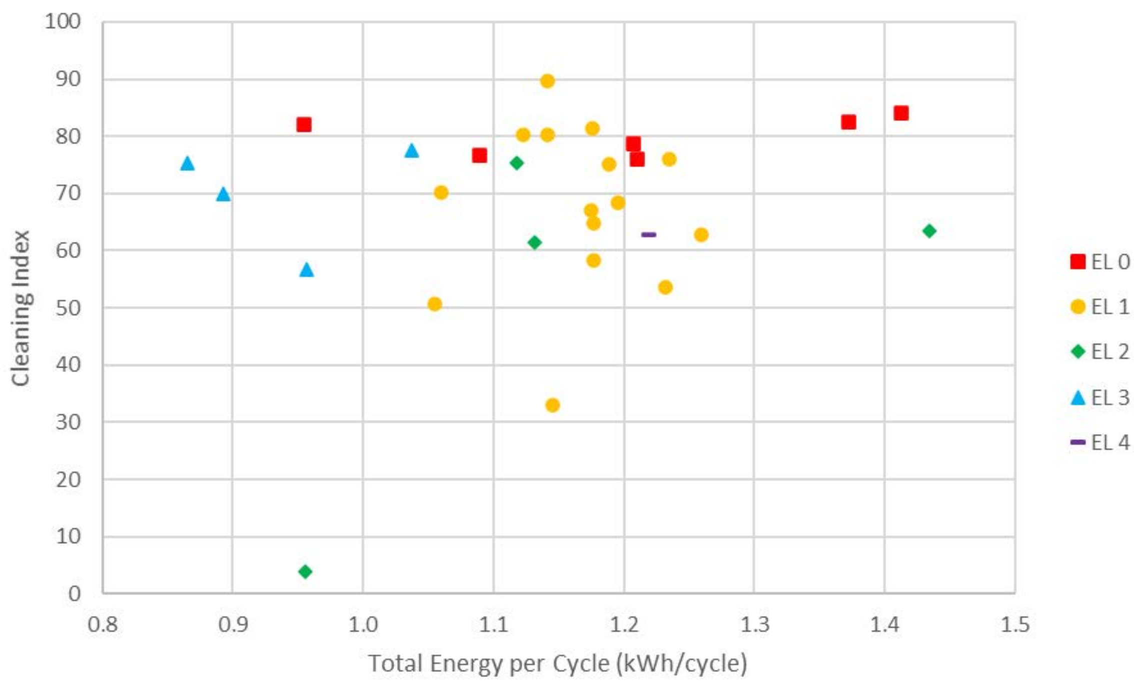


Figure 5.6 Standard Dishwasher Medium Soil Load Cleaning Performance vs. Machine Energy Consumption

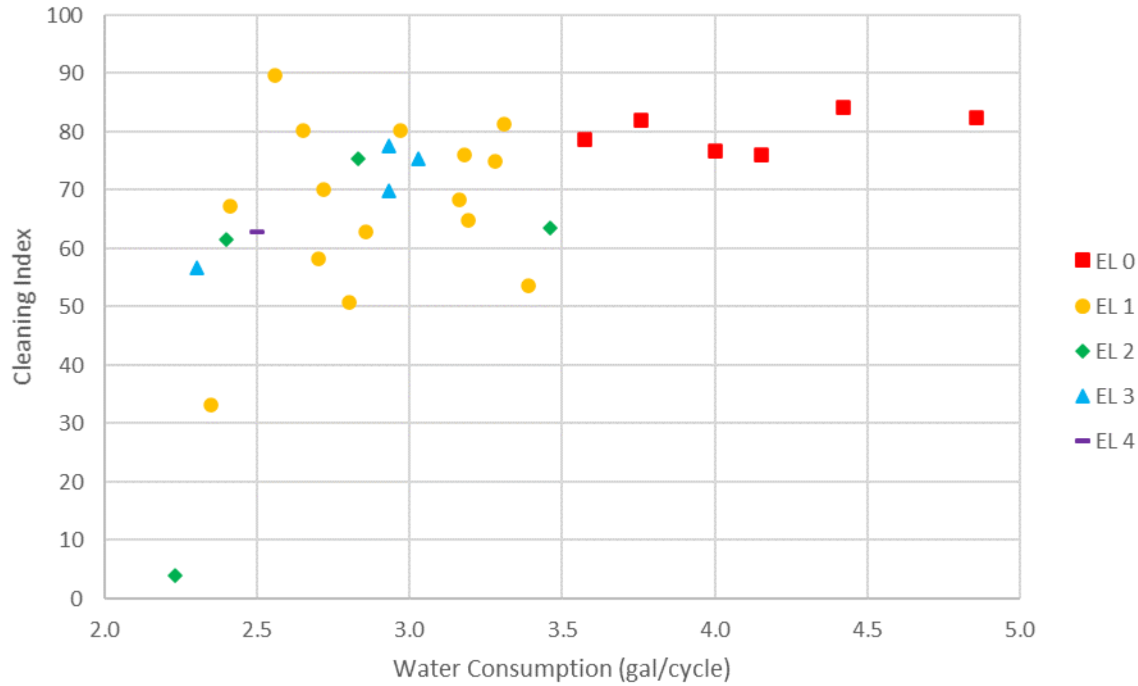


Figure 5.7 Standard Dishwasher Medium Soil Load Cleaning Performance vs. Water Consumption

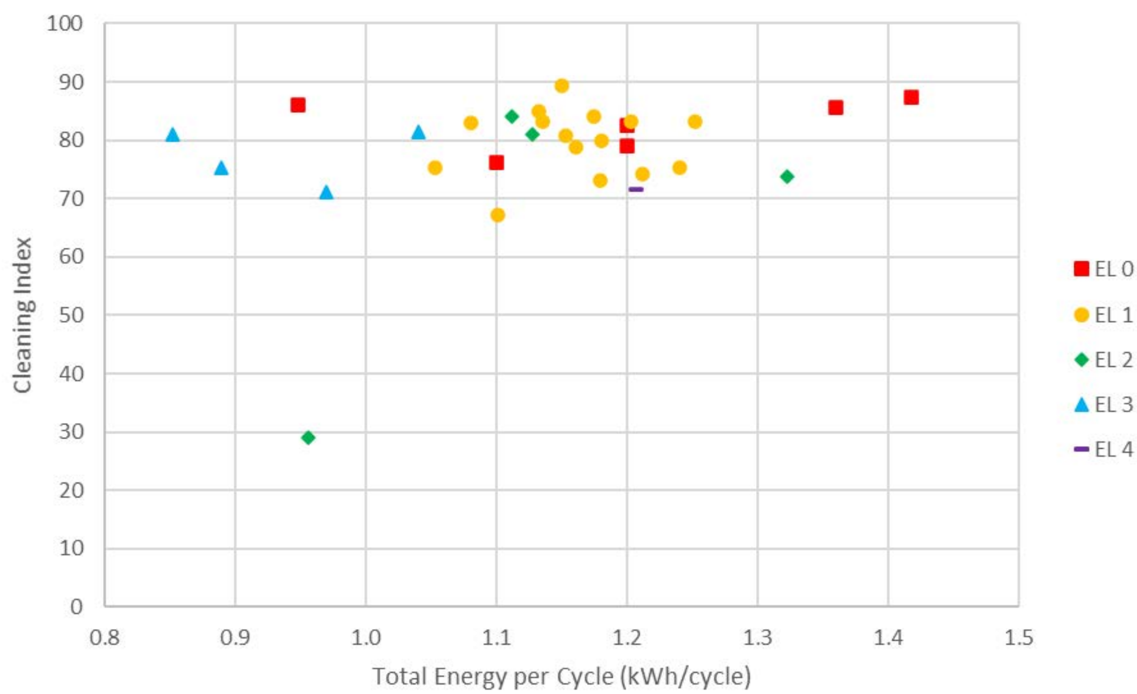


Figure 5.8 Standard Dishwasher Light Soil Load Cleaning Performance vs. Machine Energy Consumption

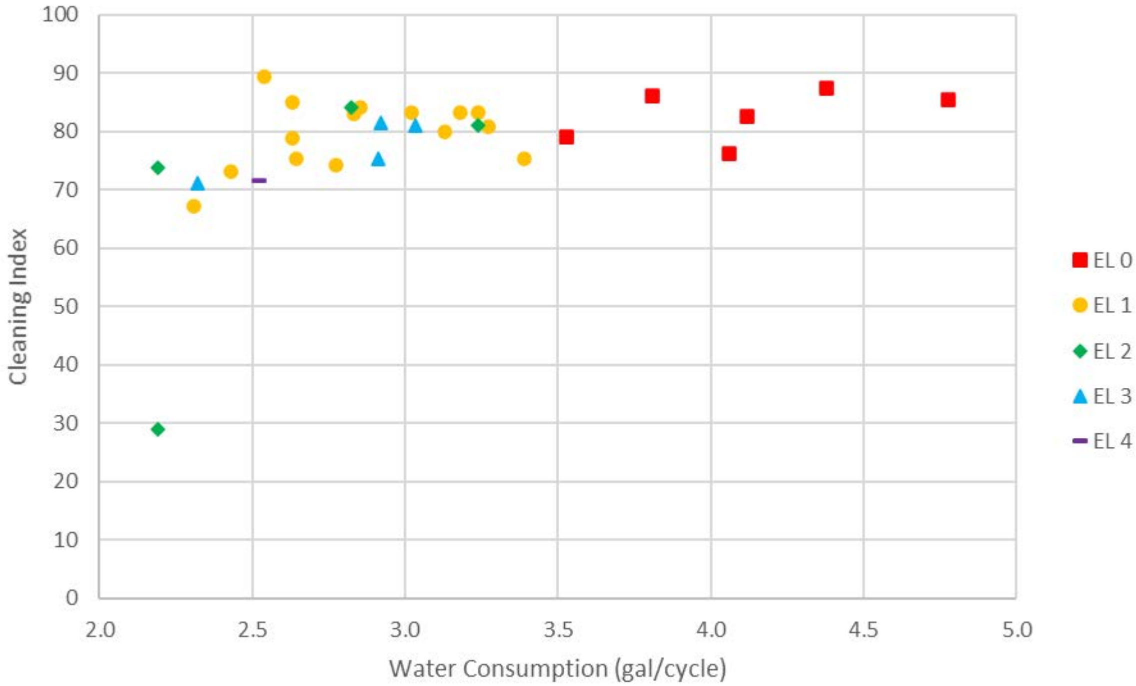


Figure 5.9 Standard Dishwasher Light Soil Load Cleaning Performance vs. Water Consumption

At heavy soil loads, cleaning performance was both more variable across all units and worse on average when compared to medium and light soil test results. Figure 5.4 shows little correlation between energy consumption and cleaning performance, with a wide range of per-cycle cleaning indices across all tests at each efficiency level. Overall, a little over 50% of the units across all efficiency levels achieved a per-cycle cleaning index of 65. The water consumption chart in Figure 5.5 showed a slightly stronger correlation. Notably, all units but one that consume more than 3.5 gal/cycle attained a per-cycle cleaning index of 65. However, overall performance degraded and the distribution of per-cycle cleaning indices widened for units below 3.5 gal/cycle, supporting the trend that cleaning performance is more likely to be unpredictable at lower efficiencies.

At medium soil loads, DOE observed that overall average cleaning performance was higher compared to heavy loads but units at high efficiencies still had more volatile cleaning indices than units at lower efficiencies. Test results indicated that the spread of cleaning performance increases considerably for units that consume less than 1.1 kWh/cycle and 3.0 gal/cycle. The results further indicated that ultra-high efficiency units are not able to consistently attain adequate cleaning performance, as only one unit that consumed below 2.5 gal/cycle was able to meet a per-cycle cleaning index of 65.

The test results for the light soil load showed a more consistent and much higher level of cleaning performance across all efficiency levels when compared to heavy and medium soil loads. Almost every unit in the light soil test was able to achieve a per-cycle cleaning index of 65, even those with the lowest machine energy consumption and nearly lowest water consumption. Figure 5.8 shows that as energy consumption changes, cleaning performance remains consistent. Based on the results in Figure 5.9, cleaning performance is maintained even at high efficiencies. Of the five units that tested with less than 2.5 gal/cycle water consumption with the light soil load, four were able to achieve a per-cycle cleaning index score of 65. These results are not unexpected, since 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 amounts).

Based on this testing, products with a per-cycle energy consumption of at least 1.1 kWh/cycle, which correlates to an EAEU of about 206 kWh/year, and per-cycle water consumption of at least 3.2 gal/cycle (the levels corresponding approximately to EL 3 as defined in this preliminary analysis) were determined to typically and reliably maintain adequate cleaning performance. While test results indicate cleaning performance may be adequate at EL 3, consumer utility may be impacted in other ways. In the December 2016 Final Determination, DOE received feedback from manufacturers that other aspects of the cycle, such as drying performance and cycle time, would be impacted at such low energy and water consumption levels.

DOE's additional investigative testing since the December 2016 Final Determination suggests that cycle time is not substantively correlated with energy and water consumption. Figure 5.10 and Figure 5.11 show the results of cycle time as a function of EAEU (based on 184 cycles/year) and water consumption, respectively, where EAEU, water consumption, and cycle times are presented as weighted averages for the heavy, medium, and light soil load cycles. The weighting factors used to calculate the averages were the same as those specified in Appendix C1 (and the new proposed Appendix C2).

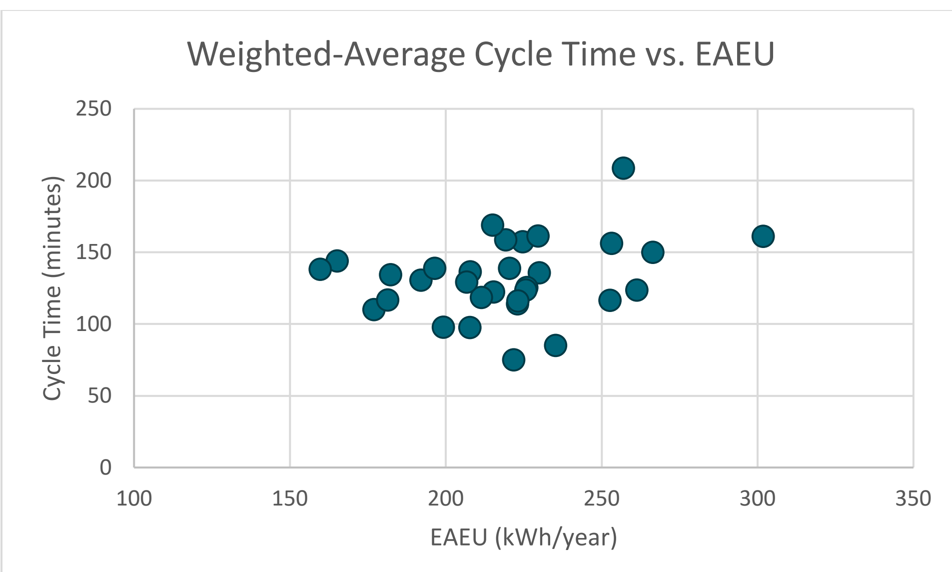


Figure 5.10 Standard Dishwasher Weighted-Average Cycle Time vs. Energy Consumption

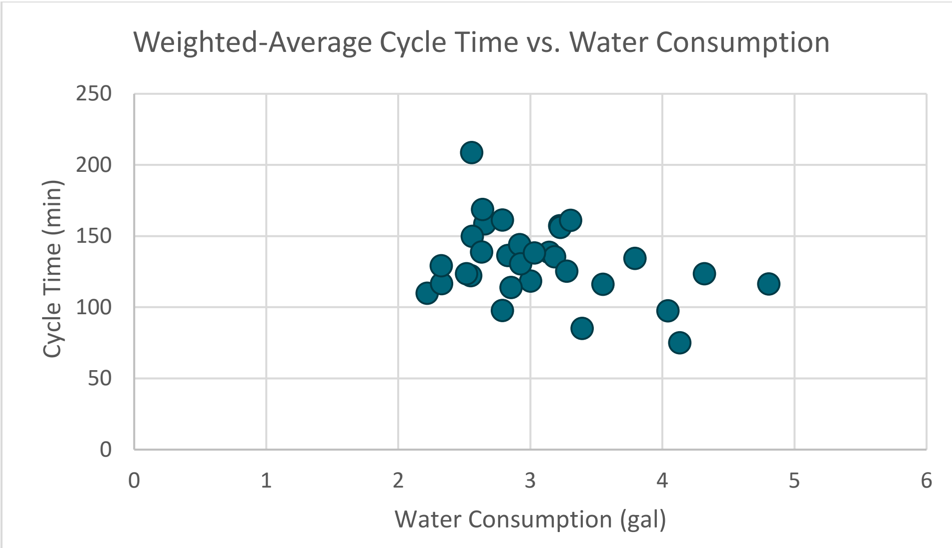


Figure 5.11 Standard Dishwasher Weighted-Average Cycle Time vs. Water Consumption

5.5.2 Expected Product Configurations

In support of this preliminary analysis, DOE conducted 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 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 and manufacturer interviews during the December 2016 Final Determination, 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.

From this information, DOE developed estimates for the typical mix of design options that manufacturers would likely use at each analyzed efficiency level. DOE relied on these estimates and its cost model to generate the cost-efficiency curves in the engineering analysis.

5.5.2.1 Baseline Construction: Standard Dishwasher

The baseline standard dishwasher is equipped with electromechanical controls which would use a linear power supply with no standby power draw. The electromechanical control panel includes 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.

5.5.2.2 Baseline Construction: Compact Dishwasher

The baseline compact 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 includes only 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 perforated stainless steel filter and a finer plastic 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 this preliminary TSD), the teardown analysis, and information from the December 2016 Final Determination, 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 Dishwashers

Efficiency Level 1

DOE research suggests that EL 1 is typically achieved in standard 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 in support of the 2016 Final Determination, 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. Soil Sensing

A dishwasher meeting EL 1 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.

3. 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.

4. 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.

5. 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.

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. Improved Filters

At EL 2, manufacturers would likely further improve the water filtering system. For EL 1, DOE expects manufacturers would use plastic water filters. The fine filter at EL 2 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 2 unit and thus allows the water line diameters and volume of the water system to be reduced as well.

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. Water Diverter Assembly

DOE believes manufacturers would likely incorporate a water diverter valve at EL 2. 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.

Efficiency Level 3

A standard 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. 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.

2. 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.

3. 3-Phase Variable-Speed Motor

The EL 3 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.

4. 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 standard 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.

2. In-Sump Integrated Heater

At EL 4, manufacturers would likely replace the in-tub tubular heating element with a design that incorporates the heating element into the sump. This design change eliminates the water volume necessary within the tub during heated portions of the cycle for the baseline through EL 3 units.

3. 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. By avoiding operation of the heater during the dry cycle, condensation drying may use less net energy for the overall cycle compared to typical heated drying. To incorporate this design option, DOE expects that manufacturers would be required to switch from a plastic tub to a stainless steel tub.

Compact Dishwashers

Starting with the baseline compact 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

Based on its teardown analysis, DOE did not observe any design option differences between compact dishwashers at the baseline and EL 1. As a result, DOE expects that a dishwasher at EL 1 would employ the same design options as a unit at the baseline but with improved controls that allow the dishwasher to maintain performance at a higher efficiency.

1. 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.

Efficiency Level 2

The max-tech compact 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 countertop units. 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 EL 1 to EL 2 are:

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. Improved Filters

At EL 2, manufacturers would likely improve the water filtering system by switching to finer-mesh stainless steel filter. 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.

3. 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.

4. Heater Incorporated into Base of Tub

DOE observed that the max-tech compact dishwasher incorporates the internal water heater into the base of the tub. This requires a lower volume of water 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. 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.

6. Tub Insulation
At EL 2 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.

5.5.3 Cost-Efficiency Curves

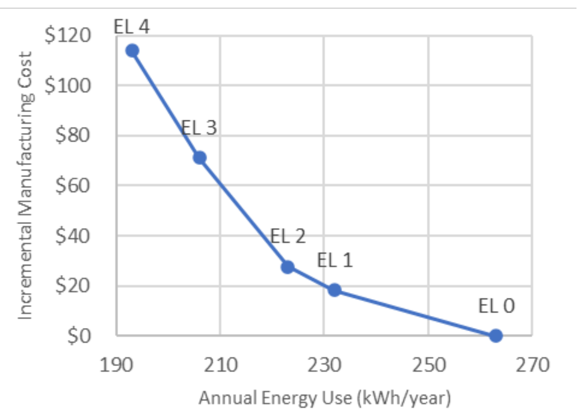
Based on product teardowns, the design options described above, and cost modeling, DOE developed the following cost-efficiency relationships for standard and compact dishwashers. The corresponding cost-efficiency curves are shown in the sections below.

5.5.3.1 Standard Dishwashers

For standard dishwashers, 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 Table 5.7 shows the incremental manufacturing costs developed in this preliminary analysis for standard dishwashers, in 2020 dollars.

Table 5.7 Standard Dishwasher Incremental Manufacturing Costs

Efficiency Level	EAEU *(kWh/year)*	Water Consumption *(gal/cycle)*	Incremental Costs *($2020)*
Baseline	263	5.0	$ -
EL 1	232	3.5	$ 18.27
EL 2	223	3.3	$ 27.53
EL 3	206	3.2	$ 71.12
EL 4	193	2.4	$ 113.86

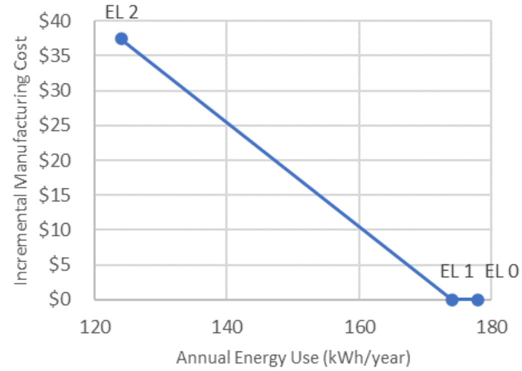


5.5.3.2 Compact Dishwashers

Similar to the cost estimates for the standard product class, DOE started with the baseline unit cost model for compact 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 5.8 shows the incremental manufacturing costs for compact dishwashers, in 2020 dollars.

Table 5.8 Compact Dishwasher Incremental Manufacturing Costs

Efficiency Level	**EAEU *(kWh/year)***	**Water Consumption *(gal/cycle)***	**Incremental Costs *($2020)***
Baseline	178	3.50	$ -
EL 1	174	3.10	$ -
EL 2	124	1.60	$ 37.41



CHAPTER 6. MARKUPS ANALYSIS

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CHAPTER 6. MARKUPS ANALYSIS

6.1 INTRODUCTION

To carry out its analyses, the U.S. Department of Energy (DOE) needed to determine the cost to the consumer of both baseline products (*i.e.*, products not subject to newly amended energy conservation standards) and more efficient products. DOE calculated such costs based on engineering estimates of manufacturing production costs, a manufacturer markup to calculate the manufacturer sales price (*i.e.*, the price to the manufacturer's first customer), and appropriate additional markups for the various distribution channels to move the product to consumers.

The total markups applied to all product classes differ by their corresponding distribution channel, as discussed below. At each point in a distribution channel, companies mark up the price of a product to cover their business costs and profit margin. In financial statements, gross margin (GM) is the difference between the company revenue and the company cost of goods sold (CGS). The GM takes account of the expenses of companies in the distribution channel, including overhead costs (sales, general, and administration); research and development (R&D); 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.

DOE estimates a baseline markup and an incremental markup for each market participant besides manufacturers. DOE defines a baseline markup as a multiplier that converts the manufacturer selling price (MSP) of equipment with baseline efficiency to the consumer purchase price. An incremental markup is defined as the multiplier to convert the incremental increase in manufacturer selling price of higher efficiency equipment to the consumer purchase price. Because companies mark up the price at each point in the distribution channel, both overall baseline and incremental markups are dependent on the distribution channel, as described in section 6.2

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, in which manufacturers sell the products directly to retailers, who then sell to consumers. According to the data published in a 2021 market research report "*Dishwashers in the U.S.*" by Euromonitor International,[2] a small percentage of home laundry products are sold through a separate new construction distribution channel, in which manufacturers sell the products to wholesalers, who in turn sell the products to general contractors, then to consumers. These two distribution channels considered in the markup analysis are shown in Figure 6.1.1 below.

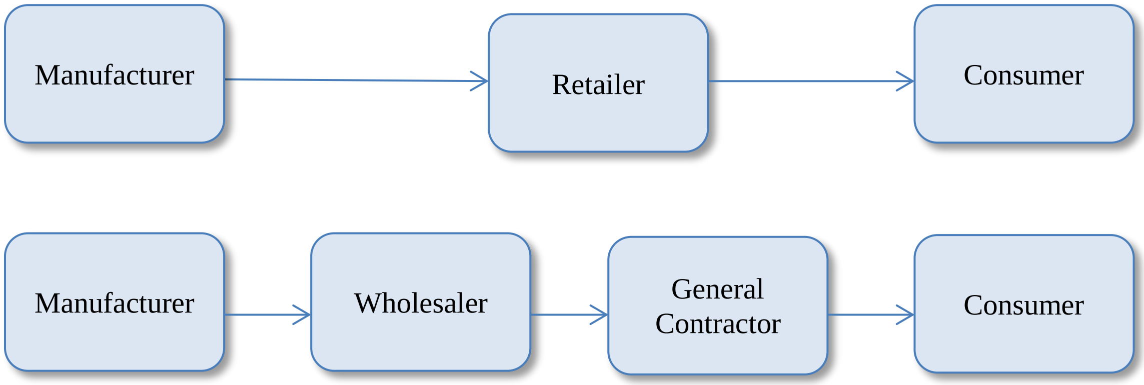

Figure 6.1.1 Distribution Channels for Dishwashers

Based on the Euromonitor market research report *Dishwashers in the U.S.*,[2] DOE assumes that 83.7% of dishwashers go through the direct retail channel, and the rest go through the wholesaler-to-contractor channel.

6.2 MANUFACTURER MARKUP

DOE uses the manufacturer markups to convert manufacturer production costs to manufacturer selling prices. A detailed description of the methodology used to derive manufacturer markups are described in Chapter 12 of the TSD.

6.3 RETAILER, WHOLESALER AND CONTRACTOR MARKUPS

A change in energy efficiency standards usually increases the manufacturer selling price that wholesalers or retailers pay. In the past, DOE used the same markups as for baseline products to estimate the product price of more efficient product. Applying a fixed markup on higher manufacturer selling price would imply an increase in the dollar margin earned by retailers, wholesalers, and contractors, and an increase in per-unit profit.

Based on microeconomic theory, the degree to which firms can pass along a cost increase depends on the level of market competition, as well as the market structure on both the supply and demand side (e.g., supply and demand elasticity). DOE examined industry data from IBISWorld and the results suggest the industry groups involved in appliance retail and wholesale exhibit a strong degree of competition (see appendix 6A).[a] In addition, consumer demand for household appliances is relatively inelastic (*i.e.*, demand is not expected to decrease substantially with an increase in the price of products). Under relatively competitive markets, it may be tenable for retailers or wholesalers to maintain a fixed markup for a short period of time after an input price increase, but the market competition should eventually force them to readjust their

[a] IBISWorld, US Industry Reports (NAICS): https://my.ibisworld.com/us/en/industry/home (Last accessed May, 2021.)

markups to reach a medium-term equilibrium in which per-unit profit is relatively unchanged before and after standards are implemented.

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

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

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

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

See Appendix 6A for further evidence supporting the use of incremental markups in this analysis. The derivation of incremental markups for retailers, wholesalers, and contractors is described in the following sections.

6.3.1 Approach for Retailer Markups

DOE based the retailer markups for dishwashers on financial data for electronics and appliance stores from the 2017 U.S. Census *Annual Retail Trade Survey* (ARTS)[3], which is the most recent survey available with detailed operating expenses for this particular sector. DOE collected itemized financial data that break down cost components incurred by firms in this sector. DOE assumes that the income statements faithfully represent the various average costs incurred by firms selling home appliances.

The baseline markup relates the manufacturer selling price of baseline products to the retailer sales price. DOE considers baseline models to be products sold under existing market conditions (*i.e.*, without newly amended energy efficiency standards). DOE calculated the baseline markup (MU_{BASE}) for retailers as an average markup using the following equation:

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

Eq. 6.1

where:

MU_{BASE} = baseline retailer markup,
CGS_{RTL} = retailer's cost of goods sold,
GM_{RTL} = retailer's gross margin,

To estimate incremental retailer markups, DOE divides retailers' operating expenses into two categories: (1) those that do not change when CGS increases due to amended efficiency standards (fixed), and (2) those that increase proportionately with CGS (variable). DOE defines labor and occupancy expenses as fixed costs, because these costs are not likely to increase as a result of a rise in CGS due to amended efficiency standards. All other expenses, as well as the net profit, are assumed to vary in proportion to CGS. Although it is possible that some of the other expenses may not scale with CGS, DOE is inclined to take a more conservative position and include these as variable costs. (Note: Under DOE's approach, a high fixed cost component yields a low incremental markup.)

DOE calculated the incremental markup (MU_{INCR}) for retailers using the following equation:

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

Eq. 6.2

where:

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

6.3.2 Derivation of Retailer Markups

The 2017 ARTS data for electronics and appliance stores provide total sales data and detailed operating expenses that are most relevant to dishwashers. To construct a complete data set for estimating markups, DOE needed to estimate CGS and GM. The most recent 2017 ARTS publishes a separate document containing historical sales and gross margin for household appliance stores. DOE took the GM as a percent of sales reported for 2017 and combined that percent with detailed operating expenses data from 2017 ARTS to construct a complete income statement for electronics and appliance stores to estimate both baseline and incremental markups. Table 6.3.1 shows the calculation of the baseline retailer markup.

Table 6.3.1 Data for Baseline Markup Calculation: Electronics and Appliance Stores

Kind of business item	Amount ($1,000,000)
Sales	99,401
Cost of Goods Sold (CGS)	66,897
Gross Margin (GM)	32,504
Baseline Markup = (CGS+GM)/CGS	**1.49**

Source: U.S. Census, 2017 Annual Retail Trade Survey

Table 6.3.2 shows the breakdown of operating expenses using the 2017 ARTS data. The incremental markup is calculated as 1.24.

Table 6.3.2 Data for Incremental Markup Calculation: Electronics and Appliance Stores

	Amount ($1,000,000)
Sales	99,401
Cost of Goods Sold (CGS)	*66,897*
Gross Margin (GM)	*32,504*
Labor & Occupancy Expenses (Fixed)	
Annual payroll	10,226
employer costs for fringe benefit	1,574
Contract labor costs including temporary help	157
Purchased utilities, total	459
Purchased Repairs and Maintenance to Buildings, Structures, and Offices	266
Cost of purchased professional and technical services	743
Purchased communication services	290
Lease and Rental Payments for Land, Buildings, Structures, Store Space, and Offices	2,686
Subtotal:	16,401
Other Operating Expenses & Profit (Variable)	
Expensed equipment	87
Cost of purchased packaging and containers	51
Other materials and supplies not for resale	387
Cost of purchased transportation, shipping and warehousing services	471
Cost of purchased advertising and promotional services	1,392
Cost of purchased software	93
Purchased Repairs and Maintenance to Machinery and Equipment	118
Lease and Rental Payments for Machinery, Equipment, and Other Tangible Items	89
Cost of data processing and other purchased computer services	66
Commission expenses	235
Depreciation and amortization charges	1,019
Taxes and license fees (mostly income taxes)	382
Other operating expenses	2,312
Net profit before tax (Operating profit)	*9,401*
Subtotal:	16,103
Incremental Markup = (CGS+Total Other Operating Expenses and Profit)/CGS	**1.24**

Source: U.S. Census, 2017 Annual Retail Trade Survey

6.3.3 Approach for Wholesaler Markups

DOE developed baseline and incremental wholesaler markups using the firm income statement for household appliances and electrical and electronic goods merchant wholesale sector from the 2017 U.S. Census *Annual Wholesale Trade Report* (AWTR)[4]. Baseline markups cover all the wholesaler's costs (both fixed and variable). DOE calculated the baseline markup for wholesalers using the following equation.

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

Eq. 6.3

where:

MU_{BASE} = wholesaler's baseline markup,
CGS_{WHOLE} = wholesaler's cost of goods sold, and
GM_{WHOLE} = wholesaler's gross margin,

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

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

Eq. 6.4

where:

MU_{INCR} = wholesaler's incremental markup,
CGS_{WHOLE} = wholesaler's cost of goods sold, and
VC_{WHOLE} = wholesaler's variable costs.

6.3.4 Derivation of Wholesaler Markups

The 2017 AWTR data for household appliances and electrical and electronic goods merchant wholesalers provide total sales data and detailed operating expenses representing dishwasher wholesalers, similar to the data used in developing retailers markups. Hence, DOE took the same approach as described in section 6.3.2 to construct a complete data set for that particular sector and estimated their baseline and incremental markups. Table 6.3.3 presents the calculation of the baseline retailer markup.

Table 6.3.3 Data for Baseline Markup Calculation: Household Appliances and Electrical and Electronic Goods Merchant Wholesale

Kind of business item	Amount ($1,000,000)
Sales	583,634
Cost of Goods Sold (CGS)	433,056
Gross Margin (GM)	150,578
Baseline Markup = (CGS+GM)/CGS	**1.35**

Source: U.S. Census, 2017 Annual Wholesale Trade Report

Table 6.3.4 shows the breakdown of operating expenses using the 2017 AWTR data. The incremental markup is calculated as 1.20.

Table 6.3.4 Data for Incremental Markup Calculation: Household Appliances and Electrical and Electronic Goods Merchant Wholesale

	Amount ($1,000,000)
Sales	583,634
Cost of Goods Sold (CGS)	*433,056*
Gross Margin (GM)	*150,578*
Labor & Occupancy Expenses (Fixed)	
Total payroll, other employee wages	44,715
Total fringe benefits	10,082
Temporary staff and leased employee expenses	1,797
Rental costs of machinery and equipment	-
Rental costs of buildings	3,440
Cost of repair to building	566
Cost of repair to machinery and equipment	592
Purchased communication services	973
Purchased utilities, total	522
Subtotal:	62,687
Other Operating Expenses & Profit (Variable)	
Purchased professional and technical services	5,087
Data processing and other purchased computer services	649
Expensed computer hardware and other equipment	1,147
Expensed purchases of software	889
Advertising and promotion services	5,627
All other expenses	-
Purchased transportation, shipping and warehousing services	-
Taxes and license fees	843
Total depreciation	4,956
Commission expenses	3,074
Purchases of packaging material and containers	-
Purchases of other materials, parts, and supplies (not for resale)	943
Net profit before tax (Operating profit)	*51,636*
Subtotal:	87,891
Incremental Markup = (CGS+Total Other Operating Expenses and Profit)/CGS	**1.20**

Source: U.S. Census, 2017 Annual Wholesale Trade Report

6.3.5 Approach for General Contractor Markups

As residential general construction industries are relatively competitive, DOE used a similar approach to that described in section 6.3.3 to develop general contractor markups. The type of itemized financial data used to estimate wholesaler markups are also available for general contractors from 2017 Economic Census. DOE collected financial data from the *Residential Building Construction* series (NAICS 236110) to estimate national average markups for residential general contractors.[5]

DOE calculated the national average baseline markup for general contractors using the following equation:

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

Eq. 6.5

Where:

MU_{BASE}= baseline general contractor markup,
CGS_{CONT}= general contractor cost of goods sold, and
GM_{CONT}= general contractor gross margin.

Analogously to wholesalers, DOE estimated the incremental general contractor markups by only marking up those costs that scale with a change in the MSP for more energy-efficient products. DOE assumed a division of costs between those that do not scale with the manufacturer price (labor and occupancy expenses), and those that do (other operating expenses and profit). Hence, DOE categorized the Census data into each major cost category and estimated incremental markups using the following equation:

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

Eq. 6.6

Where:

MU_{INCR} = incremental general contractor markup,
CGS_{CONT} = general contractor cost of goods sold, and
VC_{CONT} = general contractor variable costs.

6.3.6 Derivation of General Contractor Markups

DOE derived markups for general contractors based on 2017 Economic Census for the residential construction sector. The residential construction sector includes establishments engaged primarily in construction work, including new construction, additions, alterations, and repairs of residential buildings. DOE assumed that the total dollar values reported by the U.S. Census, once converted to a percentage basis, represent revenues and expenses for an average or typical general contracting business. The first data column in Table 6.3.5 summarizes the expenses for general contractors in residential building construction as expenses per dollar sales revenue.

Table 6.3.5 Data for Baseline Markup Calculation: Residential Building Construction

Kind of business item	Amount ($1,000)
Sales	339,799,926
Cost of Goods Sold (CGS)	245,966,240
Gross Margin (GM)	,93,833,686
Baseline Markup = (CGS+GM)/CGS	**1.38**

Source: U.S. Census Bureau. 2017. Residential Building Construction. Sector 23: 236115-236118.

Table 6.3.6 shows the breakdown of operating expenses using 2017 Economic Census for the residential construction sector. The incremental markup is calculated as 1.27.

Table 6.3.6 Data for Incremental Markup Calculation: Residential Building Construction

	Amount ($1,000)
Sales	339,799,926
Cost of Goods Sold (CGS)	*245,966,240*
Gross Margin (GM)	*93,833,686*
Payroll Expenses	23,189,001
Total payroll, other employee wages	18,243,976
Total fringe benefits	3,357,643
Temporary staff and leased employee expenses	1,587,382
Occupancy Expenses	3,413,413
Rental costs of buildings	1,440,086
Communication services	1,194,127
Cost of repair to machinery and equipment	779,200
Other Operating Expenses	18,063,273
Data processing and other purchased computer services	314,847
Expensed computer hardware and other equipment	508,902
Expensed purchases of software	373,420
Advertising and promotion services	1,976,729
All other expenses	11,162,785
Taxes and license fees	1,580,517
Total depreciation ($1,000)	2,146,073
Net Profit Before Income Taxes	49,167,999
Incremental Markup = (CGS+Total Other Operating Expenses and Profit)/CGS	**1.27**

Source: U.S. Census Bureau. 2017. Residential Building Construction. Sector 23: 236115-236118.

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 used state and local tax data provided by the Sales Tax Clearinghouse[6]. DOE assigned state-level average tax values for each household used in the life-cycle cost analysis, as shown in Table 6.4.1.

Table 6.4.1 Average Sales Tax Rates by State

State	Average State and Local Tax Rate %	State	Average State and Local Tax Rate %	State	Average State and Local Tax Rate %
Alabama	8.65	Kentucky	6.00	North Dakota	6.25
Alaska	1.30	Louisiana	9.40	Ohio	7.20
Arizona	7.30	Maine	5.50	Oklahoma	8.55
Arkansas	9.15	Maryland	6.00	Oregon	--
California	8.65	Massachusetts	6.25	Pennsylvania	6.35
Colorado	6.35	Michigan	6.00	Rhode Island	7.00
Connecticut	6.35	Minnesota	7.45	South Carolina	7.45
Delaware	--	Mississippi	7.05	South Dakota	6.00
Dist. of Columbia	6.00	Missouri	7.00	Tennessee	9.50
Florida	7.10	Montana	--	Texas	7.95
Georgia	7.35	Nebraska	6.10	Utah	7.15
Hawaii	4.00	Nevada	8.25	Vermont	6.10
Idaho	6.00	New Hampshire	--	Virginia	5.75
Illinois	8.60	New Jersey	6.60	Washington	9.25
Indiana	7.00	New Mexico	7.05	West Virginia	6.15
Iowa	6.95	New York	8.45	Wisconsin	5.45
Kansas	8.40	North Carolina	7.00	Wyoming	5.35

6.5 SUMMARY OF MARKUPS

Table 6.5.1 summarizes the national average markups at each stage in the distribution channel and the average sales tax.

Table 6.5.1 Summary of Markups for Dishwashers

Markup	Manufacturer → Retailer → Consumer		Manufacturer → Wholesaler → General Contractor → Consumer	
	Baseline Markup	**Incremental Markup**	**Baseline Markup**	**Incremental Markup**
Manufacturer	1.22		1.22	
Wholesaler	-	-	1.35	1.20
Retailer	1.49	1.24	-	-
General Contractor	-	-	1.38	1.27
Sales Tax	1.073		1.073	
Overall	1.95	1.62	2.44	2.00

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CHAPTER 7. ENERGY AND WATER USE ANALYSIS

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CHAPTER 7. ENERGY AND WATER USE ANALYSIS

7.1 INTRODUCTION

To perform the life-cycle cost (LCC) and payback period (PBP) calculations described in chapter 8, DOE determined the savings in operating costs that consumers would derive from higher efficiency standards for dishwashers. DOE used consumer energy and water use data, along with energy and water prices, to develop the most significant component of consumer operating costs in the LCC and PBP analyses[a]. This chapter describes how DOE established 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 during its cycle: operating the machine, heating the water, and drying the dishes. The energy used to operate the machine powers (1) a motor (to pump water and dispose of food) and (2) the heating element (to boost the supplied water's temperature to the required washing and rinsing temperature and dry the dishes). 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 =	nominal increase in water temperature (difference between the nominal inlet hot water temperature, assumed to be 125 ºF, and the average annual ground water temperature);
K =	specific heat of water in kWh per gallon per degree Fahrenheit (0.0024 kWh/gal/ ºF), or Btus per gallon per degree Fahrenheit (8.2 Btu/gal/ ºF);
e =	efficiency of electric water heater (99.9 percent), gas water heater (78.4 percent), or oil water heater (78.0 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.

[a] Maintenance and repair costs are the other contributors.

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-sized dishwashers 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-sized dishwashers and compact dishwashers, respectively. The annual energy use and water use per-cycle are reported here for both 215 annual cycles and 184 annual cycles. The previous DOE dishwasher test procedure used 215 annual cycles; however, in the current test procedure, DOE has decreased annual cycles to 184. Values for both annual cycle estimates are included for continuity in Table 7.2.1 and Table 7.2.2.

Table 7.2.1 Standard-sized 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)
	215 annual cycles	184 annual cycles		
Baseline	307	263	5.00	0.0
1	295	232	3.50	0.5
2	270	223	3.30	0.5
3	255	206	3.20	0.5
4	225	193	2.40	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)
	215 annual cycles	184 annual cycles		
Baseline	222	178	3.50	0.5
1	203	174	3.10	0.5
2	130	124	1.60	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 specific to dishwashing and heating only. The per-cycle dishwasher energy use is simply the annual dishwasher energy use divided by the average cycles per year.[1]

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

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

Where:

DW_{ANNUAL} = total annual dishwasher energy consumption,
DW_{CYCLE} = per-cycle dishwasher energy consumption,
N = dishwasher use of 184 cycles per year from the DOE test procedure,
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 in the following equation:

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

Per-cycle dishwasher energy use falls into two general categories: (1) machine (motor energy for pumping water and for an electrical heating element for dish drying); and (2) water heating. 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 the difference between the water heater setpoint temperature of 125 ºF and the annual average ground water temperature, and a specific heat of 0.0024 kWh/gal-ºF (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 7.2.4 show overall energy use and each component’s energy use by efficiency level for standard-sized and compact dishwashers, respectively.

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

Level	Energy Use * (kWh/yr)	Energy Use ** (kWh/yr)	Water Use (gal/cyc)	Standby Power (W)	Per-Cycle Energy Use Component		
					Total+ (kWh/cyc)	National Average Water Heating++ (kWh/cyc)	Machine & Drying (kWh/cyc)
Baseline	302	258	5.00	0.0	1.40	0.82	0.59
1	266	228	3.50	0.5	1.22	0.57	0.65
2	256	220	3.30	0.5	1.17	0.54	0.64
3	237	203	3.20	0.5	1.08	0.52	0.56
4	222	191	2.40	0.5	1.02	0.39	0.62

* Recalculated based on 215 cycles per year and the updated water heater energy use.

** Recalculated based on the DOE test procedure value of 184 cycles per year and the updated water heater energy use.

\+ Annual standby energy use is based on an assumed dishwasher cycle of 2.04 hours and 184 cycles per year.

++ Based on the use of an electric water heater at 99.9% efficiency and an average of 67.9 ºF nominal increase in water temperature.

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

Level	Energy Use* (kWh/yr)	Energy Use** (kWh/yr)	Water Use (gal/cyc)	Standby Power (W)	Per-Cycle Energy Use Component		
					Total+ (kWh/cyc)	National Average Water Heating++ (kWh/cyc)	Machine & Drying (kWh/cyc)
Baseline	203	174	3.50	0.5	0.93	0.57	0.35
1	200	172	3.10	0.5	0.91	0.51	0.40
2	142	122	1.60	0.5	0.64	0.26	0.38

* Recalculated based on 215 cycles per year and the updated water heater energy use.

** Recalculated based on the DOE test procedure value of 184 cycles per year and the updated water heater energy use.

\+ Annual standby energy use is based on an assumed dishwasher cycle of 1.59 hours and 184 cycles per year.

++ Based on the use of an electric water heater at 99.9% efficiency and an average of 67.9 ºF nominal increase in water temperature.

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. To estimate the average number of dishwasher cycles per year in people's homes and based on a representative sample of U.S. households, DOE used data from the EIA's 2015 *Residential Energy Consumption Survey* (*RECS 2015*).[2] *RECS 2015* collected data on 5,686 housing units and was constructed by EIA to be nationally representative of the households in the United States. The representative sample of U.S. households included the following considerations: (1) the household had a dishwasher and (2) the dishwasher use (defined as the number of dishwasher cycles per week) was greater than zero. Of the 5,686 housing records, 3242 housing records has and used a dishwasher.

DOE estimated the annual number of dishwasher cycles for each sample household using *RECS 2015* data on the number of dishwasher cycles per week. Based on the *RECS 2015* weighted sample, DOE obtained the weighted average dishwasher usage of 185 cycles per year.

DOE calculated the annual energy consumption of dishwashers from the per-cycle values reported in the previous section's 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 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 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-sized dishwashers and in Table 7.3.2 for compact dishwashers reflect an annual use of 185 cycles. The annual water heating energy consumption reflects the use of an electric, gas, or oil water heater.

Table 7.3.1 Standard-sized 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	260	151	0.66	0.66	109	0.0	926
1	230	106	0.46	0.46	120	4.2	648
2	222	100	0.43	0.44	118	4.2	611
3	204	97	0.42	0.42	104	4.2	593
4	192	73	0.32	0.32	115	4.2	444

*Water-heating energy use is based on water heater efficiencies of 99.9% for electric, 78.4% for gas, and 78.0% for oil.

**Annual energy use based on an annual average of 185 cycles.

+Standby hours = 8,766 hours minus 185 × 2.04 hours per cycle = 8,388 hours

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	176	106	0.46	0.46	66	4.2	648
1	173	94	0.41	0.41	75	4.2	574
2	123	48	0.21	0.21	71	4.2	296

* Water-heating energy use is based on water heater efficiencies of 99.9% for electric, 78.4% for gas, and 78.0% for oil.

** Annual energy use based on an annual average of 185 cycles.

+Standby hours = 8,766 hours minus 185 cycles per year × 1.59 hours per cycle = 8,472 hours

7.4 VARIABILITY OF DISHWASHER USE

For each of the 3,242 households (out of a total of 5,686) that the *RECS 2015* reported as having a dishwasher and an operating frequency greater than zero, RECS provides data on the number of dishwasher cycles per week. For calculating dishwasher energy use, DOE used the RECS data to calculate an estimate of annual number of cycles. The average weighted number of cycles per year derived from the *RECS 2015* data is 185.

Having determined number of cycles of dishwasher use per year for each RECS household, DOE determined the corresponding annual energy and water consumption. Figure

7.4.1 shows the probability distribution of the dishwasher use that DOE determined for each RECS household.

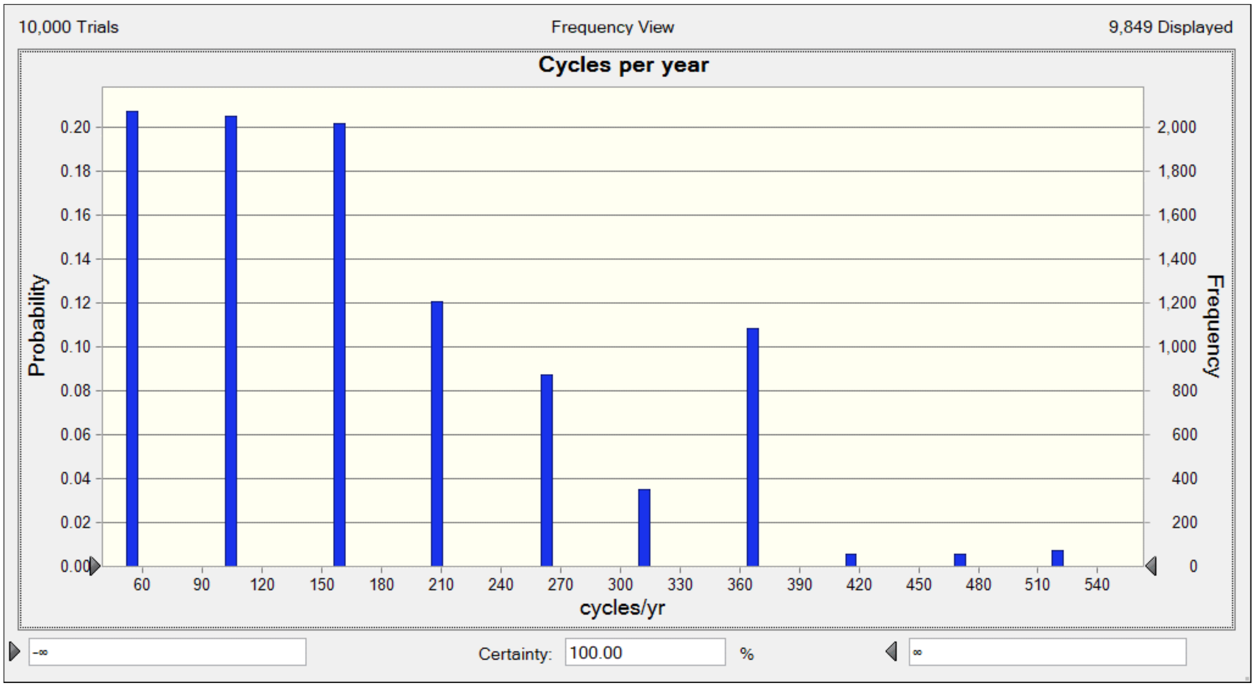

Figure 7.4.1 Distribution of Annual Dishwasher Use (Cycles per Year) Based on *RECS 2015* Usage Data

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CHAPTER 8. LIFE-CYCLE COST AND PAYBACK PERIOD ANALYSIS

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CHAPTER 8. LIFE-CYCLE COST AND PAYBACK PERIOD ANALYSIS

8.1 INTRODUCTION

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

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

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

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

Inputs to the LCC and PBP calculations are described in sections 8.2, 8.3 and8.4. Results of the LCC and PBP analysis are presented in section 8.5.

DOE performed the calculations discussed herein using a Microsoft Excel® spreadsheet that is accessible at http://www.eere.energy.gov/buildings/appliance_standards/). Details and instructions for using the spreadsheet are provided in appendix 8A of this technical support document (TSD).

8.1.1 General Analysis Approach

Life-cycle cost is calculated using the following equation:

$$LCC = TIC + \sum_{t=0}^{N-1} \frac{OC_t}{(1+r)^t}$$

Eq. 8.1

Where:

LCC =	life-cycle cost (in dollars),
TIC =	total installed cost in dollars,
$\sum$ =	sum over the appliance lifetime, from year 1 to year N,
N =	lifetime of the appliance in years,
OC =	operating cost in dollars,
r =	discount rate, and
t =	year to which operating cost is discounted.

The payback period is the ratio of the increase in total installed cost (i.e., from a less energy efficient design to a more efficient design) to the decrease in annual operating expenditures. This type of calculation results in what is termed a simple payback period, because it does not take into account changes in energy expenses 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:

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

Eq. 8.2

Where:

ΔTIC =	difference in total installed cost between a more energy efficient design and the baseline design, and
ΔOC =	difference in annual operating expenses.

Payback periods are expressed in years. Payback periods greater than the life of the product indicate that the increased total installed cost is not recovered through reduced operating expenses.

Recognizing that inputs to the determination of consumer LCC and PBP may be either variable or uncertain, DOE conducts the LCC and PBP analysis by modeling both the uncertainty and variability of the inputs using Monte Carlo simulation and probability distributions for inputs. Appendix 8B provides a detailed explanation of Monte Carlo simulation and the use of probability distributions and discusses the tool used to incorporate these methods.

DOE calculates impacts relative to a case without amended or new energy conservation standards (referred to as the “no-new-standards case). In the no-new-standards case, some consumers may purchase products with energy efficiency higher than a baseline model. For any given standard level under consideration, consumers expected to purchase a product with efficiency equal to or greater than the considered level in the no-new-standards case would be unaffected by that standard.

DOE calculates the LCC and PBP as if all consumers purchase a dishwasher in the expected initial year of compliance with a new or amended standard. At this time, the expected compliance date of potential energy conservation standards for dishwashers manufactured in, or imported into, the United States is in 2027. Therefore, DOE conducted the LCC and PBP analysis assuming purchases take place in 2027.

8.1.2 Overview of Analysis Inputs

The LCC analysis uses inputs for establishing (1) the purchase expense, otherwise known as the total installed cost*,* and (2) the operating costs over the product lifetime.

The primary inputs for establishing the total installed cost are:

- *Baseline manufacturer cost*: The costs incurred by the manufacturer to produce products that meet current minimum efficiency standards, or another efficiency level designated as the baseline for analysis.

- *Standard-level manufacturer cost*: The manufacturer cost (or cost increase) associated with producing products that meet particular efficiency levels above the baseline.

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

- *Installation cost*: All costs required to install the product, including labor, overhead, and any miscellaneous materials and parts.

- *Learning rate:* The cost reduction factor associated with economies of scale and technology learning.

The primary inputs for calculating the operating cost are:

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

- *Energy prices*: The prices consumers pay for energy (*e.g.*, electricity or natural gas).

- *Energy price trends*: DOE used the EIA's *Annual Energy Outlook 2021* (*AEO 2021*) to project energy prices[1].

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

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

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

The inputs for calculating the PBP are the total installed cost and the first-year operating costs. The inputs to operating costs are the first-year energy cost. The PBP uses the same inputs as the LCC analysis, except the PBP does not require energy price trends or discount rates.

Figure 8.1.1 depicts the relationships among the inputs to installed cost and operating cost for calculating a product's LCC and PBP. In the figure, the tan boxes indicate inputs, the green boxes indicate intermediate outputs, and the blue boxes indicate final outputs. Table 8.1.1 provides a summary of inputs used in the analysis.

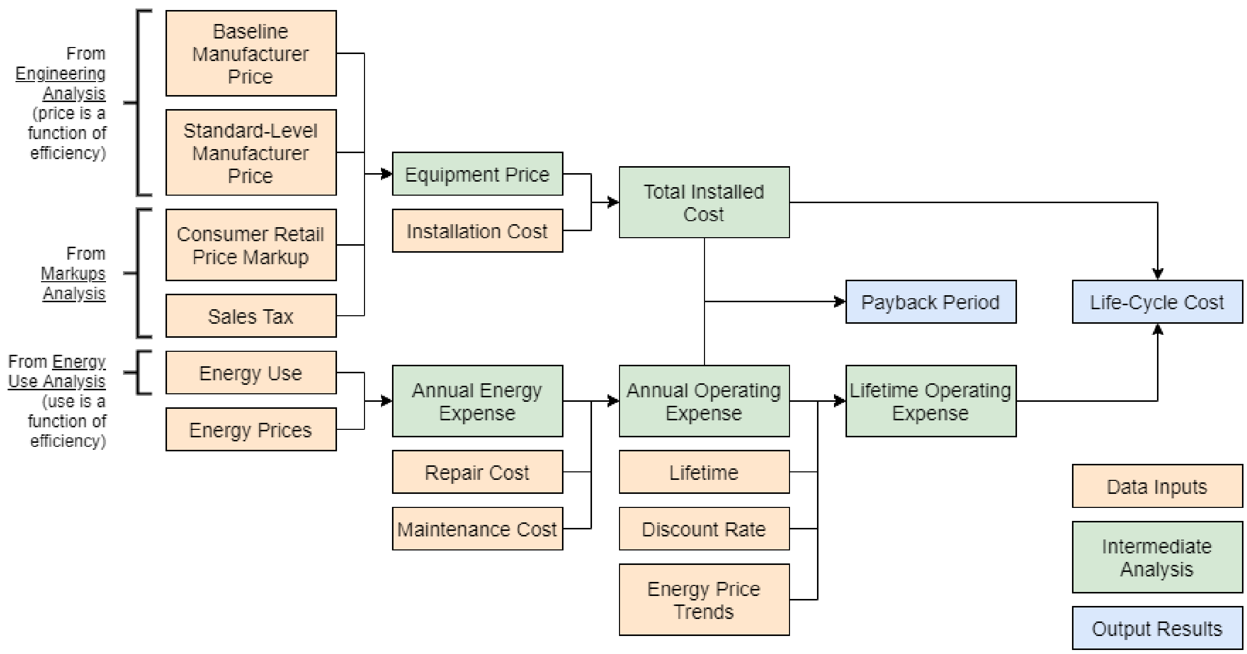

Figure 8.1.1 Flow Diagram of Inputs for the Determination of LCC and PBP

Table 8.1.1 Summary of Inputs to Life-Cycle Cost and Payback Period

Inputs	Average or Typical Value	Characterization
Total Installed Cost Inputs		
Product Price	Varies by distribution channel	Single-point value
Sales Tax	National average 7.28%	Varies by region
Operating Cost Inputs		
Operating Hours	185	Distribution (see chapter 7 of this preliminary analysis TSD for details)
Electricity Prices	Residential sector: 0.132 $/kWh	Vary by region and season
Electricity Price Trends	*AEO 2021* reference case	Vary by *AEO 2021* growth scenario
Product Lifetime	Mean: 15.2 years	Weibull distribution
Discount Rate	Residential sector: 4.30%	Residential: Vary by type of purchase
Assumed Date Standards Become Effective	2027	Single-point value

8.1.3 Sample of Dishwasher Users

The LCC and PBP calculations detailed here are for a representative sample of individual dishwasher users. By developing consumer samples, DOE accounts for the variability in energy consumption and energy price associated with a range of consumers.

As described in chapter 7 of this TSD, DOE used the DOE Energy Information Administration (EIA)'s 2015 *Residential Energy Consumption Survey* (*RECS 2015*) to develop household samples for dishwashers based on households that use its dishwasher.[2] The *RECS 2015* consists of 5,686 housing units and is representative of the household population of the United States. DOE assigned a unique annual energy use and energy price to each household in the sample. The large sample of households considered in the analysis provides wide ranges of annual energy use and energy prices.

8.2 TOTAL INSTALLED COST INPUTS

DOE uses the following equations to define the total installed cost. The consumer purchase cost is equal to the manufacturer cost multiplied by markups, and where applicable, sales tax. The cost varies based on the distribution channel through which the consumer purchases the product. The installation cost represents all costs to the consumer for installing the product, including labor, overhead, and any miscellaneous materials and parts. The installation cost may vary by efficiency level.

$$
\begin{aligned}
TIC &= CPC + IC \\
TIC_{EL} &= CPC_{EL} + IC_{EL} \\
&= (CPC_{BASE} + \Delta CPC_{EL}) + (INST_{BASE} + \Delta IC_{EL}) \\
&= (CPC_{BASE} + INST_{BASE}) + (\Delta CPC_{EL} + \Delta IC_{EL}) \\
&= IC_{BASE} + (\Delta COST_{MFG} \times MU_{TOTAL_{IN}}) + \Delta IC_{EL}
\end{aligned}
$$

Eq. 8.3

Where:

TIC =	total installed cost,
CPC =	consumer purchase cost,
IC =	installation cost,
TIC_{EL} =	total installed cost for higher efficiency level model,
CPC_{EL} =	consumer product cost for higher efficiency level model,
IC_{EL} =	installation cost for higher efficiency level model,
CPC_{BASE} =	consumer product cost for baseline model,
ΔCPC_{EL} =	change in product cost for higher efficiency level model,
IC_{BASE} =	baseline installation cost,
$\Delta INST_{EL}$ =	change in installation cost for higher efficiency level model,
$\Delta COST_{MFG}$ =	change in manufacturer cost for higher efficiency level model, and
MU_{TOTAL_IN} =	overall incremental markup (product of manufacturer markup, incremental retailer or distributor markup, and sales tax).

The rest of this section provides information about each of the inputs that DOE used to calculate the total installed cost of dishwashers.

8.2.1 Manufacturer Costs

DOE developed manufacturer costs at each efficiency level for all the product classes for dishwashers as described in chapter 5 of this TSD.

8.2.1.1 Baseline Manufacturer Cost

DOE developed the baseline manufacturer costs for all the product classes of dishwashers (described in chapter 5 of this TSD, Engineering Analysis).

Table 8.2.1 Dishwashers: Baseline Manufacturer Cost

Product Class	Baseline Annual Energy Use * (kWh/year)	Baseline Annual Energy Use ** (kWh/year)	Baseline Water Use (gallons/cycle)	Baseline Manufacturer Cost (2020$)
Standard-Sized	263	260	5.0	$148
Compact	178	176	3.5	$171

*Based on the assumption of 184 cycles per year.
**Based on the assumption of 185 cycles per year and updated water heater energy use inputs.

8.2.1.2 Incremental Manufacturer Cost by Efficiency Level

DOE developed manufacturer cost increases associated with increases in dishwasher efficiency levels. 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 and per cycle water use for both product classes.

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

Efficiency Level	Annual Energy Use * (kWh/year)	Annual Energy Use ** (kWh/year)	Water Use (gallons/cycle)	Manufacturer Cost Increases (2020$)
Baseline	263	260	5.00	--
1	232	230	3.50	$18
2	223	222	3.30	$28
3	206	204	3.20	$71
4	193	192	2.40	$114

*Based on the assumption of 184 cycles per year.
**Based on the assumption of 185 cycles per year and updated water heater energy use inputs.

Table 8.2.3 Compact Dishwashers: Standard-Level Manufacturer Cost Increases

Efficiency Level	Annual Energy Use * (kWh/year)	Annual Energy Use ** (kWh/year)	Water Use (gallons/cycle)	Manufacturer Cost Increases (2020$)
Baseline	178	176	3.50	--
1	174	173	3.10	$0
2	124	123	1.60	$37

*Based on the assumption of 184 cycles per year.
**Based on the assumption of 185 cycles per year and updated water heater energy use inputs.

8.2.2 Overall Markup

For a given distribution channel, the overall markup is the value determined by multiplying all the associated markups and the applicable sales tax together to arrive at a single overall distribution chain markup value. Because there are baseline and incremental markups associated with the various market participants, the overall markup is also divided into a baseline markup (*i.e.*, a markup used to convert the baseline manufacturer price into a consumer price) and an incremental markup (*i.e.*, a markup used to convert a standard-compliant manufacturer cost increase due to an efficiency increase into an incremental consumer price). See Table 8.2.4. Refer to chapter 6 of this TSD for details.

Table 8.2.4 Dishwashers: Overall Markups

Markup	**Mfr --> Retailer --> Consumer**		**Mfr --> Wholesalers --> General Contractors --> Consumer**	
	Baseline	**Incremental**	**Baseline**	**Incremental**
Manufacturer	1.24		1.24	
Wholesaler			1.35	1.20
Retailer	1.49	1.24		
General Contractor			1.38	1.27
Sales Tax	1.0728		1.0728	
Overall	1.98	1.65	2.48	2.04

8.2.3 Application of Learning Rate for Product Prices

Examination of historical price data for certain appliances and equipment that have been subject to energy conservation standards indicates that an assumption of constant real prices may, in many cases, overestimate long-term trends in appliance and equipment 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 that is relevant to price projections for selected appliances and equipment.[3] The extensive literature on the "learning" or "experience" curve phenomenon is typically based on observations in the manufacturing sector.[a]

In the experience curve method, the real cost of production is related to the cumulative production or "experience" with a manufactured product. This experience is usually measured in terms of cumulative production. A common functional relationship used to model the evolution of production costs in this case is:

[a] In addition to Desroches (2013), see Weiss, M., Junginger, H.M., Patel, M.K., Blok, K., (2010a). A Review of Experience Curve Analyses for Energy Demand Technologies. Technological Forecasting & Social Change. 77:411-428.

$$Y = a\,X^{(-b)}$$

Eq. 8.4

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 rate (LR), which is given by:

$$LR = 1 - 2^{(-b)}$$

Eq. 8.5

In typical learning curve formulations, the learning rate parameter is derived using two historical data series: cumulative production and price (or cost).

To derive a learning rate parameter for dishwashers, DOE combined historical Producer Price Index (PPI) data for "all other miscellaneous household appliances" between 1988 and 2014 and for primary products of major household appliance manufacturing between 2016 and 2020 from the Bureau of Labor Statistics' (BLS).[b]

DOE used PPI data for all other miscellaneous household appliances to represent dishwashers as there were no PPI data specific to dishwashers. However, the all other miscellaneous household appliances PPI was discontinued beyond 2014 due to insufficient sample size. To extend the price index beyond 2014, DOE assumed that the price index of primary products of major household appliance manufacturing would trend similarly to the all other miscellaneous household appliances. DOE then applied the annual change rates for the primary products on the price index of all other miscellaneous household appliances to obtain a combined price index series representative of dishwashers from 1988 to 2020. The price index reflect nominal prices, adjusted for changes in product quality. An inflation-adjusted price index representative of dishwashers was calculated by dividing the combined price index by the implicit price deflator for Gross Domestic Product as shown inFigure 8.2.1.

[b] Series ID PCU33522033522085 and PCU335220335220P; http://www.bls.gov/ppi/.

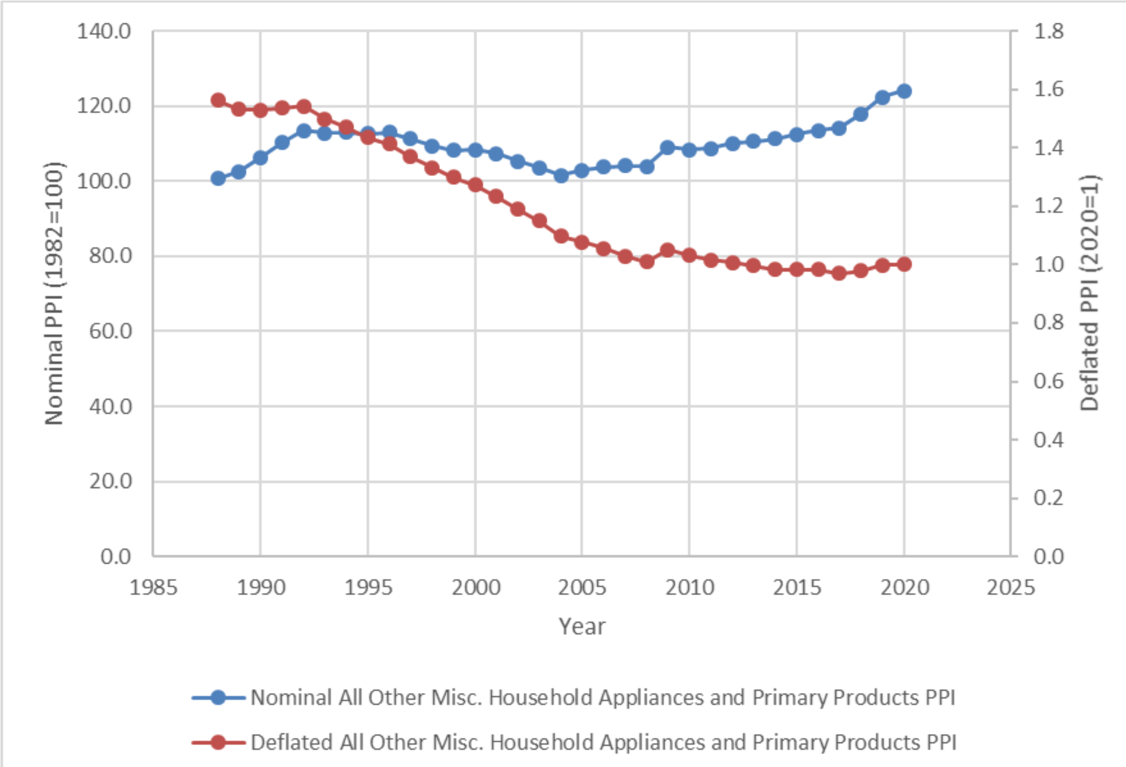

Figure 8.2.1 Nominal and Deflated Combined All Other Miscellaneous Household Appliances and Primary Products of Major Household Appliance Manufacturing PPI from 1988 to 2020

DOE assembled a time series of historical annual shipments of dishwashers for 1972–2020. The data for historical annual shipments were used to project future shipments and to estimate cumulative shipments (production). Projected shipments after 2020 were obtained from the no-new-standards case projections made for the NIA (see chapter 9 of this TSD).

To estimate learning rate parameter, a least-squares power-law fit was performed on the deflated combined price index versus cumulative shipments. (See Figure 8.2.2.)

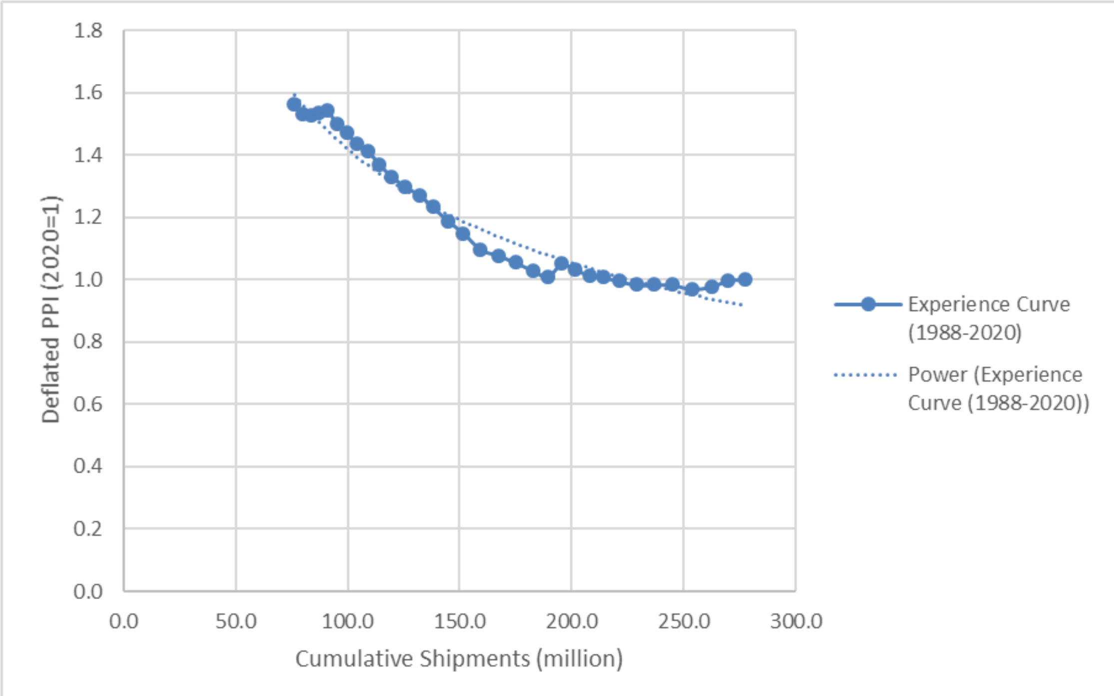

Figure 8.2.2 Relative Price versus Cumulative Shipments of Other Miscellaneous Household Appliances and Primary Products from 1988 to 2020, with Power Law Fit

The form of the fitting equation is:

$$P(X) = P_o X^{(-b)}$$

Eq. 8.6

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. DOE notes that the cumulative shipments on the right hand side of the equation can have a dependence on price, so there is an issue with simultaneity where the independent variable is not 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.

For dishwashers, the parameter values obtained are:

$P_o = 10.249^{+1.920}_{-1.617}$(95% confidence), and
b = 0.429±0.034 (95% confidence).

The estimated learning rate (defined as the fractional reduction in price expected from each doubling of cumulative production) is 25.7±1.7% (95% confidence).

Since the production costs estimated in the engineering analysis was developed in 2018 for dishwashers, DOE derived the price factor index, with 2018 equal to 1, to project prices for dishwashers in each future year in the analysis period. The index value in a given year is a function of the learning rate parameter (*b*) and the cumulative production projection through that year. DOE applied the same value to project prices for each considered efficiency level. The estimated price factor index for dishwasher is shown in Figure 8.2.3.

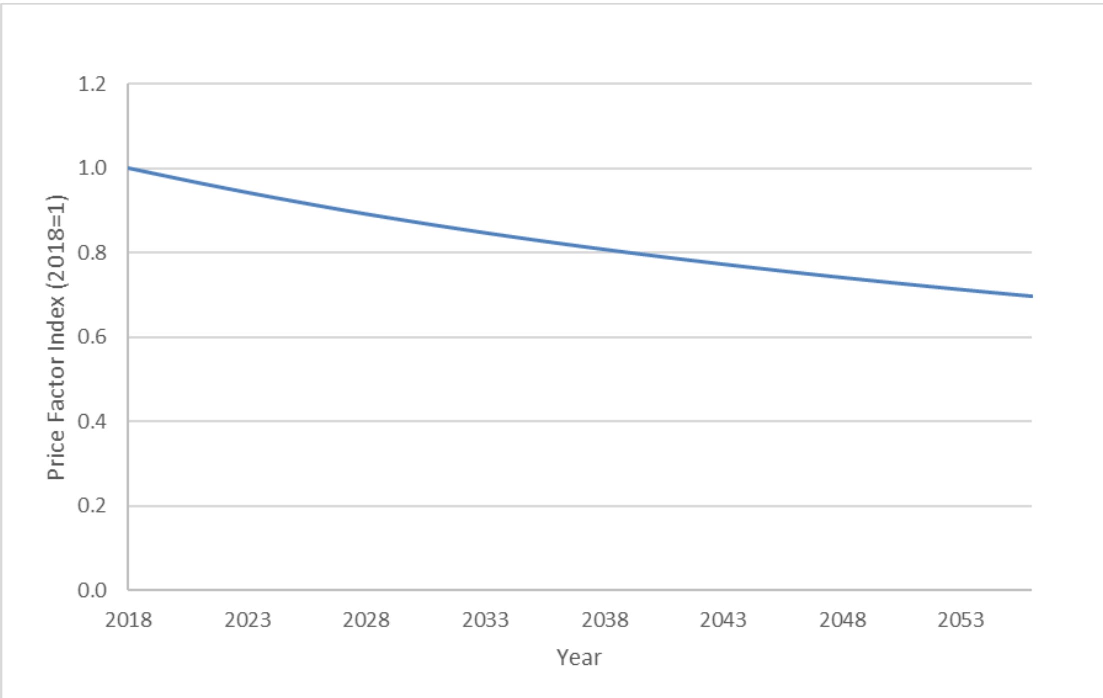

Figure 8.2.3 Price Factor Index for Dishwashers

8.2.4 Installation Cost

The installation cost covers all labor and material costs associated with installing a dishwasher in the place of use. DOE derived baseline installation costs for dishwashers from data in the *RS Means Residential Cost Data*,[4] which provides estimates on the labor required to install dishwashers. Table 8.2.5 summarizes the nationally representative average bare costs and, overhead and profit costs of a four-or-more-cycle dishwasher based on a two hour and half installation assumption. DOE determined that installation costs would not be impacted with increased efficiency standard levels.

Table 8.2.5 Dishwashers: Baseline Installation Costs

Crew L-1	Bare Costs (2020$/hr)	Incl. O&P (2020$/hr)
0.25 Electrician	$40.82	$66.75
1 Plumber		
	Total = $66.75 × 2.5 hr	$166.88

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

8.2.5 Total Installed Cost

The total installed cost is the sum of the consumer product cost and installation cost. Table 8.2.6 and Table 8.2.7 present the total installed cost for each dishwasher product class at each efficiency level examined.

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 (2020$)	Installation Cost (2020$)	Total Installed Cost (2020$)
Baseline	260	5.00	$274	$167	$441
1	230	3.50	$303	$167	$469
2	222	3.30	$317	$167	$484
3	204	3.20	$384	$167	$551
4	192	2.40	$450	$167	$617

*Based on 185 cycles per year and updated water heater energy use inputs.

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 (2020$)	Installation Cost (2020$)	Total Installed Cost (2020$)
Baseline	176	3.50	$353	$167	$485
1	173	3.10	$353	$167	$485
2	123	1.60	$417	$167	$543

*Based on 185 cycles per year and updated water heater energy use inputs.

8.3 OPERATING COST INPUTS

DOE defines operating cost (OC) as the addition of energy costs, water costs, repair costs, and maintenance costs for both the baseline efficiency levels and higher efficiency levels:

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

$$OC = (AEC \times PRICE_{ENERGY}) + (AWC \times PRICE_{WT}) + RC + MC$$

Eq. 8.7

Where:

OC = operating cost,

EC = energy cost associated with operating the product,
WC = water cost associated with operating the product,
RC = repair cost associated with component failure, and
MC = maintenance cost.
AEC = annual energy consumption for baseline product,
$PRICE_{ENERGY}$ = energy price,
AWC = annual water consumption for baseline product, and
$PRICE_{WTR}$ = water price.

Table 8.3.1 shows the inputs for determining annual operating costs and their discounted values throughout the product lifetime.

Table 8.3.1 Inputs for Operating Cost

Annual energy and water consumption
Energy and water prices and price trends
Repair and maintenance costs
Product lifetime
Discount rate
Effective date of standard

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

8.3.1 Annual Energy and Water Consumption

The *annual energy and water consumption* is the site energy and water use associated with operating the product.

Annual energy and water consumption vary with product efficiency. For each product class, DOE calculated the annual energy use for record in the household sample at each efficiency level, as described in chapter 7 of this TSD. By developing household samples using *RECS 2015*, DOE performed the LCC and PBP calculations to account for the variability in the usage and price of both energy and water associated with each household. Refer to chapter 7 of this TSD to review the variability of annual energy and water consumption for dishwashers.

Table 8.3.2 and Table 8.3.3 provide the average annual energy and water consumption by efficiency level for standard-sized and compact dishwashers, respectively. 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 2015*, 45.2 percent of households use electric water heaters, 52.2 percent use gas including propane and liquid petroleum gas (LPG), and 2.5 percent use fuel oil.

Table 8.3.2 Standard-Sized Dishwashers: Annual Energy and Water Use by Efficiency Level

Efficiency Level	Annual Energy Use* (kWh/year)	Annual Energy Use Water Heating**			Annual Water Use (1000 gal./year)
		Electric (kWh/year)	Gas (MMBtu/year)	Oil (MMBtu/year)	
Baseline	260	173	0.35	0.02	0.92
1	230	169	0.24	0.01	0.64
2	222	164	0.23	0.01	0.60
3	204	148	0.22	0.01	0.59
4	192	150	0.17	0.01	0.44

*Based on 185 cycles per year and updated water heater energy use inputs.
**Electric, gas, and oil water heating based on water heater efficiencies of 99.9 percent for electric, 78.4 percent for gas, 78.0 percent for oil.

Table 8.3.3 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	176	115	0.24	0.01	0.64
1	173	119	0.22	0.01	0.57
2	123	95	0.11	0.01	0.29

8.3.2 Energy and Water Prices

Energy prices are the prices paid by consumers for energy (e.g. electricity or natural gas). Multiplying the annual energy consumption by the energy price yields the annual energy cost. *Water prices* are the prices paid by consumers for water and wastewater. Multiplying the annual water consumption by the water and wastewater prices yield the annual water cost. DOE used *energy price trends* to forecast energy prices into the future and, along with the product lifetime and discount rate, to establish the present value of lifetime energy costs. DOE used *water price trends* to forecast water and wastewater prices into the future.

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

Average and Marginal Electricity Prices

DOE derived average and marginal annual energy prices for each of the RECS 2015 regions in the United States using the latest data from EIA. The LCC sampling process then assigned an appropriate energy price to each dishwasher in the sample, depending on its location. Because marginal prices more accurately captures the incremental costs or savings associated with a change in energy use from higher efficiency, it provides a better representation of incremental change in consumer costs than average energy prices. Therefore, DOE applied average energy prices for the energy use of the product purchased in the no-new-standards case, and marginal electricity prices for the incremental change in energy use associated with the other efficiency levels considered.

8.3.2.1 Base Year Energy Prices

To derive average annual energy prices, DOE first derived base year (2020) average annual energy prices. To estimate the annual marginal energy prices (which are used to determine the cost to the consumer of the change in energy consumed), DOE estimated seasonal marginal price factors that were then used to adjust the annual average energy prices.

Derivation of Average Energy Prices for the Base Year.

DOE first derived base year (2020) average annual residential electricity, natural gas, and (2019) LPG and fuel oil prices for each State using the most recent historical data from EIA. For electricity prices, DOE used 2020 data from EIA's Form 861M.[5] For natural gas prices, DOE used 2020 data from EIA's Natural Gas Navigator.[6] For LPG and fuel oil prices, DOE used 2019 data from EIA's State Energy Consumption, Price, and Expenditure Estimates (SEDS)[7] and escalated the prices to 2020 using EIA's *2020 Annual Energy Outlook* (AEO" 2020).[8]

Derivation of Seasonal Marginal Price Factors.

Annual electricity and natural gas prices were adjusted using seasonal marginal price factors to determine annual marginal electricity and natural gas prices. For electricity and natural gas, DOE used EIA state level data from the last 10 years (2011 to 2020) to estimate marginal price as the slope of the rate of change in the energy costs versus change in energy consumption. Since marginal prices change significantly by season, DOE calculated separate winter and non-winter marginal prices separately. The seasonal marginal price factors are then calculated as the ratio of the marginal price to the average for each State and residential and commercial market sectors. For LPG and fuel oil, DOE estimated that average and marginal energy prices are the same. For a detailed discussion of the development of marginal energy price factors and for a comparison to other data and methods, see appendix 8C.

To aggregate the State level energy prices into the RECS 2015 regions, DOE weighted each State's average energy price by the State's population in 2019.[9]

Table 8.3.4 shows the average electricity prices and Table 8.3.5 shows the marginal electricity prices for each geographic regions. For use in the LCC model, prices were scaled to 2020$.

Table 8.3.4 Average Residential Electricity Prices in 2020, 2020$

	Geographic Area	$/kWh
1	New England Census Division	$0.183
2	Middle Atlantic Census Division	$0.145
3	East North Central Census Division	$0.126
4	West North Central Census Division	$0.126
5	South Atlantic Census Division	$0.129
6	East South Central Census Division	$0.139
7	West South Central Census Division	$0.116
8	Mountain North Census Division	$0.119
9	Mountain South Census Division	$0.113
10	Pacific Census Division	$0.183

Source: EIA 2020.

Table 8.3.5 Marginal Residential Electricity Prices in 2020, 2020$

	Geographic Area	$/kWh
1	New England Census Division	$0.171
2	Middle Atlantic Census Division	$0.144
3	East North Central Census Division	$0.117
4	West North Central Census Division	$0.120
5	South Atlantic Census Division	$0.126
6	East South Central Census Division	$0.128
7	West South Central Census Division	$0.106
8	Mountain North Census Division	$0.123
9	Mountain South Census Division	$0.107
10	Pacific Census Division	$0.201

Source: EIA 2020.

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 8.3.6 are in dollars per million Btu ($/MMBtu).

Table 8.3.6 Average Residential Natural Gas Prices in 2020, 2020$

	Geographic Area	$/MMBtu
1	New England Census Division	$15.27
2	Middle Atlantic Census Division	$13.05
3	East North Central Census Division	$10.83
4	West North Central Census Division	$10.67
5	South Atlantic Census Division	$18.17
6	East South Central Census Division	$14.31
7	West South Central Census Division	$14.01
8	Mountain North Census Division	$8.25
9	Mountain South Census Division	$12.83
10	Pacific Census Division	$14.02

Source: EIA Natural Gas Navigator for 2020.

To estimate future prices, DOE used the projected annual changes in average residential natural gas prices in the reference case projection in *AEO 2021*. The AEO price trends do not distinguish between marginal and average prices, so DOE used the same trends for both.

Table 8.3.7 shows the natural gas marginal price factors for each geographic regions.

Table 8.3.7 Residential Marginal Natural Gas Price Factors

	Geographic Area	Non-Winter	Winter
1	New England Census Division	0.83	0.96
2	Middle Atlantic Census Division	0.64	0.91
3	East North Central Census Division	0.55	0.85
4	West North Central Census Division	0.57	0.85
5	South Atlantic Census Division	0.58	0.79
6	East South Central Census Division	0.58	0.84
7	West South Central Census Division	0.52	0.73
8	Mountain North Census Division	0.71	0.87
9	Mountain South Census Division	0.59	0.77
10	Pacific Census Division	0.87	1.01

Source: EIA 2011-2020.

Table 8.3.8 and Table 8.3.9 show the national average LPG and fuel oil prices in 2019 for each geographic regions.

Table 8.3.8 Average Residential LPG Prices in 2019, 2020$

	Geographic Area	$/MMBtu
1	New England Census Division	$33.29
2	Middle Atlantic Census Division	$30.05
3	East North Central Census Division	$19.80
4	West North Central Census Division	$16.04
5	South Atlantic Census Division	$32.37
6	East South Central Census Division	$23.45
7	West South Central Census Division	$24.41
8	Mountain North Census Division	$21.57
9	Mountain South Census Division	$26.99
10	Pacific Census Division	$26.95

Source: EIA SEDS 2019.

Table 8.3.9 Average Monthly Residential Oil Prices in 2019, 2020$

	Geographic Area	$/MMBtu
1	New England Census Division	$19.07
2	Middle Atlantic Census Division	$20.17
3	East North Central Census Division	$18.70
4	West North Central Census Division	$18.88
5	South Atlantic Census Division	$19.18
6	East South Central Census Division	$18.07
7	West South Central Census Division	$16.97
8	Mountain North Census Division	$19.05
9	Mountain South Census Division	$20.85
10	Pacific Census Division	$21.70

Source: EIA SEDS 2019.

Water Prices

DOE obtained data on public supply water prices for 2016 from the *Water and Wastewater Rate Survey* conducted by Raftelis Financial Consultants and the American Water Works Association.[10] The survey covers approximately 262 water utilities and 181 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 price average would lead to a 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 262 or 181 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.

For this dishwasher rulemaking, DOE also developed water prices for consumers who rely on private well water systems for their water needs rather than the public supply system. DOE applied the appropriate water costs- (either public system or private) to the representative share of U.S. consumers relying on that water source to arrive at a single water and single wastewater price. DOE found that costs on average for septic system users and public wastewater systems are comparable. The methodology used for these calculations can be found in Appendix 8D. Table 8.3.10 presents the results of the calculation of the weighted costs for water and wastewater service. The price units in the table are 2020 dollars per thousand gallons ($/1000 gal.).

Table 8.3.10 Average Water and Wastewater Prices per Unit Volume, 2020$

Census Region	Average Water $/1000 gal.	Marginal Water $/1000 gal.	Average Wastewater $/1000 gal.	Marginal Wastewater $/1000 gal.
Northeast	$4.53	$3.91	$6.91	$5.28
Midwest	$4.26	$3.37	$6.71	$5.72
South	$4.62	$4.49	$6.38	$5.37
West	$6.76	$5.28	$6.78	$4.20
National Average	$5.02	$4.32	$6.61	$5.14

8.3.1.1 Energy 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 a projection of annual national-average residential and commercial electricity prices consistent with cases described on p. E-8 in EIA's *AEO 2021*. [c, 1]

[c] DOE used the more conservative (i.e., lower) price projections found in the AEO 2021 No-CPP case.

DOE calculated LCC and PBP using three separate projections from *AEO 2021*: 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 8.3.1 through Figure 8.3.4 show the residential electricity, natural gas, LPG and fuel oil price trends based on the three *AEO 2021* projections. For the LCC results presented in section 8.5, DOE used only the energy price forecasts from the AEO reference case.

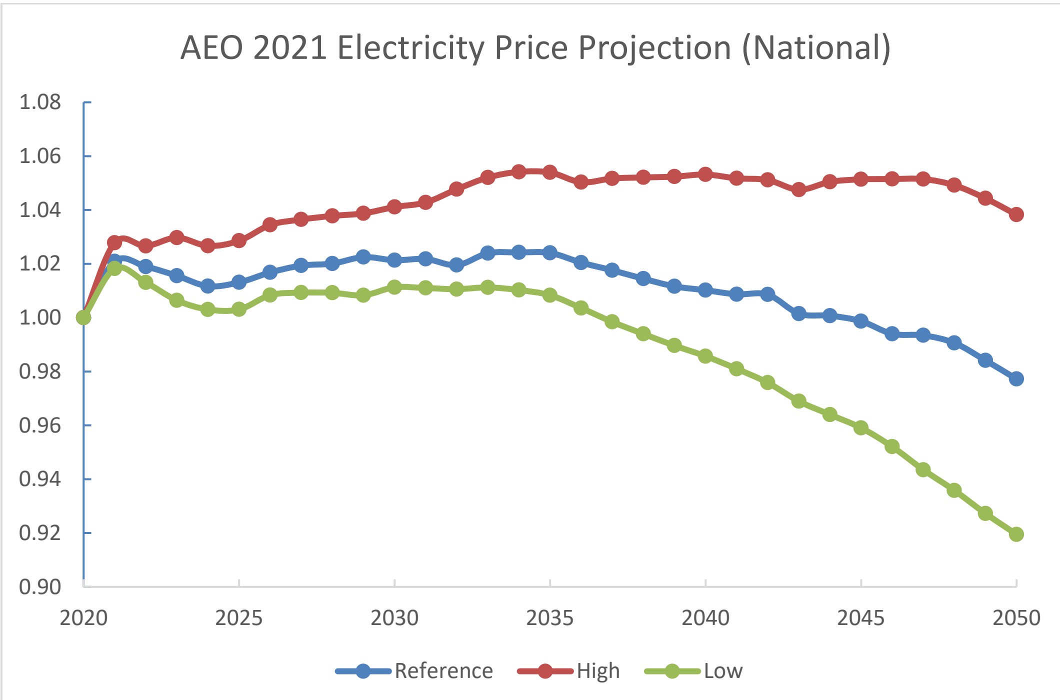

Figure 8.3.1 Electricity Price Trends

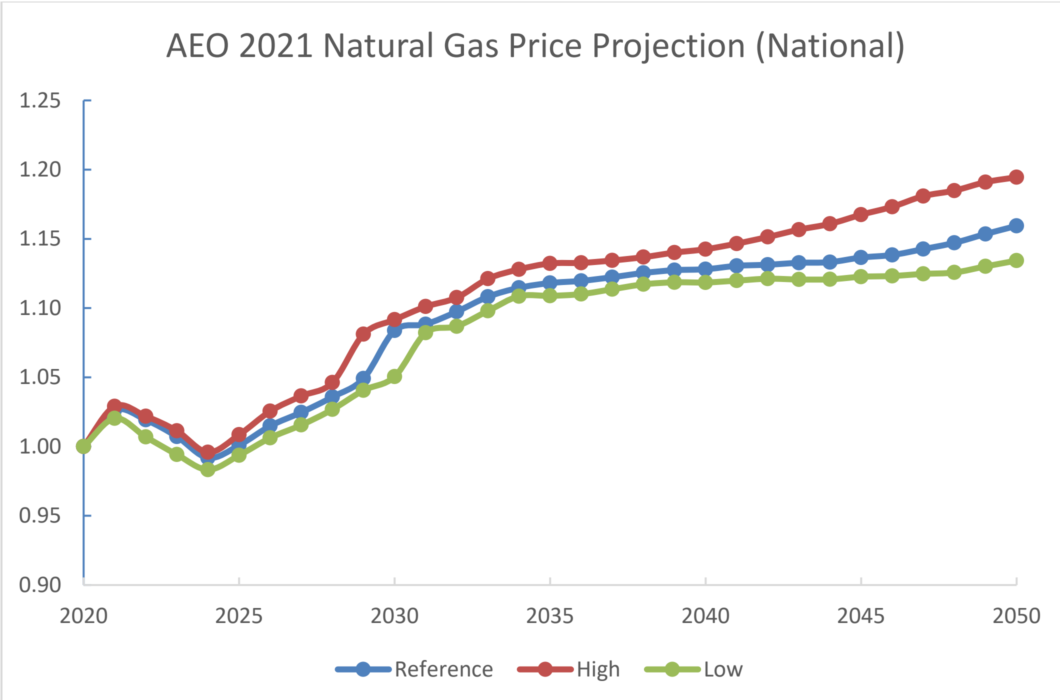

Figure 8.3.2 Natural Gas Price Trends

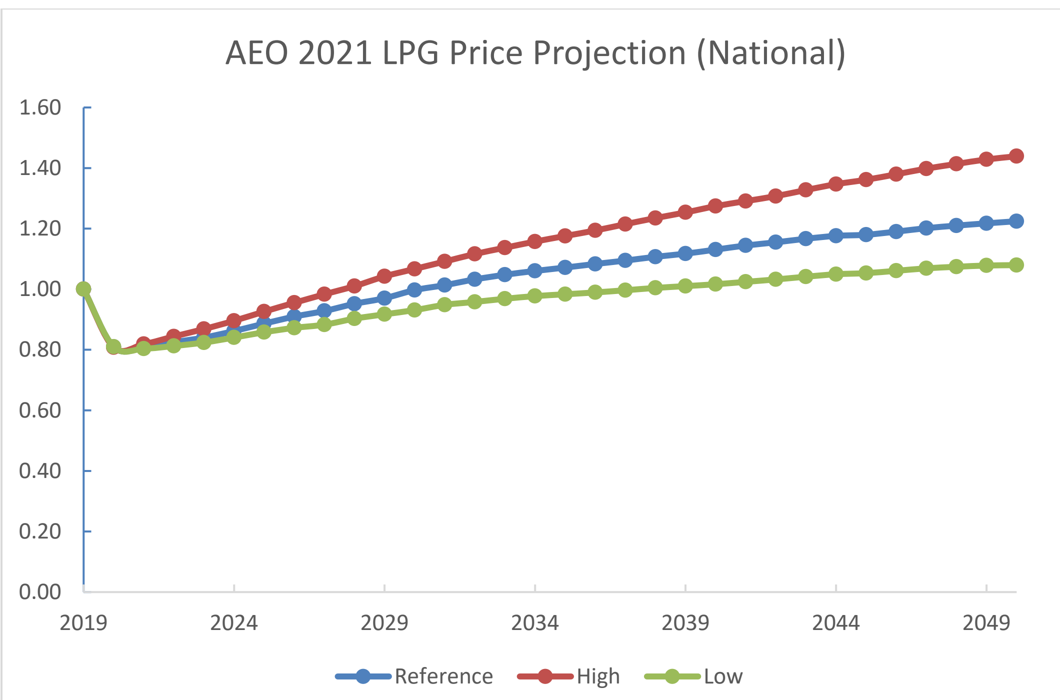

Figure 8.3.3 LPG Price Trends

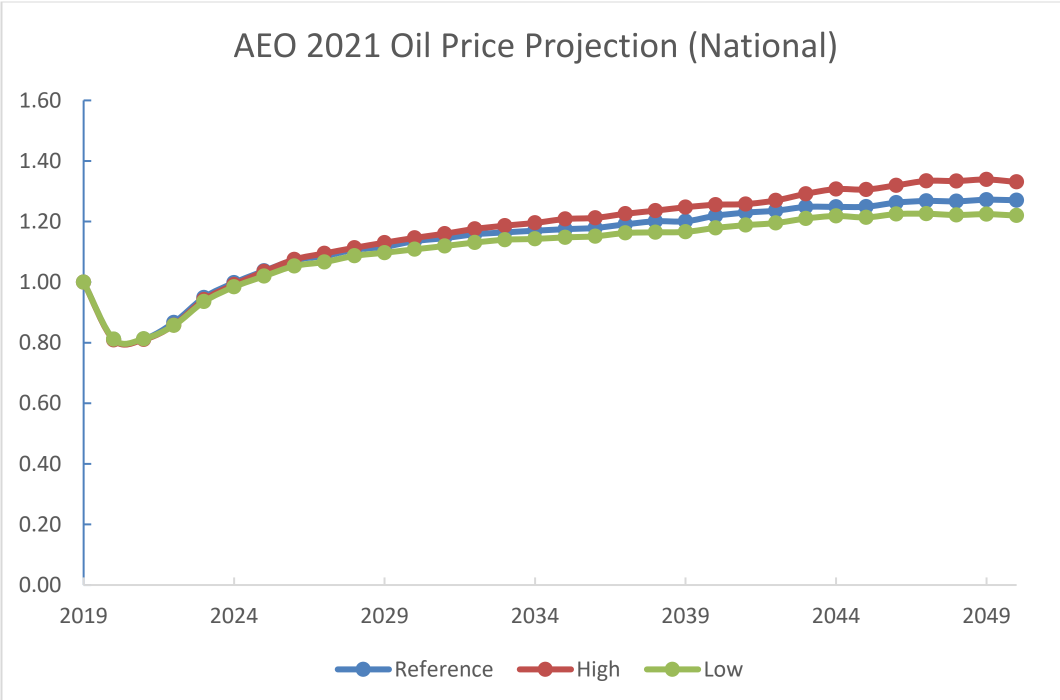

Figure 8.3.4 Fuel Oil Price Trends

8.3.1.2 Water Price Trends

To estimate the future trend for water and wastewater prices, DOE used Bureau of Labor Statistics historic trend data in the national water price index (U.S. city average) from 1986 through 2020.[11] DOE extrapolated the future trend based on the linear growth from 1986 to 2020 to forecast prices through 2086. Figure 8.3.5 shows historical and projected trends in water and wastewater prices.

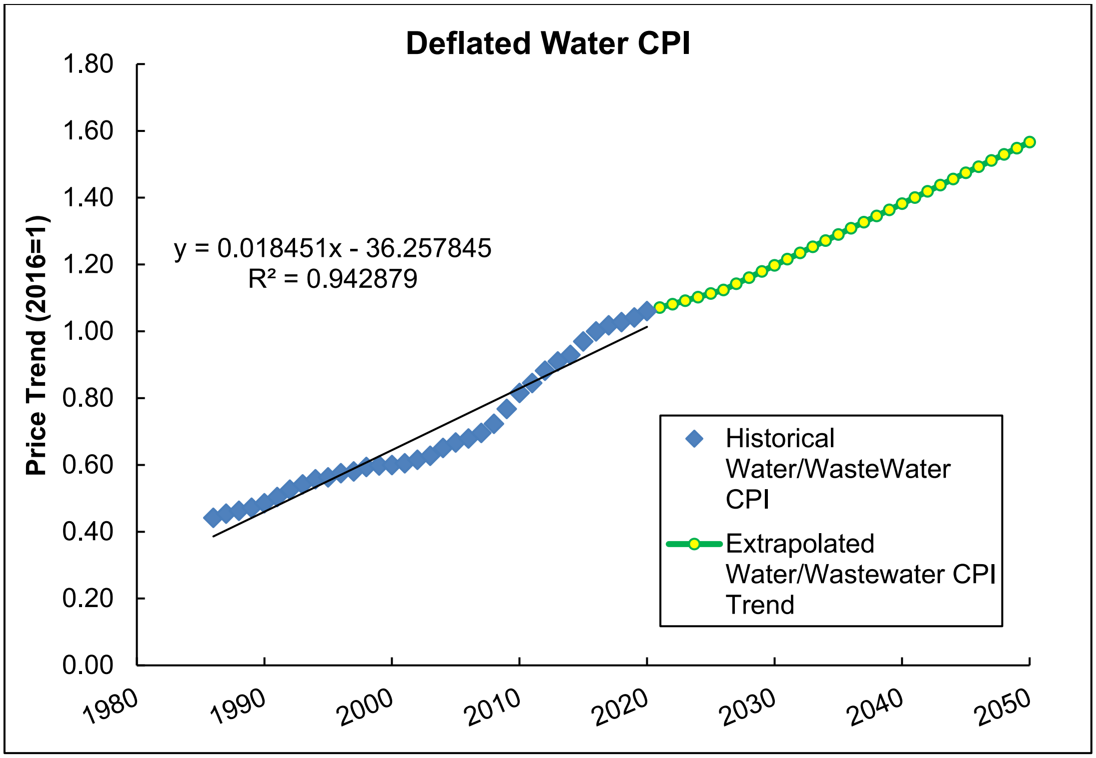

Figure 8.3.5 Water and Wastewater Water Price Trend

8.3.3 Repair Costs and Maintenance Costs

The repair cost is the cost to repair the product when a component fails. The maintenance cost is the cost of regular product maintenance.

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 derived baseline repair costs for dishwashers from data in the *RS Means Residential Cost Data*,[4] which provide estimates on the labor required to repair dishwashers. DOE estimated an average repair cost of $242.63, over the product's lifetime. DOE did not include any changes in repair and maintenance costs for products more efficient than baseline products. (See Table 8.3.11)

Table 8.3.11 Dishwashers: Baseline Repair Costs

Crew L-1	Bare Costs (2020$/hr)	Incl. O&P* (2020$/hr)
0.25 Electrician 1 Plumber	$62.90	$97.05
Total = $97.05 × 2.5 hr		$242.63

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

8.3.4 Product Lifetime

The product lifetime is the age at which a product is retired from service. Because product lifetime varies, DOE uses a lifetime distribution to characterize the probability a product will be retired from service at a given age.

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),[12] 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[13] and 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 15.2 years.

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

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

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

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

Eq. 8.8

Where:

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

When $\beta = 1$, the failure rate is constant over time, giving the distribution the form of a cumulative exponential distribution. In the case of appliances, β commonly is greater than 1, reflecting an increasing failure rate as appliances age. DOE estimated a delay parameter of $\theta = 1$ year, based on the typical manufacturer warranty period for dishwashers. Based on values for dishwashers, DOE assumed a maximum lifetime of 60 years and an average lifetime of 15.2 years, then solved for the scale and shape parameters. Table 8.3.12 shows the lifetime parameters of the Weibull probability distribution, and Figure 8.3.6 shows the corresponding Weibull distribution. See appendix 8E of this TSD for more details.

Table 8.3.12 Lifetime Parameters for Dishwashers

Value			Weibull Parameters		
Minimum (*years*)	**Average (*years*)**	**Maximum (*years*)**	***α* (scale)**	***β* (shape)**	***θ* (delay)**
2	15.2	60	15.9	1.8	1

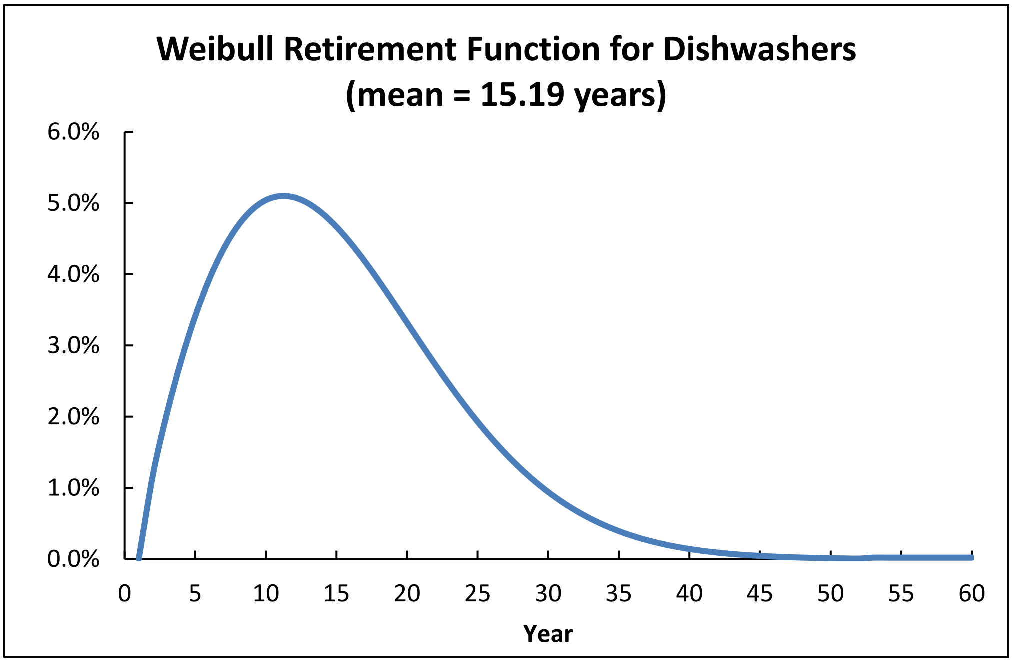

Figure 8.3.6 Weibull Probability Distribution for Dishwasher Lifetime

8.3.5 Discount Rates

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

DOE calculates the consumer discount rate using publicly available data (the Federal Reserve Board's *Survey of Consumer Finance*s (SCF)) to estimate a consumer's required rate of return or opportunity cost of funds related to appliances.[14] In the economics literature, opportunity cost reflects potential foregone benefit resulting from choosing one option over another. Opportunity cost of capital refers to the rate of return that one could earn by investing in an alternate project with similar risk; similarly, opportunity cost may be defined as the cost associated with opportunities that are foregone when resources are not put to their highest-value use.[15]

DOE's method views the purchase of a higher efficiency appliance as an investment that yields a stream of energy cost savings. The stream of savings is discounted at a rate reflecting (1) the rates of return associated with other investments available to the consumer, and (2) the observed costs of credit options available to the consumer to reflect the value of avoided debt. DOE notes that the LCC does not analyze the appliance purchase decision, so the implicit discount rate is not relevant in this model. The LCC estimates net present value over the lifetime of the product, so the appropriate discount rate will reflect the general opportunity cost of household funds, taking this time scale into account.

Given the long time horizon modeled in the LCC, the application of a marginal interest rate associated with an initial source of funds is inaccurate. Regardless of the method of purchase, consumers are expected to continue to rebalance their debt and asset holdings over the LCC analysis period, based on the restrictions consumers face in their debt payment requirements and the relative size of the interest rates available on debts and assets. DOE estimates the aggregate impact of this rebalancing using the historical distribution of debts and assets. The discount rate is the rate at which future savings and expenditures are discounted to establish their present value.

DOE estimates separate discount rate distributions for six income groups, divided based on income percentile as reported in the SCF, see Table 8.3.13. This disaggregation reflects the fact that low and high income consumers tend to have substantially different shares of debt and asset types, as well as facing different rates on debts and assets. Summaries of shares and rates presented in this chapter are averages across the entire population.

Table 8.3.13 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, 2010, 2013, 2016.

Shares of Debt and Asset Classes

DOE's approach involved identifying all household debt or asset classes in order to approximate a consumer's opportunity cost of funds over the product's lifetime. This 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 now includes 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 8.3.14). The household-level discount rates are then aggregated to form discount rate distributions for each of the six income groups.[e]

[e] 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 SCF for 1995, 1998, 2001, 2004, 2007, 2010, 2013, and 2016.[f] (See Table 8.3.14) DOE derived the household-weighted mean percentages of each source of across the twenty-one years covered by the eight survey versions. DOE posits that these long-term averages are most appropriate to use in its analysis.

Table 8.3.14 Types of Household Debt and Equity by Percentage Shares (%)

Type of Debt or Equity	Percentage Shares by Income Group (%)						
	1	2	3	4	5	6	All
Debt:							
Mortgage	14.6	22.2	33.6	43.5	47.6	37.1	31.3
Home equity loan	1.6	2.0	2.4	3.5	4.6	7.7	3.1
Credit card	15.4	12.0	9.3	6.1	4.1	1.9	9.1
Other installment loan	31.7	27.3	23.3	16.4	11.2	5.8	21.4
Other line of credit	1.3	1.8	1.5	2.0	2.5	2.4	1.8
Other residential loan	0.7	0.4	0.5	0.4	0.3	0.2	0.5
Equity:							
Savings account	18.8	14.8	11.2	8.8	7.8	7.1	12.2
Money market account	3.5	4.5	3.8	3.6	4.4	6.8	4.2
Certificate of deposit	6.5	6.8	4.8	3.9	3.3	3.4	5.1
Savings bond	1.7	1.8	1.6	1.7	1.4	1.2	1.6
State & Local bonds	0.0	0.1	0.2	0.2	0.4	1.4	0.3
Corporate bonds	0.1	0.1	0.2	0.2	0.1	0.4	0.2
Stocks	2.3	3.1	3.9	4.8	6.0	12.4	4.7
Mutual funds	1.9	3.1	3.8	4.9	6.2	12.2	4.6
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Sources: Federal Reserve Board. *Survey of Consumer Finances (SCF)* for 1995, 1998, 2001, 2004, 2007, 2010, 2013, 2016.

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 SCF for 1995, 1998, 2001, 2004, 2007, 2010, 2013, and 2016, which associates an interest rate with each type of debt for each household in the survey.

[f] 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 21-year span covered by the eight surveys included is sufficiently representative of recent debt and equity shares and interest rates.

DOE adjusted the nominal rates to real rates for each type of debt by using the annual inflation rate for each year (using the Fisher formula).[g] In calculating effective interest rates for home equity loans and mortgages, DOE also accounted for the fact that interest on both such loans is tax deductible. This rate corresponds to the interest rate after deduction of mortgage interest for income tax purposes and after adjusting for inflation. The specific inflation rates vary by SCF year, while the marginal tax rates vary by SCF year and income bin as shown in Table 8.3.15. For example, a 6 percent nominal mortgage rate has an effective nominal rate of 5.5 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.

Table 8.3.15 Data Used to Calculate Real Effective Household Debt Rates

Year	Inflation Rate (%)	Applicable Marginal Tax Rate by Income Group (%)					
		1	2	3	4	5	6
1995	2.81	15.0	15.0	15.0	28.0	28.0	39.6
1998	1.55	15.0	15.0	15.0	28.0	28.0	39.6
2001	2.83	10.0	15.0	15.0	27.5	27.5	39.1
2004	2.68	10.0	15.0	15.0	25.0	25.0	35.0
2007	2.85	10.0	15.0	15.0	25.0	25.0	35.0
2010	1.64	10.0	15.0	15.0	25.0	25.0	35.0
2013	1.46	10.0	15.0	15.0	25.0	25.0	37.3
2016	1.26	10.0	15.0	15.0	25.0	25.0	37.3

Table 8.3.16 shows the household-weighted average effective real rates in each year and the mean rate across years. 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 2027.

[g] Fisher formula is given by: Real Interest Rate = [(1 + Nominal Interest Rate) / (1 + Inflation Rate)] – 1. Note that for this analysis DOE used a minimum real effective debt interest rate of 0 percent.

Table 8.3.16 Average Real Effective Interest Rates by Income Group for Household Debt

Type of Debt	Real Effective Interest Rates by Income Group (%)						
	1	2	3	4	5	6	All
Mortgage	4.27	3.90	3.76	3.06	2.93	2.31	3.33
Home equity loan	4.37	4.45	3.96	3.36	3.26	2.57	3.48
Credit card	9.54	10.92	10.87	11.25	10.76	10.16	10.47
Other installment loan	6.22	7.24	6.02	5.44	4.65	4.64	6.19
Other line of credit	4.14	3.80	5.90	5.53	4.64	5.14	4.97
Other residential loan	6.73	6.44	5.38	5.15	4.44	4.13	5.44

Sources: Federal Reserve Board. *Survey of Consumer Finances (SCF)* for 1995, 1998, 2001, 2004, 2007, 2010, 2013, 2016.

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 (1989-2018). The rates for stocks are the annual returns on the Standard and Poor's 500 for 1989–2018.[16] The interest rates associated with AAA corporate bonds were collected from Moody's time-series data for 1989–2018.[17] Rates on Certificates of Deposit (CDs) accounts came from Cost of Savings Index (COSI) data covering 1989–2018. [h, 18, 19, 20, 21, 22] The interest rates associated with state and local bonds (20-bond municipal bonds) were collected from Federal Reserve Board economic data time-series for 1989–2018. [i, 23, 24] The interest rates associated with treasury bills (30-Year treasury constant maturity rate) were collected from Federal Reserve Board economic data time-series for 1989–2018. [j, 24, 25] Rates for money market accounts are based on three-month money market account rates reported by Organization for Economic Cooperation and Development (OECD) from 1989–2018.[26] Rates for savings accounts are assumed to be half the average real money market rate. Rates for mutual funds are a weighted average of the stock rates and the bond rates.[k] DOE adjusted the nominal rates to real rates using the annual inflation rate in each year (see appendix 8F). In addition, DOE adjusted the nominal rates to real effective rates by accounting for the fact that interest on such equity types is taxable. The capital gains marginal tax rate varies for each household based on income as shown in Table 8.3.17.

[h] The Wells COSI is based on the interest rates that the depository subsidiaries of Wells Fargo & Company pay to individuals on certificates of deposit (CDs), also known as personal time deposits. Wells Fargo COSI started in November 2009.[22] From July 2007 to October 2009 the index was known as Wachovia COSI[23] and from January 1984 to July 2007 the index was known as GDW (or World Savings) COSI.[24,25]

[i] This index was discontinued in 2016. To calculate the 2017 and 2018 values, DOE compared 1977-2018 data for 30-Year Treasury Constant Maturity Rate[29] and Moody's AAA Corporate Bond Yield[20] to the 20-Bond Municipal Bond Index data.[28]

[j] From 2003-2005 there are no data. For 2003-2005, DOE used 20-Year Treasury Constant Maturity Rate.[29]

[k] SCF reports what type of mutual funds the household has (e.g. stock mutual fund, savings bond mutual fund, etc.). For mutual funds with a mixture of stocks and bonds, the mutual fund interest rate is a weighted average of the stock rates (two-thirds weight) and the savings bond rates (one-third weight).

Table 8.3.17 Average Nominal and Real Interest Rates for Household Equity

Year	Applicable Marginal Tax Rate by Income Group (%)					
	1	2	3	4	5	6
1995	12.5	12.5	12.5	28.0	28.0	33.8
1998	12.5	12.5	12.5	24.0	28.0	29.8
2001	7.5	10.0	15.0	21.3	27.5	27.1
2004	7.5	10.0	15.0	21.3	25.0	27.1
2007	5.0	10.0	15.0	20.0	25.0	25.0
2010	5.0	7.5	15.0	20.0	25.0	25.0
2013	5.0	7.5	15.0	20.0	25.0	27.4
2016	5.0	7.5	15.0	20.0	25.0	27.4

Average real effective interest rates for the classes of household assets are listed in Table 8.3.18. 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 2027. The average nominal interest rates and the distribution of real interest rates by year are shown in appendix 8F.

Table 8.3.18 Average Real Effective Interest Rates for Each Household Equity Type by Income Group

Equity Type	Real Effective Interest Rates by Income Group (%)						
	1	2	3	4	5	6	All
Savings accounts	0.35	0.34	0.32	0.29	0.29	0.27	0.32
Money market accounts	0.69	0.68	0.64	0.59	0.59	0.54	0.63
Certificate of deposit	0.94	0.92	0.87	0.79	0.79	0.73	0.87
Treasury Bills (T-bills)	2.43	2.38	2.25	2.06	2.06	1.90	2.23
State/Local bonds	2.18	2.13	2.02	1.85	1.85	1.70	1.84
AAA Corporate Bonds	3.20	3.13	2.97	2.71	2.71	2.50	2.80
Stocks (S&P 500)	7.95	7.79	7.38	6.74	6.74	6.22	6.97
Mutual funds	6.65	6.67	6.40	5.81	5.88	5.21	5.94

Discount Rate Calculation and Summary

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

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

Where:

$DR_i =$ discount rate for consumer i,
$Share_{i,j} =$ 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 above.

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 at the low end to 30 percent and greater at the high end. Giving equal weight to each survey, DOE compiled the eight-survey distribution of discount rates.

Table 8.3.19 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 8F presents the full probability distributions for each income group that DOE used in the LCC and PBP analysis.

Table 8.3.19 Average Real Effective Discount

Income Group	Discount Rate (%)
1	4.74
2	5.01
3	4.52
4	3.87
5	3.51
6	3.18
Overall Average	4.30

Source: Board of Governors of the Federal Reserve System, Survey of Consumer Finances (1995 – 2016)

8.4 ENERGY EFFICIENCY DISTRIBUTIONS

To estimate the percentage of consumers who would be affected by a potential standard at any of the considered efficiency levels, DOE first develops a distribution of efficiencies for products that consumers purchase under the no-new-standards case.

To assign a no-new-standards case energy efficiency distribution for 2027, DOE conducted a model number-weighted no-new standards case efficiency analysis for dishwashers based on DOE's Compliance Certification Database (CCD) for Dishwashers.[27] Table 8.4.1 presents the market shares of the efficiency levels in the no-new-standards case for standard-sized dishwashers in 2027, the year of compliance. Table 8.4.2 presents the market shares of the efficiency levels in the no-new-standards case for compact dishwashers in 2027.

Table 8.4.1 Standard-Sized Dishwashers: No-New-Standards Case Efficiency Market Share for 2027

Efficiency Level	Annual Energy Use* (kWh/year)	Water Use (gal/cycle)	Market Share (%)
Baseline	260	5.00	8%
1	230	3.50	63%
2	222	3.30	18%
3	204	3.20	9%
4	192	2.40	2%

*Based on the assumption of 185 cycles per year and updated water heater energy use inputs.

Table 8.4.2 Compact Dishwashers: No-New-Standards Case Efficiency Market Shares for 2027

Efficiency Level	Annual Energy Use* (kWh/year)	Water Use (gal/cycle)	Market Share (%)
Baseline	176	3.50	28%
1	173	3.10	60%
2	123	1.60	12%

*Based on the assumption of 185 cycles per year and updated water heater energy use inputs.

8.5 LIFE-CYCLE COST AND PAYBACK PERIOD RESULTS

The LCC calculations were performed for each of the 10,000 consumers in the sample of households established for each product class. Each LCC calculation sampled inputs from the probability distributions that DOE developed to characterize many of the inputs to the analysis.

For each product class, DOE calculated the average installed cost, first year's operating cost, lifetime operating cost, and LCC for each EL. These averages are calculated assuming that all of the sample households purchase a product at each EL. This allows the installation costs, operating costs, and LCCs for each EL to be compared under the same conditions, across a variety of sample households. DOE used these average values to calculate the PBP for each EL, relative to the baseline EL.

DOE first assigned dishwashers to households using the efficiency distribution in the no-new-standards case. DOE calculated the LCC and PBP for all households as if each were to purchase a new dishwasher in the expected year of compliance with amended standards. For any given EL, DOE measures the change in LCC relative to the LCC in the no-new-standards case, which reflects the estimated efficiency distribution of dishwashers in the absence of new or amended energy conservation standards.

The following sections present the key LCC and PBP findings, as well as figures that illustrate the range of LCC and PBP effects among a sample of households. A household is considered to have received a net LCC cost if the household had negative LCC savings at the EL being analyzed. DOE presents the average LCC savings for affected households, which includes only households with non-zero LCC savings due to the standard.

8.5.1 Summary of Results

Table 8.5.1 through Table 8.5.2 show the LCC and PBP results by efficiency level for the standard-sized dishwashers. The average operating cost is the discounted sum.

Table 8.5.1 Summary of LCC and PBP Results by Efficiency Level for Standard-Sized Dishwashers

Efficiency Level	Average Costs 2020$				Simple Payback years
	Installed Cost	First Year's Operating Cost	Lifetime Operating Cost	LCC	
0	$441	$57	$672	$1,113	--
1	$469	$52	$612	$1,081	5.9
2	$484	$51	$597	$1,080	7.0
3	$551	$49	$568	$1,119	12.9
4	$617	$47	$542	$1,159	16.7

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 8.5.2 Summary of Life-Cycle Cost Savings Relative to the No-New-Standards Case for Standard-Sized Dishwashers

Efficiency Level	Life-Cycle Cost Savings	
	Average Savings 2020$	% of Consumers that Experience Net Cost
1	$32	3%
2	$4	43%
3	($35)	77%

4	($72)	88%

Note: The LCC savings for each TSL are calculated relative to the no-new-standards case efficiency distribution. The calculation does not includes households with zero LCC savings (no impact).
*Parentheses indicate negative values

Table 8.5.3 and Table 8.5.4 show the LCC and PBP results by TSL for compact dishwashers. The average operating cost is the discounted sum.

Table 8.5.3 Summary of LCC and PBP Results by Efficiency Level for Compact Dishwashers

Efficiency Level	Average Costs 2020$				Simple Payback years
	Installed Cost	First Year's Operating Cost	Lifetime Operating Cost	LCC	
0	$485	$44	$519	$1,004	--
1	$485	$44	$511	$996	0.0
2	$543	$36	$420	$963	7.1

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 8.5.4 Summary of Life-Cycle Cost Savings Relative to the No-New-Standards Case for Compact Dishwashers

Efficiency Level	Life-Cycle Cost Savings	
	Average Savings 2020$	% of Consumers that Experience Net Cost
0	--	--
1	$8	5%
2	$36	40%

Note: The LCC savings for each TSL are calculated relative to the no-new-standards case efficiency distribution. The calculation does not includes households with zero LCC savings (no impact).

8.5.2 Distribution of Impacts

The figures in this section show the distribution of LCCs in the no-new-standards case for each product class. The figures are presented as frequency charts that show the distribution of LCCs, and LCC impacts with their corresponding probability of occurrence. DOE generated the figures for the distributions from a Monte Carlo simulation run based on 10,000 samples.

8.5.2.1 No-New-Standards Case LCC Distributions

Figure 8.5.1 and Figure 8.5.2 show the frequency charts for the baseline LCC for both dishwashers product classes.

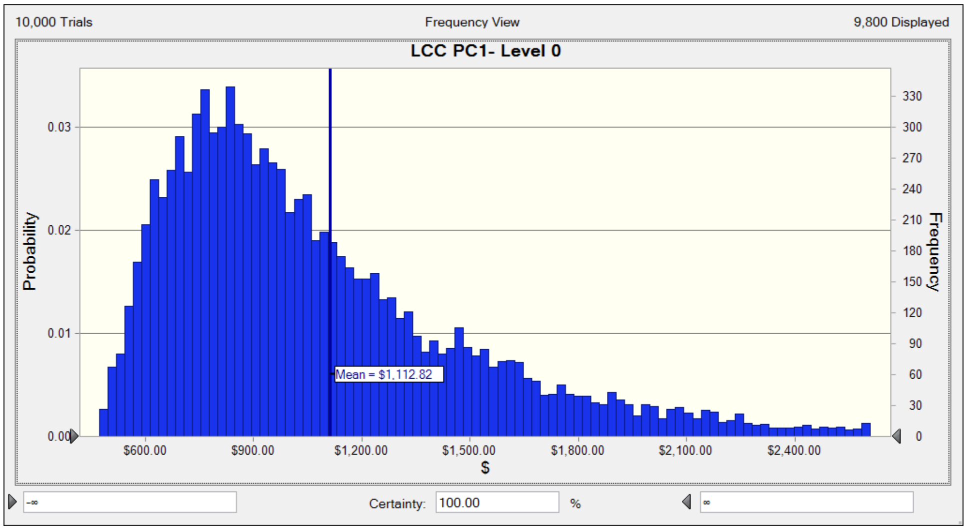

Figure 8.5.1 Standard-Sized Dishwashers: No-New-Standards Case LCC Distribution

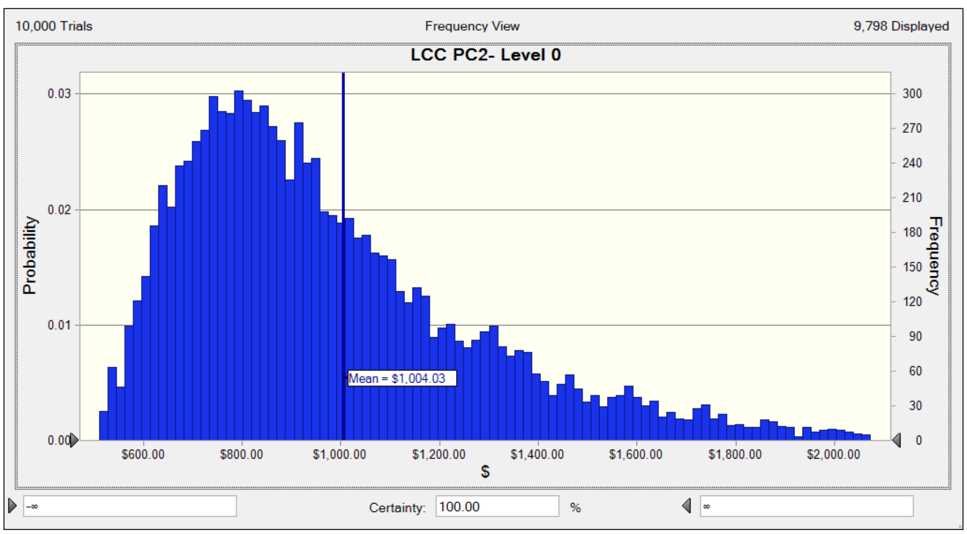

Figure 8.5.2 Compact-Sized Dishwashers: No-New-Standards Case LCC Distribution

8.5.2.2 Efficiency Level Distributions of LCC Impacts

Figure 8.5.3 is an example of a frequency chart that shows the distribution of LCC differences for the case of Efficiency Level 1 for standard-size dishwashers. In the figure, a text box next to a vertical line at a given value on the x-axis shows the mean change in LCC (a savings of $32.49 in the example here). The note, "Certainty is 100.00% from -Infinity to +Infinity," means that 100 percent of owners of standard-size dishwasher will have LCC savings or not be affected by the efficiency level compared to the no-new-standards case. Refer to section 8.4 on the distribution of product efficiencies under the no-new-standards case. DOE can generate a frequency chart like the one shown in Figure 8.5.3 for each efficiency level and product class.

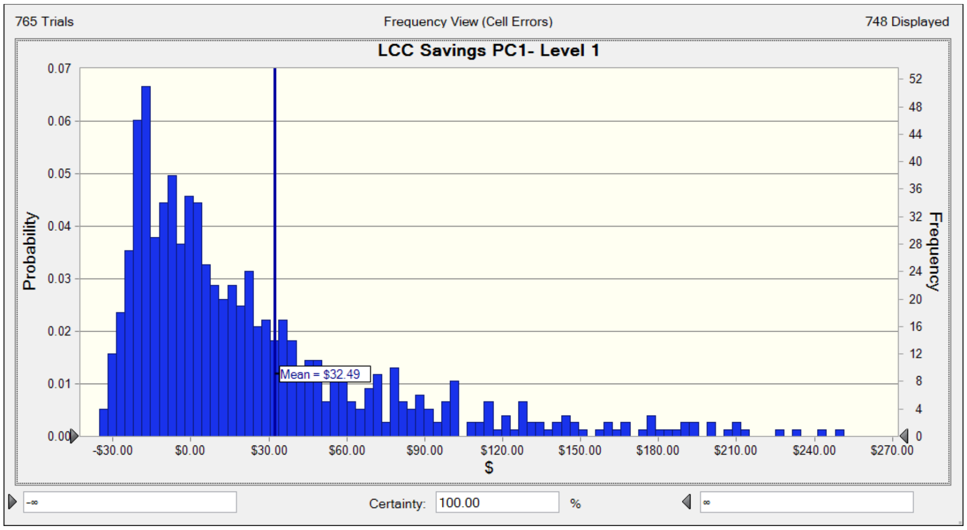

Figure 8.5.3 Standard-size Dishwashers: Distribution of LCC Impacts for Efficiency Level 1

8.5.3 Range of Impacts

Figure 8.5.4 and Figure 8.5.5 show the range of LCC savings for all efficiency levels considered for standard-size and compact-size 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.

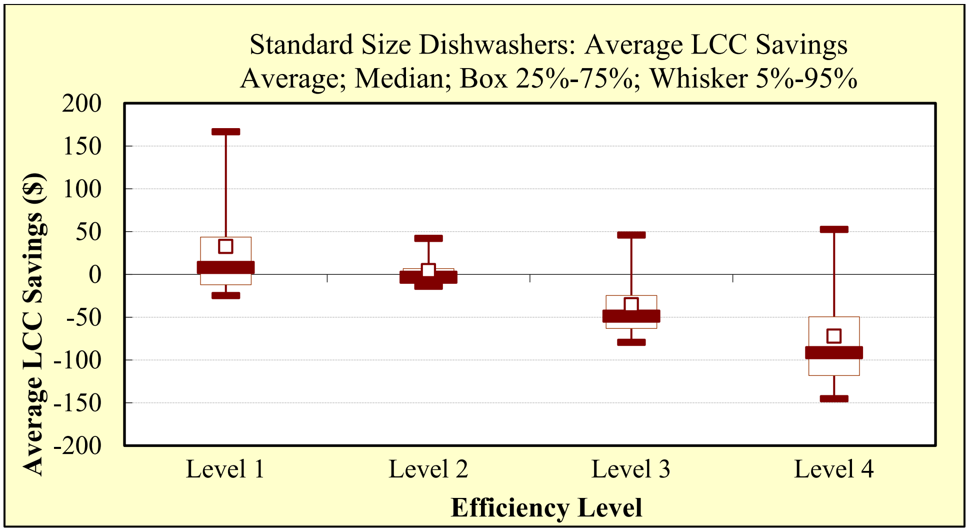

Figure 8.5.4 Range of LCC Savings for Standard-Sized Dishwashers

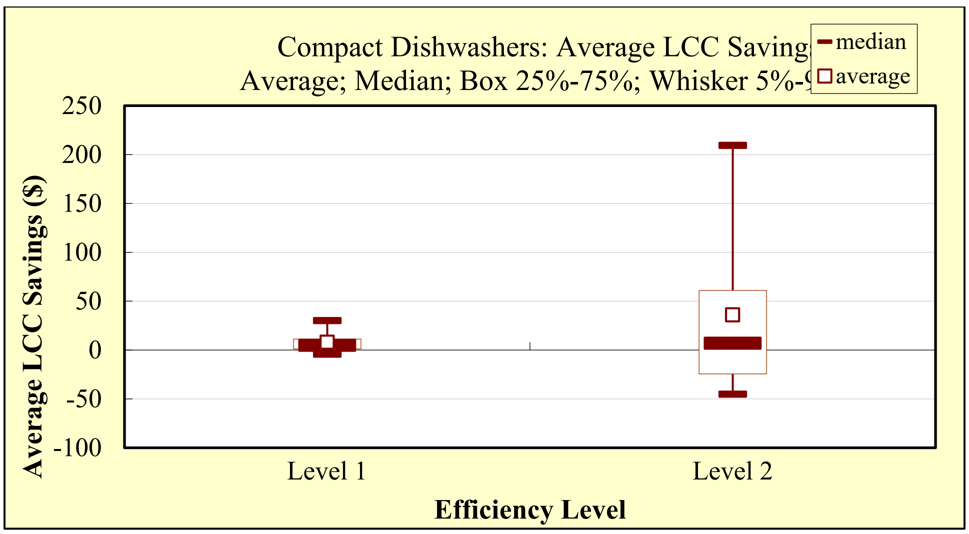

Figure 8.5.5 Range of LCC Savings for S Compact Dishwashers

8.6 REBUTTABLE PAYBACK PERIOD

DOE develops rebuttable PBPs to provide the legally established rebuttable presumption that an energy conservation 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 cost savings. (42 U.S.C. §6295 (o)(2)(B)(iii))

The basic equation for rebuttable PBP is the same as that shown for the PBP in section 8.1.1. Unlike the analyses described in section 8.1.1, however, the rebuttable PBP is not based on household samples and probability distributions. The rebuttable PBP is based instead on discrete, single-point values. For example, whereas DOE uses a probability distribution of regional energy prices in the distributional PBP analysis, it uses only the national average energy price to determine the rebuttable PBP.

Other than the use of single-point values, the most notable difference between the distributional PBP and the rebuttable PBP is the latter's reliance on the DOE test procedure to determine a product's annual energy consumption. DOE based the annual energy consumption for the rebuttable PBP on the number of operating hours per year specified in DOE's proposed test procedure for dishwashers. The following sections identify the differences, if any, between the annual energy consumptions determined by the distributional PBP and the rebuttable PBP for both product classes of dishwashers.

8.6.1 Inputs to the Rebuttable Payback Period Analysis

Because inputs for determining total installed cost for calculating the distributional PBP were based on single-point values, only the variability and/or uncertainty in the inputs for determining operating cost contributed to variability in the distributional PBPs. The following summarizes the single-point values that DOE used in determining the rebuttable PBP.

- Manufacturing costs, markups, sales taxes, and installation costs were based on the single-point values used in the distributional LCC and PBP analysis.
- Energy prices were based on national average values for the year that new standards would take effect.
- An average discount rate or lifetime is not required in calculating the rebuttable PBP.
- The effective date of any new standard is assumed to be 2027.

8.6.2 Results of Rebuttable Payback Period Analysis

DOE calculated rebuttable PBPs for each efficiency level relative to the distribution of product efficiencies estimated for the baseline. In other words, DOE did not determine the rebuttable PBP relative to the no-new-standards case energy efficiency, but relative to the distribution of product energy efficiencies for the baseline (*i.e.*, the case without new energy conservation standards).

Table 8.6.1 and Table 8.6.2 present the rebuttable PBPs for standard-sized and compact dishwashers, respectively.

Table 8.6.1 Standard-Sized Dishwashers: Rebuttable Payback Periods

Efficiency Level	AEU* (kWh/year)	Water Use (gal/cycle)	Rebuttable PBP (years)
Baseline	260	5.00	--
1	230	3.50	4.1
2	222	3.30	5.1
3	204	3.20	10.2
4	192	2.40	12.7

*Based on the assumption of 185 cycles per year and updated water heater energy use inputs.

Table 8.6.2 Compact Dishwashers: Rebuttable Payback Periods

Efficiency Level	AEU* (kWh/year)	Water Use (gal/cycle)	Rebuttable PBP (years)
Baseline	176	3.50	--
1	173	3.10	0.0
2	123	1.60	5.5

*Based on the assumption of 185 cycles per year and updated water heater energy use inputs.

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CHAPTER 9. SHIPMENTS ANALYSIS

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CHAPTER 9. SHIPMENTS ANALYSIS

9.1 INTRODUCTION

Projections of product shipments are a necessary input for calculating the national energy savings (NES) and the net present value (NPV) of potential new or amended energy efficiency standards. Shipments also are a necessary input to the manufacturer impact analysis (see chapter 12 of this Technical Support Document (TSD). This chapter describes the U.S. Department of Energy (DOE) method of projecting and results for projected annual shipments for dishwashers.

The shipments model takes an accounting approach, tracking the entry and exit of products into and out of the housing stock, resulting in an age distribution of in-service product stock for each year in the analysis period. Rather than extrapolating a current shipments trend, the analysis uses key drivers of shipments, including construction forecasts and product retirement functions, to project sales in different market segments. For dishwashers, DOE accounted for two market segments: (1) shipments to new construction; and (2) shipments to replace retired units in existing housing stock. To estimate the effect of potential standard levels on product shipments, the shipments model accounts for the effects of changes in purchase price and energy efficiency on the consumer purchase decision.

The shipments model was developed as a part of the Excel spreadsheet used for the national impacts analysis (NIA). Appendix 10A of this TSD describes how to access the NIA workbook and provides basic instructions for its use.

The rest of this chapter explains the shipments model in more detail. Section 9.2 presents an overview of the shipments model; section 9.3 describes the data inputs; section 9.4 presents the projection of shipments in the case without new or amended standards, section 9.5 discusses the effect of potential standards on shipments; and section 9.6 presents results for various efficiency levels considered.

9.2 SHIPMENTS MODEL OVERVIEW

DOE's shipments model takes an accounting approach, tracking the vintage of units in the existing housing stock and in expected housing stock trends. The stock accounting uses historic product shipments, an initial number of in-service product stock, and a retirement function to develop an estimate of the age distribution of in-service product stock for all years in the analysis period.

Market segments represent distinct inputs to the shipments forecast. To project the shipments in each year, DOE first computed the demand for two markets:

- new construction (including additions to existing buildings),
- replacement of retired units

DOE combined these markets to obtain the total demand for new shipments using the following equation:

$$Ship(y) = Ship_{New\ Construction}(y) + \ Ship_{Replacement}(y)$$

Where:

$Ship(y)$ = total shipments in year y,
$Ship_{NewConstruction}\ (y)$ = Shipments for new construction in year y, and
$Ship_{Replacement}(y)$ = Shipments for replacing the retired units in year y.

The no-new-standards 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 multiplied by 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. DOE determined the demand for replacement shipments in a given year by computing the number of shipments from previous years that would be expected to retire in that year. The probability that a given product will retire A years after installation is:

$$\boldsymbol{P_{ret}(A) = P_{surv}(A-1) - \ P_{surv}(A)}$$

Where:

A = the product's age (years since installation),
$P_{ret}(A)$ = the probability that a product is retired when it is A years old, and
$P_{surv}(A)$ = the probability that the product survives (i.e., is not retired) for A years after installation.

The retirement probability function is used to compute the expected product retirements in year y, given a time series of historical shipments spanning the maximum expected age reached by any product, A_{max}:

$$Ship_{replacement}(y) = \sum_{\boldsymbol{v=y-A_{\max}}}^{\boldsymbol{y-1}} \boldsymbol{P_{ret}(y-v)\, Ship(v)}$$

Where:

y = current year,
v = product vintage (i.e., year of shipment),
A_{max} = maximum expected lifetime (yr),
$P_{ret}(y-v)$ = probability of retirement in year $y-v$ of product's lifetime, and

$Ship(v)$ = total shipments of products that occurred in a particular vintage (number of units).

The age distribution of 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. Operating cost depends on the product age distribution under a potential standards case scenario that produces increasing efficiency over time, where older, less efficient units may have higher operating costs, while newer, more efficient units will have lower operating costs.

DOE calculated total stock of dishwashers by integrating historical shipments data beginning with a specific year. To estimate future shipments, DOE developed a series of equations that define the dynamics and accounting of stocks. For new units, the equation is:

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

Where:

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

The above equation states that the number of one-year-old units is equal to the number of new units purchased the previous year. Other equations describe the accounting for the in-service stock of units. In the equation below, as the year is advanced from *y* to *y+1*, the age is also incremented from *age* to *age+1*. Over time, a fraction of the stock is removed; that fraction is determined by a retirement probability function, $P_{Rtr}(age)$. For most appliances that have been used by U.S. consumers for a long time, replacements typically constitute the majority of shipments. Most of those replacements occur when a unit wears out and fails.

$$Stock(y + 1, age + 1) = Stock(y, age) \times [1 - P_{ret}(age)]$$

The affected stock is the in-service stock of the product that is affected by a potential energy efficiency standard level. The affected stock consists of those in-service units that are purchased in or after the year a potential standard takes effect, as described by the following equation.

$$\mathrm{Stock}_{aff}(\mathrm{y}) = Ship(y) + \sum_{age=1}^{y-Std_{yr}} Stock\ (y, age)$$

Where:

$Stock_{aff}(y)$ = affected stock of units of all vintages that are operational in year *y*,
$Ship(y)$ = shipments in year *y*,
Std_yr = compliance date of potential standard, and

$\sum_{age=1}^{y-Std_{yr}} Stock\,(y, age)=$ stock of units of all vintages shipped after the potential standards year that are operational in year y.

For the current analysis, DOE assumed that any potential new or amended energy efficiency standards for dishwashers would require compliance in 2027. Thus, all appliances purchased starting in 2027 are affected by the potential standard level. DOE's analysis considers shipments over a 30-year period, from 2027 through 2056.

9.3 DATA INPUTS AND MARKET SEGMENTS

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 dishwashers by developing a single model for all dishwashers and then disaggregating the shipments into the two product classes—standard-sized and compact dishwashers.

9.3.1 Historical Shipments

To establish historical shipments, DOE relied on data provided by the Association of Home Appliance Manufacturers (AHAM) 2018 historical tables.[1] The shipments data do not distinguish between product classes and include units for the residential sector only (Figure 9.3.1).

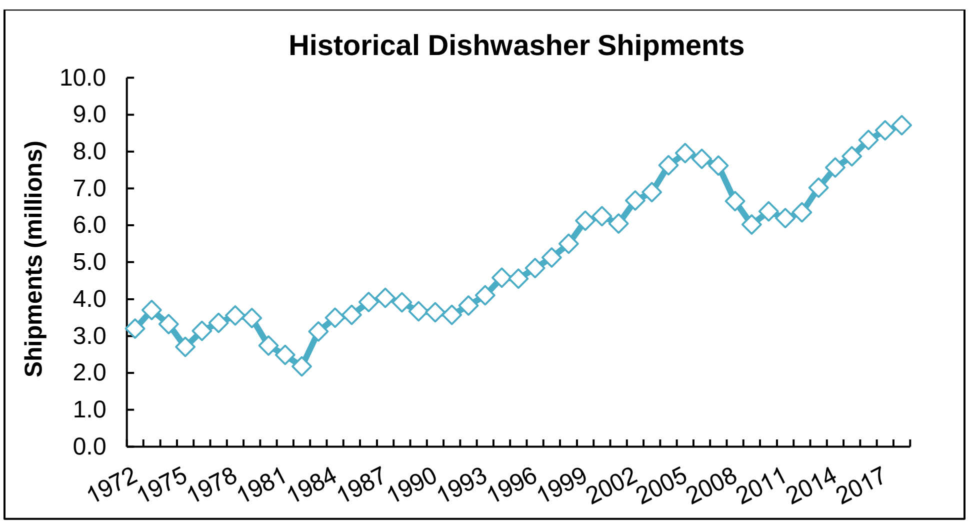

Figure 9.3.1 Historical Dishwasher Shipments, Domestic plus Imports

To determine the percentage of shipments of compact dishwashers, DOE used data from the U.S. DOE's Compliance Certification Database. As of March 2021, 5.1 percent of dishwashers in the database were compact dishwashers.[2]

9.3.2 Projecting Shipments by Market Segment

The market for dishwashers consists of replacement units for products that have been retired and units that were installed in new homes. The following sections discuss the replacement and new construction markets in further detail.

9.3.2.1 Replacements

To determine shipments for the replacement market, DOE's model tracks the total stock of units by vintage. DOE estimated a stock of dishwashers by vintage by integrating historical shipments from 1972. Over time, some units are retired and removed from the stock, triggering the shipment of a replacement unit. To estimate how long a unit will function before retiring, DOE used a survival function based on the distributions of product lifetime (which had an average value of 15.2 years). For a more complete discussion of dishwasher lifetimes, refer to chapter 8. The retirement function is applied to both historical and projected shipments from all of the market segments. Figure 9.3.2 shows the survival and retirement functions that DOE used to estimate replacement shipments.

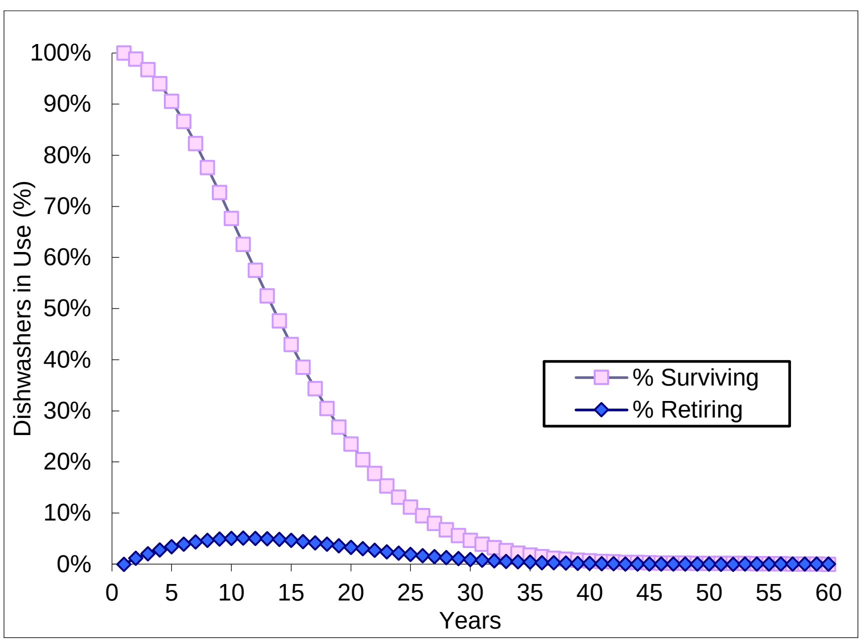

Figure 9.3.2 Dishwashers: Retirement Function

9.3.2.2 Installations in New Homes

To forecast the shipments of dishwashers to new homes for any given year, DOE multiplied the forecasted new housing completions by the forecasted saturation of dishwashers in new housing.

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 reference case projections from the DOE's Energy Information Administration (EIA)'s *Annual Energy Outlook 2021* (*AEO2021*) through 2050.[3] *AEO2021* provides three scenarios for housing starts: a reference case, a high economic growth case, and a low economic growth case, as shown on 0. DOE used only the forecasts from the reference case to estimate shipments to new construction. For 2051–2056, DOE froze completions at the level achieved in 2050.

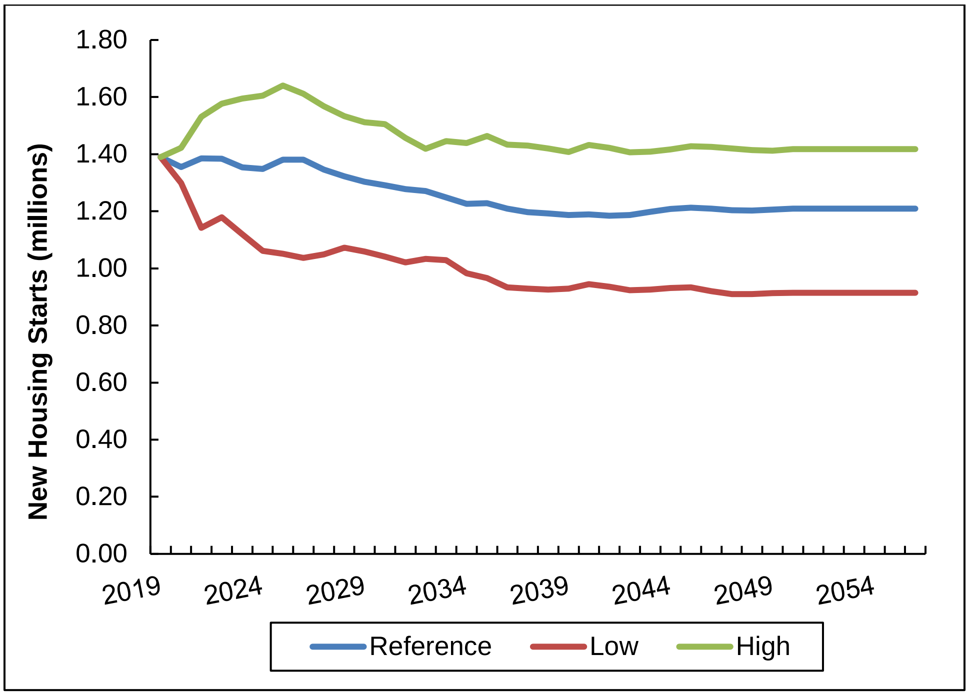

Figure 9.3.3 Projected New Housing Starts, 2019–2056

Table 9.3.1 presents historical data on the market saturation of dishwashers based on various sources: the AHAM 2005 *Fact Book*,[4] various issues of *Appliance Magazine*,[5] NFO World Group,[6] the U.S. Census Bureau's American Housing Survey for 2011, 2013, 2015, 2017, and 2019, and EIA's Residential Energy Consumption Survey (RECS) for 1993,[7] 1997,[8] 2001,[9] 2005,[10] 2009,[11] and 2015.[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 on the market saturations for new housing. According to RECS, dishwasher saturation in new housing for 1997, 2001, 2005, 2009, and 2015 was 78.1 percent, 81.5 percent, 85.1 percent, 87.4 percent, and 90.2 percent respectively. Because of the increasing rate of saturation, DOE used the most recent RECS data point (from 2015) to forecast saturations throughout the forecast period.

Table 9.3.1 Dishwashers: Historical Market Saturations

Year	AHAM*	Overall Household Saturation (%)				New Households (%) RECS§
		Appl†	NFO‡	AHS∞	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						
2011				67.0		
2012						
2013				67.5		
2014						
2015				68.2	67.4	90.2

Year	AHAM*	Overall Household Saturation (%)				New Households (%) RECS§
		Appl†	NFO‡	AHS∞	RECS§	
2016						
2017				71.6		
2018						
2019				73.9		

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; ∞AHS 2011, 2013, 2015, 2017, and 2019, and §DOE-EIA, RECS 1997, 2001, 2005, 2009, and 2015.

9.4 SHIPMENTS IN THE NO-NEW-STANDARDS CASE

Figure 9.4.1 shows the projected shipments in the no-new-standards case (the case without new energy efficiency standards) and the historical shipments DOE used to calibrate that forecast.

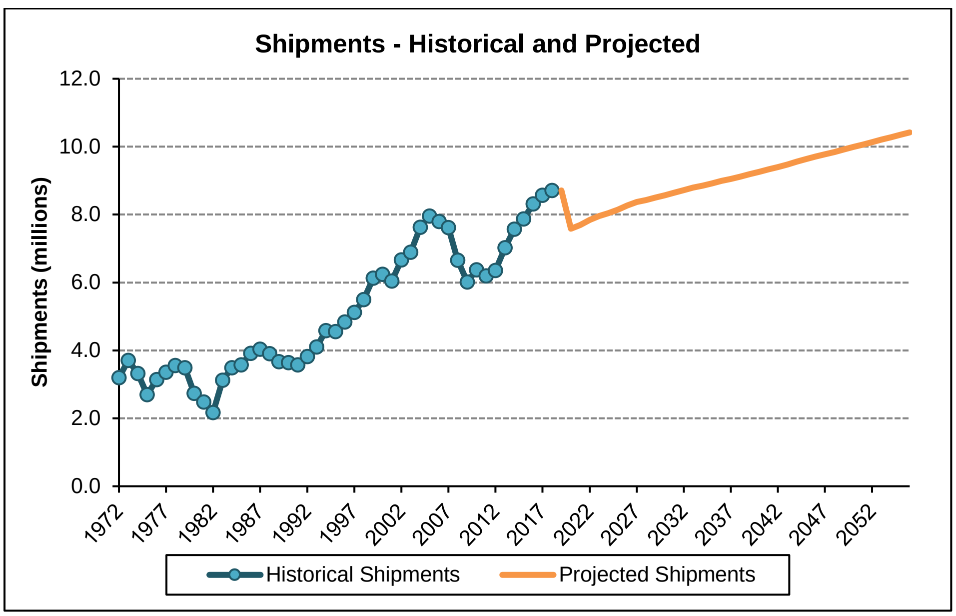

Figure 9.4.1 Dishwashers: Historical and No-New Standards Shipments Projection (1972-2056)

9.5 IMPACT OF POTENTIAL STANDARDS ON SHIPMENTS DEMAND

DOE's analysis generally finds that higher efficiency products have a higher purchase price and installed cost (where relevant). Economic literature suggests that higher first costs will have an effect on consumers' product purchase decisions.

DOE conducted a literature review and an analysis of appliance price and efficiency data to estimate the effects on product shipments from increases in product purchase price and product energy efficiency.[13] Existing studies of appliance markets suggest that the demand for durable goods, such as appliances, is price-inelastic. The evidence indicates that appliances are a normal good, so that rising incomes increase the demand for appliances. In addition, studies indicate that consumer behavior reflects relatively high implicit discount rates[a] when comparing appliance prices and appliance operating costs.

DOE used the available data for the period 1989 - 2009 on household appliance purchases to evaluate broad market trends and conduct simple regression analyses. These data indicate that there has been a rise in appliance shipments and a decline in appliance purchase price and operating costs over the time period. Other relevant variables include household income, which has also risen during this time, new residential construction, and stock retirements of existing appliances. Using aggregated data for five residential appliances, DOE performed a regression analysis to estimate the price elasticity of appliance demand and the shipments response (elasticity) to appliance efficiency.

DOE's regression analysis estimated a price elasticity of demand of -0.45. Thus, a price increase of 10 percent would result in a shipments decrease of 4.5 percent, *all other factors held constant*. The efficiency elasticity is estimated to be +0.2 (*i.e.*, a 10 percent efficiency improvement would result in a shipments increase of 2%, *all else equal*).

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

Because DOE's projections of shipments and national impacts from potential standards consider a 30-year period, it is necessary to consider how price elasticity evolves in the years after a new standard takes effect. DOE considered the price elasticity developed above to be a short-term value, but was unable to identify sources specific to appliances sufficient to model differences in short- and long-term price elasticities. Therefore, to estimate how the price

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[a] 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.

elasticity changes through time, DOE relied on a study pertaining to automobiles.[14,b] This study shows that the price elasticity of demand for automobiles declines in the years following a change in purchase price, a trend also observed in appliances and other durables.[15] As time passes since the change in purchase price, the price elasticity becomes more inelastic until it reaches a terminal value around the tenth year after the price change. Table 9.5.1 shows the relative change over time in the price elasticity of demand for automobiles. DOE developed a time series of price elasticity for residential appliances based on the relative change over time in the price elasticity of demand for automobiles.

Table 9.5.1 Change in Relative Price Elasticity following a Change in Purchase Price

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

DOE estimated total shipments in each higher efficiency case by incorporating the effects of the price elasticity and "efficiency elasticity" into the shipments projection for the no-new-standards case. Note that in the equation below, the price elasticity is a function of the year because it changes with time.

$$Ship_{STD\_p}(j) = (Rpl_{BASE\_p}(j) + M_{BASE\_p}(j)) \times (1 - e_p(j) \times \Delta P(j) + \varepsilon_e \times \Delta OC(j))$$

Where:

$Ship_{STD\_p}(j)$ = total shipments of product p in year j under the potential standards case,
$Rpl_{BASE\_p}(j)$ = units of product p retired and replaced in year j under the no-new-standards case,
$M_{BASE\_p}(j)$ = new owners of product p in year j under the no-new-standards case,
$e_P(j)$ = price elasticity in year j (equals -0.45 for year 1),
ε_e = efficiency elasticity (+0.2)
$\Delta P(j)$ = change in price due to a higher efficiency level in year j, and
$\Delta OC(j)$ = change in operating costs due to a higher efficiency level in year j.

9.6 SHIPMENTS PROJECTION

This section compares the shipments projected under the no-new-standards case with those projected for all the efficiency levels (ELs) considered for dishwashers.

Figure 9.6.1 shows total projected annual shipments of dishwashers in the no-new-standards case and under each EL.

[b] DOE relies on this study for efficiency scaling factors because it provides the greatest detail out of all the available studies on price elasticity over time.

Table 9.6.1 Projected Annual Shipments of Standard-Sized and Compact Dishwashers

Efficiency Level	Annual Shipments (million units)				
	2021	2030	2040	2050	2056
No-New-Standard case	7.84	8.65	9.33	10.06	10.49
1	7.84	8.65	9.33	10.06	10.49
2	7.84	8.61	9.33	10.06	10.49
3	7.84	8.35	9.16	9.95	10.41
4	7.84	8.09	8.99	9.78	10.25

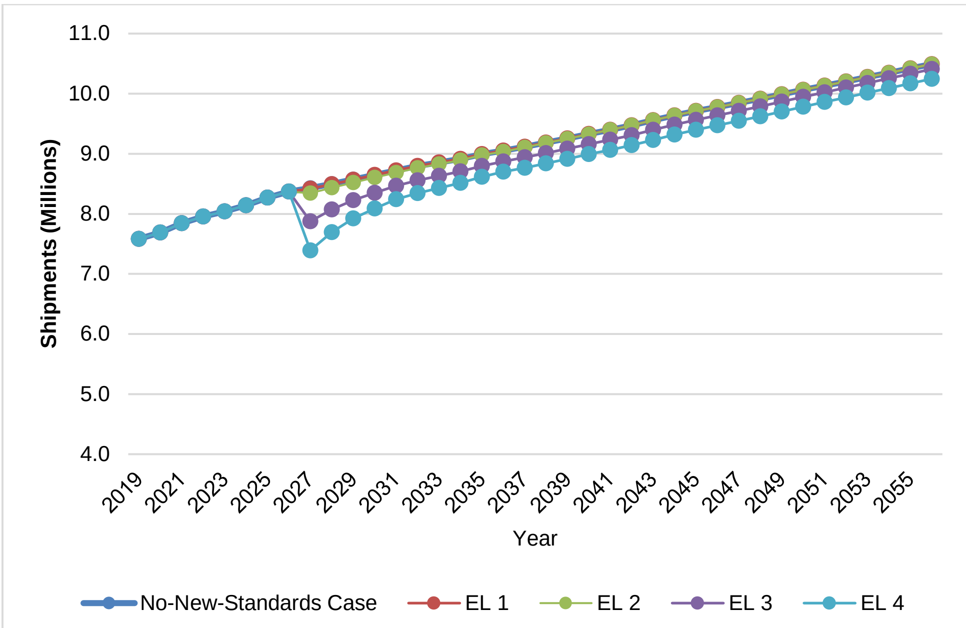

Figure 9.6.1 Projected Standard-Sized and Compact Dishwasher Shipments in the No-New-Standards and Each Efficiency Level

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CHAPTER 10. NATIONAL IMPACT ANALYSIS

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CHAPTER 10. NATIONAL IMPACT ANALYSIS

10.1 INTRODUCTION

This chapter describes the method the U.S. Department of Energy's (DOE's) used to conduct a national impact analysis (NIA) of potential energy efficiency standard levels for dishwashers, and the results of the analysis. For each potential standard level, DOE evaluated the following impacts: (1) national energy and water savings (NES and NWS), (2) monetary value of the energy and water savings for consumers of dishwashers, (3) increased total installed costs, and (4) the net present value (NPV) of energy and water savings, which is the difference between the savings in operating costs and the increase in total installed costs.

DOE determined both the NES and NPV for all the efficiency levels (ELs) considered for dishwashers. DOE performed all calculations using a Microsoft Excel spreadsheet model, which is accessible on the Internet at www.eere.energy.gov/buildings/appliance_standards/. The spreadsheet combines the calculations for determining the NES and NPV for each considered NIA model, combine the calculations for determining the NES and NPV for each considered EL with input from the appropriate shipments model. Details and instructions for using the NIA model are provided in appendix 10A of this technical support document (TSD).

The NIA calculation starts with the shipments model. Chapter 9 of this TSD provides a detailed description of the shipments model that DOE used to project future purchases of dishwashers, and how potential standards might affect the level of shipments.

The analysis is described more fully in subsequent sections. The descriptions include overviews of how DOE performed each model's calculations and summaries of the major inputs. Table 10.1.1 summarizes inputs to the NIA model.

Table 10.1.1 Inputs to Calculating National Energy Savings and Net Present Value

Input	Data Description
Shipments	Annual shipments from shipments model (chapter 9).
Compliance date of standard	2027.
Analysis period	For products shipped between 2027 through 2056.
Energy efficiency in no-new-standards case	Annual growth rate of 0.25 percent based on 2020 efficiency levels.
Energy efficiency in higher efficiency cases	Roll-up/shift scenario.
Annual energy consumption per unit	Annual weighted-average values as a function of shipments-weighted unit energy consumption (UEC).
Total installed cost per unit	Annual weighted-average values as a function of efficiency distribution.

Input	Data Description
Energy cost per unit	Annual weighted-average values as a function of the annual UEC and energy prices (see chapter 8).
Repair and maintenance costs per unit	Annual values as a function of efficiency level (see chapter 8).
Trend in energy prices	Based on Energy Information Administration's (EIA's) Annual Energy Outlook (*AEO*) 2021 Reference case (see chapter 8).
Energy site-to-primary factor	A time-series conversion factor that accounts for energy used to generate electricity.
Full-fuel-cycle multiplier	Developed to include the energy consumed in extracting, processing, and transporting or distributing primary fuels.
Discount rate	3 percent and 7 percent.
Present year	Future expenses are discounted to 2021.

10.1.1 Efficiency Levels

DOE analyzed the benefits and burdens of four ELs for the standard-sized dishwashers product class, and two ELs for the compact dishwasher product class. The ELs are equal to the ELs analyzed in the life-cycle cost and payback period analysis (chapter 8).

EL 4 represents, where possible, the maximum technologically feasible (max-tech) improvements in energy and water efficiency for standard dishwashers. EL 3 represents the next highest EL for standard-sized dishwashers. EL 2 represents an intermediate level between EL 1 and EL 3 for standard-sized dishwashers, and the max-tech level for compact dishwashers. EL 1 represents and intermediate level between the baseline and EL 2 for both standard and compact dishwashers. Table 10.1.2 presents the EL numbers and corresponding efficiencies for dishwashers.

Table 10.1.2 Efficiency Levels for Dishwashers

	Standard-Sized		Compact	
EL	**Annual Energy Use*** **(kWh/year)**	**Water Use (gallons/cycle)**	**Annual Energy Use (kWh/year)**	**Water Use (gallons/cycle)**
0	260	5.00	176	3.50
1	230	3.50	173	3.10
2	222	3.30	123	1.60
3	204	3.20		
4	192	2.40		

*Based on 185 cycles per year and improved water heating efficiency. See chapter 8 for more details.

10.2 PROJECTED ENERGY EFFICIENCY TREND

This section describes the method DOE used to forecast the energy efficiencies of dishwashers under the no-new-standards case (without new energy efficiency standards) and for each efficiency level as a potential higher efficiency case. The trend in forecasted energy efficiency is a key factor in estimating NES and NPV for the no-new-standards case and each efficiency level. For calculating the NES, per-unit average annual energy consumption is a direct function of product energy efficiency. For the NPV, both the per-unit total installed cost and the per-unit annual operating cost are dependent on product energy efficiency. This section provides efficiency distributions for both product classes.

To assign a no-new-standards case energy efficiency distribution for 2027 (the year a potential standard would become effective), DOE developed an efficiency distribution for dishwashers based on DOE's Compliance Certification Database (CCMS) for dishwashers.[1] DOE used an annual improvement rate of 0.25 percent to project a future energy efficiency increase for the no-new-standards case. Figure 10.2.1 presents the current no-new-standards case efficiency distribution and the no-new-standards case efficiency projected for 2027 for standard-sized and compact dishwashers. The leftmost marker for each product class represents the shipment weighted annual energy use (SWAEU) calculated from CCMS as described above. DOE calculated by extrapolation that, in the no-new-standards case, the SWAEU will decrease from 228 kWh/year in 2027 to 212 kWh/year in 2056 for standard-sized dishwashers, and from 168 kWh/year to 156 kWh/year in 2056 for compact dishwashers.

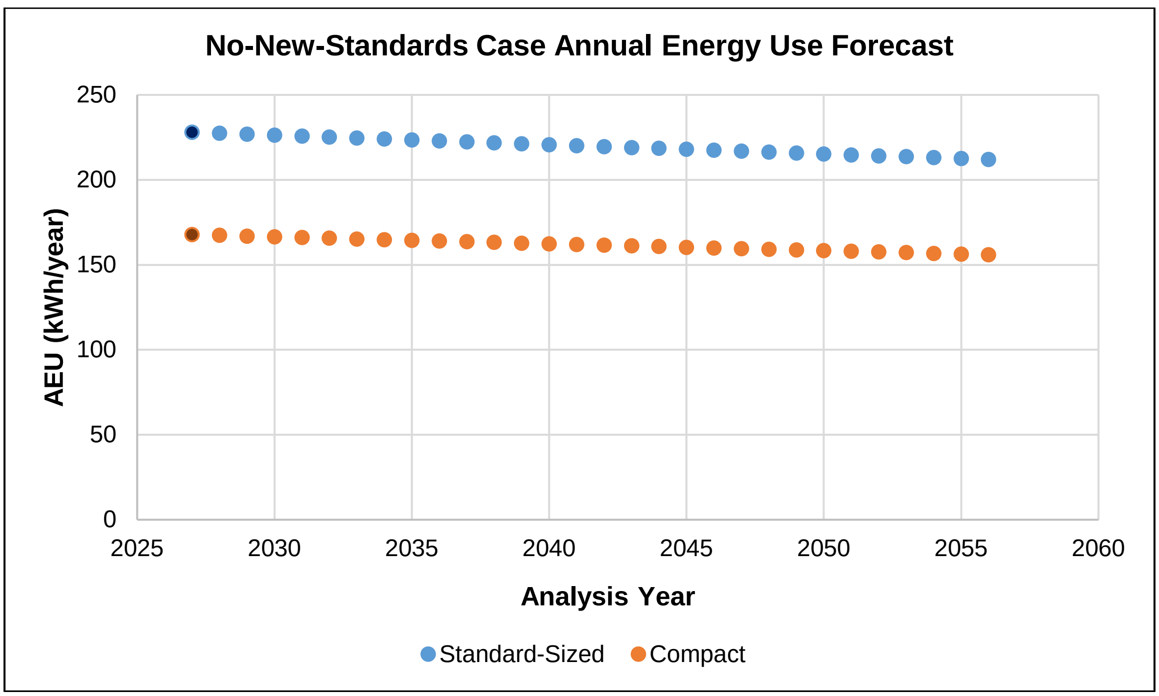

Figure 10.2.1 Current and Projected No-New-Standards Case Trend in Annual Energy Use for Dishwashers

To determine the potential standards-case forecasted efficiencies, DOE assumed a "roll-up" scenario to establish the shipment-weighted efficiency for the year that potential standards are assumed to take effect (2027). DOE assumed that product efficiencies in the no-new-standards case that did not meet the potential standard under consideration would “roll up” to meet the new standard level. DOE also assumed that all product efficiencies in the no-new-standards case that exceeded the potential standard would not be affected. Taking the market share projections for 2027 as a starting point, DOE projected potential standards-case efficiencies based on assumptions regarding future efficiency improvements.

Table 10.2.1 and Table 10.2.2 show the product efficiency distributions for the no-new-standards case and each EL in 2027, based on the annual energy use (AEU) and per-cycle water use for each product class that DOE is considering. The tables also present the SWAEU and shipment-weighted water use (SWWU) associated with the no-new-standards case and each EL.

Table 10.2.1 Standard-Sized Dishwashers: 2027 Market Share Efficiency Distributions for No-New-Standards and Higher Efficiency Cases

Efficiency Level	AEU (kWh/year)	Water Use (gal/cycle)	Market Share Efficiency Distribution (%)				
			No-New-Standards Case	Efficiency Level			
				1	2	3	4
Baseline	260	5.00	8.2	0.0	0.0	0.0	0.0
1	230	3.50	63.4	71.5	0.0	0.0	0.0
2	222	3.30	17.7	17.7	89.2	0.0	0.0
3	204	3.20	9.2	9.2	9.2	98.4	0.0
4	192	2.40	1.6	1.6	1.6	1.6	100.0
SWAEU (kWh/year)			228	226	220	204	192
SWWU (gal/cycle)			3.55	3.42	3.28	3.19	2.40

Table 10.2.2 Compact Dishwashers: 2027 Efficiency Distributions for No-New-Standards and Higher Efficiency Cases

Efficiency Level	AEU (kWh/year)	Water Use (gal/cycle)	Market Share Efficiency Distribution (%)		
			No-New-Standards case	Efficiency Level	
				1	2
Baseline	176	3.50	28.3	0.0	0.0
1	173	3.10	60.0	11.7	0.0
2	123	1.60	11.7	88.3	100.0
SWAEU (kWh/year)			168	167	123
SWWU (gal/cycle)			3.04	1.78	1.60

10.3 NATIONAL ENERGY AND WATER SAVINGS

DOE calculated the NES and NWS difference between the no-new-standards case and each potential higher efficiency case for dishwashers. DOE’s analysis considers the energy and water use over the lifetime of products shipped in the 30 year period beginning in the compliance year, 2027. The analysis period ends when all of the products shipped in the 30-year period are retired from the stock.

DOE calculates NES and NWS expressed as:

- Site energy: Accounts for the energy used at the dishwasher point of use,
- Primary energy: Includes the energy used to generate electricity,
- Full-fuel-cycle (FFC) energy: Includes the energy consumed in extracting, processing, and transporting or distributing primary fuels, and
- Gallons of water: Accounts for the water consumed at the dishwasher point of use.

10.3.1 Definitions

DOE calculates annual NES and NWS for a given year as the difference between the national annual energy consumption (AEC) or national annual water consumption (AWC) in a no-new-standards case and a higher efficiency case. The following equation shows that DOE calculated national annual energy and water savings as the difference between two projections: a no-new-standards case and a higher efficiency case. Positive values of NES represent energy savings (*i.e.*, national annual energy consumption under a higher efficiency case is less than the no-new-standards case).

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

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 2027 and ends after 30-year analysis period (2056). The calculation is represented by the following equations.

$$NES_{cumulative} = \sum NES_y$$

$$NWS_{cumulative} = \sum NWS_y$$

In determining national AEC, DOE first calculates AEC at the site. DOE calculates the national annual site 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). National annual energy consumption is calculated using the following equation.

$$AEC\text{-}s_y = \sum STOCK_V \times UEC_V$$

Where:

AEC_{-S} = National annual energy consumption each year in quadrillion British thermal units (quads) summed over vintages of the product stock, $STOCK_V$.

$STOCK_V$ = Stock of product (millions of units) of vintage V surviving in the year for which DOE calculated annual energy consumption.

UEC_V	=	Unit 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 of this TSD, to avoid including savings attributable to shipments displaced (units not purchased) because of potential standards, DOE used the projected higher efficiency case shipments and the higher efficiency case stock, to calculate the AEC for the no-new-standards case.

10.3.2 Annual Energy and Water Consumption per Unit

DOE developed per-unit annual energy and water consumption as a function of product energy and water efficiency for dishwashers (see chapter 7 of this TSD). DOE used the SWAEUs and SWWUs presented in Table 10.2.1 and Table 10.2.2, along with the estimates of annual energy and water consumption by efficiency level, to estimate the shipment-weighted average annual per-unit energy and water consumption under the no-new-standards and higher efficiency cases. The average annual per-unit energy and water consumptions projected for 2027 for each product class and EL are shown in Table 10.3.1.

Table 10.3.1 Shipment-Weighted Average Annual Per-Unit Energy and Water Consumption

Product Class		Efficiency Level			
Standard-Sized	**Baseline**	**1**	**2**	**3**	**4**
Annual energy use (kWh/yr)	260	230	222	204	192
Avg. elec use (kWh/yr)	173	169	164	148	150
Avg. gas use (MMBtu/yr)	0.35	0.24	0.23	0.22	0.17
Avg. oil use (MMBtu/yr)	0.02	0.01	0.01	0.01	0.01
Water use (1,000 gal/yr)	0.92	0.64	0.60	0.59	0.44
Compact	**Baseline**	**1**	**2**		
Annual energy use (kWh/yr)	176	173	123		
Avg. elec use (kWh/yr)	115	119	95		
Avg. gas use (MMBtu/yr)	0.24	0.22	0.11		
Avg. oil use (MMBtu/yr)	0.01	0.01	0.01		
Water use (1,000 gal/yr)	0.64	0.57	0.29		

As described in chapter 9, DOE forecasts an initial drop in dishwasher shipments in response to an assumed increase in purchase price attributable to potential 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. 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.[2] A United Kingdom (UK) study in 2006 quantified the energy and water consumption of washing by hand as a function of place settings.[3] 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 by machine. More recently, the U.S. Geological Service (USGS) provided estimates for water consumption from dishwashers as compared to water consumption from doing dishes by hand.[4] The USGS reported that dishwashers typically use between 6 and 16 gallons per cycle, and that dishwashing by hand uses between 9 and 27 gallons per cycle. Using this source, DOE assumed that hand washing consumed 200 percent of the water used in machine washing.

Table 10.3.2 summarizes the average results from the Bonn and UK studies, the USGS, and the estimates DOE incorporated in its NIA model to quantify the energy and water impacts of consumers who forego purchasing a dishwasher.

Table 10.3.2 Impacts on Energy and Water Use of Hand Washing Compared to Machine Washing

Source	Increase for Hand Washing Relative to Machine Washing (%)	
	Energy Use	**Water Use**
Bonn University*	67	450
UK†	210	250
USGS	NA	150-450
DOE estimate	140	200

Sources: *Bonn University, 2005.[2] †UK, Market Transformation Programme, 2006.

10.3.3 Shipments and Product Stock

As described in chapter 9, DOE forecasted shipments of dishwashers under the no-new-standards case and all higher efficiency cases. Because the increased total installed cost of more efficient products may cause some customers to forego purchasing the product, shipments forecasted under the higher efficiency cases may be lower than under the no-new-standards case. DOE believes it would be inappropriate to count energy savings that result from shipments that decline because of higher efficiency cases (i.e. potential standards). Therefore, each time a higher efficiency case was compared with the no-new-standards, DOE used shipments associated with that particular higher efficiency case. As a result, all of the calculated energy savings are attributable to higher energy efficiencies in the potential standards cases.

The product stock in a given year is the number of products shipped from earlier years that survive in that year. The shipments model tracks the number of units shipped each year and its results are an input into the NIA. 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 called the survival function. Chapter 9 of this TSD provides additional details about the survival functions that DOE used for dishwashers.

10.3.4 National Annual Energy and Water Consumption

The AEC and AWC are the products 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 on a per-unit level, DOE used the following equation to calculate the annual energy consumption; the equation for water consumption is the similar to the equation for energy consumption but calculates water consumption.

$$AEC\text{-}s_y = \sum STOCK_V \times UEC_V$$

To determine national annual energy consumption, DOE calculated the annual energy consumption at the site and then applied conversion factors to calculate primary and full-fuel-cycle energy consumption, respectively, as described in the next section. Annual water consumption is calculated at the site without the application of conversion factors.

10.3.5 Site-to-Primary Energy Conversion Factors

The site-to-primary energy conversion factors are multiplicative factors used to convert site energy consumption into primary or source energy consumption, and are expressed in quads. For electricity from the grid, primary energy consumption is equal to the heat content of the fuels used to generate that electricity.[a] For natural gas and fuel oil, primary energy is equivalent to site energy.

DOE used annual conversion factors based on the version of the National Energy Modeling System (NEMS)[b] that corresponds to *AEO 2021*.[1] The factors are marginal values, which represent the response of the national power system to incremental changes in consumption. The conversion factors change over time in response to projected changes in generation sources (the types of power plants projected to provide electricity). Specific conversion factors were generated from NEMS for a number of end uses in each sector. Appendix 10B describes how DOE derived these factors.

Table 10.3.3 and Figure 10.3.1 show the conversion factors used for dishwashers. DOE used the factors corresponding to other uses in the residential sector The value *AEO 2021* reported for 2050 (the last year available in *AEO 2021*) was extrapolated through the end of the analysis period.

Table 10.3.3 Site-to-Primary Conversion Factors (MMBtu primary/MWh site) Used for Dishwashers

	2027	2030	2035	2040	2045	2050+
Residential (Other Uses)	9.320	9.259	9.258	9.206	9.154	9.134

[a] For electricity sources such as nuclear energy and renewable energy, the primary energy is calculated using the convention used by EIA (see appendix 10B).

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

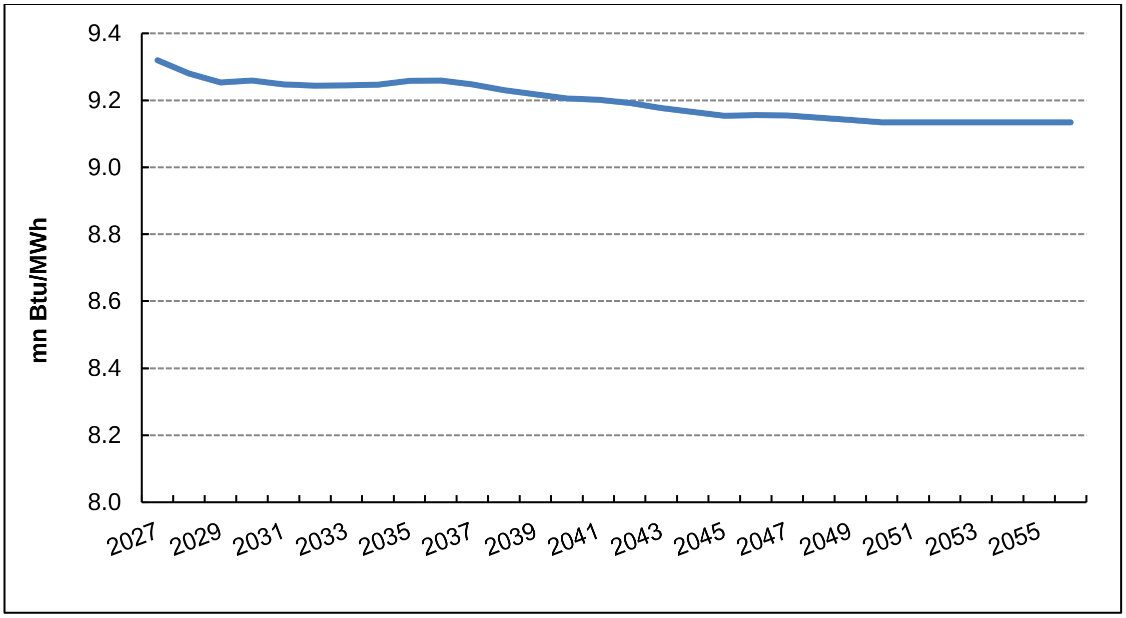

Figure 10.3.1 Site-to-Power-Plant Energy Use Conversion Factors for Dishwashers

10.3.6 Full-Fuel-Cycle Multipliers

DOE uses FFC multipliers to account for the energy consumed in extracting, processing, and transporting or distributing primary fuels, which are referred to as upstream activities. DOE developed FFC multipliers using data and projections generated for *AEO 2021*. *AEO 2021* provides information about the energy system, including projections of future oil, natural gas, and coal supplies; energy use for oil and gas field and refinery operations; and fuel consumption and emissions related to electric power production. The information can be used to define a set of parameters that represent the energy intensity of energy production. For natural gas, the FFC multiplier includes leakage in upstream activities

The method used to calculate FFC energy multipliers is described in appendix 10B of this TSD. Table 10.3.4 shows the FFC energy multipliers used for dishwashers for selected years. The 2050 values were used for the years after 2050.

Table 10.3.4 Full-Fuel-Cycle Energy Multipliers (Based on *AEO 2021*)

	2027	2030	2035	2040	2045	2050+
Electricity	1.041	1.039	1.038	1.037	1.038	1.037
Natural gas	1.096	1.098	1.098	1.098	1.100	1.099
Petroleum fuels	1.171	1.171	1.173	1.179	1.180	1.185

10.4 NET PRESENT VALUE

DOE calculated the NPV of the increased product cost and reduced operating costs associated with the difference between the no-new-standards case and each potential standards case for each dishwasher product class.

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,[c] and
PVC = present value of increased total installed costs (including purchase price and installation costs).

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

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

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

Where:
OCS = total annual-savings in operating costs each year summed over vintages of the stock, $STOCK_V$,
DF = discount factor in each year,
TIC = total annual increases in installed cost summed over vintages of the stock, $STOCK_V$, and
y = year in the forecast.

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

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

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

Where:
OCS_y = operating cost savings per unit in year y,
$STOCK_V$ = 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 as a new unit,
TIC_y = total increase in installed product cost in year y.
$SHIP_y$ = shipments of product in year y, and
$UTIC_y$ = annual per-unit increase in installed product cost in year y.

[c] The operating cost includes energy, water, repair, and maintenance.

DOE determined the total increased product installed cost for each year from 2027 to 2056. DOE determined the present value of operating cost savings for each year from 2027 to the year when all units purchased in 2056 are estimated to retire (2115). DOE calculated installed cost and operating cost savings as the difference between a higher efficiency case and a no-new-standards case. As with the calculation of NES, DOE did not use no-new-standards case shipments to calculate total annual installed costs and operating cost savings. As with the NES calculation, to avoid including savings attributable to shipments displaced by consumers deciding not to buy higher-cost products, DOE used the potential standards-case projection of shipments and, in turn, the potential standards-case stock, to calculate these quantities.

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 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 no-new-standards case and a higher efficiency case) multiplied by the shipments forecasted for the potential standards case. As with the calculation of NES, DOE did not use no-new-standards 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 potential standards-case projection of shipments and, in turn, the potential 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 dishes by hand.

The *total annual operating cost savings* are equal to the change in annual operating costs (difference between no-new-standards case and higher efficiency case) per unit multiplied by the shipments forecasted in the higher efficiency case. DOE did not calculate operating cost savings using no-new-standards case shipments. Annual operating costs include repair and maintenance costs, as well as the primary costs for energy and water.

10.4.3 Total Installed Cost

The per-unit total installed cost is a function of product energy efficiency. Therefore, DOE used the shipments-weighted efficiencies of the no-new-standards case and higher efficiency cases described in section 10.2, in combination with the total installed costs developed in chapter 8, to estimate the shipments-weighted average annual per-unit total installed cost under the various cases. Table 10.4.1 shows the shipment-weighted average total installed cost for dishwsahers in the residential sector in 2027 based on the efficiencies that correspond to the no-new-standards case and each higher efficiency case.

Table 10.4.1 Shipment-Weighted Average Per-Unit Total Installed Costs for No-New-Standards and Higher Efficiency Cases (2020$)

Standard-Sized					
	Efficiency Level				
	No-New-Standard Case	**1**	**2**	**3**	**4**
SWAEU	228	226	220	204	192
Shipments-Weighted Avg. Product Cost (2020$)	$480	$482	$492	$552	$617
Compact					
	Efficiency Level				
	No-New-Standard Case	**1**	**2**		
SWAEU	168	167	123		
Shipments-Weighted Avg. Product Cost (2020$)	$492	$492	$543		

As discussed in chapter 8 of this TSD, DOE developed a price trend based on an experience curve for miscellaneous household appliances. DOE used the price trend to project the prices of dishwashers sold in each year of the forecast period (2027-2056). DOE applied the same values to project prices for each product class at each EL. For dishwashers, the estimated average annual rate of price decline is 0.94 percent. To investigate the effect of different product price projections on the consumer NPV for various efficiency levels, DOE also considered two alternative price trends. Details on how those alternative price trends were developed are documented in appendix 10C of this TSD, which also presents the results of DOE’s analysis.

The total annual increase in installed cost for a given higher efficiency 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.

Per-unit annual operating costs include the annual costs for energy and water, repair, and maintenance. 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 potential 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 of this TSD, to estimate energy prices in future years, DOE multiplied the recent electricity prices by a projection of annual national-average residential electricity prices.

10.4.4 Discount Factor

DOE multiplies monetary values in future years by a discount factor to determine present values. The discount factor (DF) is described by the equation:

$$DF = \frac{1}{(1+r)^{(y-y_p)}}$$

Where:

r = discount rate,

y = year of the monetary value, and

y_P = year in which the present value is being determined.

DOE uses both a 3-percent and a 7-percent real discount rate when estimating national impacts. Those discount rates were applied in accordance with the Office of Management and Budget (OMB)'s guidance to Federal agencies on developing regulatory analyses (OMB Circular A-4, September 17, 2003, and section E., "Identifying and Measuring Benefits and Costs," therein). DOE defined the present year as 2021.

10.4.4.1 Present Value of Increased Installed Costs and Savings

The present value of increased installed costs is the annual increase in installed cost for each year (*i.e.,* the difference between the higher efficiency case and no-new-standards case), discounted to the present and summed over the forecast period (2027-2056). The increase in total installed costs refers to both product and installation costs associated with the higher energy efficiency of products purchased under a higher efficiency case compared to the no-new-standards case.[d] DOE calculated annual increases in installed cost as the difference in total cost of new products installed each year, multiplied by the shipments in the higher efficiency case.

The present value of operating cost savings is the annual savings in operating cost (the difference between the no-new-standards case and a standards case) discounted to the present and summed from the compliance year, 2027, to the time when the last unit installed in 2056 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 no-new-standards 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.

[d] 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.

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 (*www.eere.energy.gov/buildings/appliance_standards/*). Details and instructions for using the spreadsheet are provided in appendix 10A.

10.5.1 National Energy and Water Savings Calculations

This section provides results of NES and NWS calculations for the higher efficiency cases analyzed for both product classes. NES results, which are cumulative for the shipments period from 2027 to 2056, represent primary and FFC energy savings, and site water savings. Because DOE based the inputs to the NIA model on weighted-average values, results are discrete point values, rather than a distribution of values as produced by the life-cycle cost and payback period analysis.

Table 10.5.1 shows the NES and NWS results for all the ELs analyzed, for standard and compact dishwashers.

Table 10.5.1 Cumulative National Energy and Water Savings

EL (PC1)	EL (PC2)	Site Energy Savings (quads)	Source Energy Savings (quads)	Full-Fuel-Cycle Energy Savings (quads)	National Water Savings (trillion gallons)
1	1	0.003	0.003	0.004	0.007
2	1	0.028	0.051	0.054	0.035
3	1	0.187	0.451	0.470	0.053
4	2	0.397	0.638	0.678	0.589

10.5.2 Net Present Value

This section provides results of calculating the NPV of consumer benefits for each EL considered for dishwashers. Results were calculated for the nation as a whole. Results, which are cumulative, are shown as the discounted value of the net savings in dollar terms. DOE based the inputs to the NIA model on weighted-average values, yielding results that are discrete point values, rather than a distribution of values as in the LCC and payback period analysis.

The present value of increased total installed costs is the cost difference between the higher efficiency case and no-new-standards case discounted to the present and summed over the period in which DOE evaluated the impacts of standards (from the effective date of standards in 2027 to 2056). 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 2056, operating costs include energy and water consumed until the last unit is retired from service.

Table 10.5.2 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 discount rate. A negative NPV indicates that the costs of a standard at a given efficiency level exceed the savings.

Table 10.5.2 Discounted Cumulative Net Present Value of Consumer Savings

Efficiency Level		Net Present Value	
Standard-Sized Dishwasher	**Compact Dishwasher**	**7 percent Discount Rate (billion 2020$)**	**3 percent Discount Rate (billion 2020$)**
1	1	0.02	0.05
2	1	0.00	0.14
3	1	(2.03)	(3.03)
4	2	(3.99)	(5.73)

REFERENCES

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CHAPTER 11. CONSUMER SUBGROUP ANALYSIS

11.1 OVERVIEW

The consumer subgroup analysis evaluates potential impacts from new standards on any identifiable groups of consumers who may be disproportionately affected by a national energy conservation standard. When appropriate, DOE will conduct this analysis as one of the analyses for the notice of proposed rulemaking (NOPR) should DOE determine to issue a NOPR. DOE will accomplish this, in part, by analyzing the life-cycle costs (LCCs) and payback periods (PBPs) for the identified consumer subgroups. DOE will evaluate variations in regional energy prices, energy use, and installation and operational costs that might affect the impacts of a standard to consumer subgroups. To the extent possible, DOE will obtain estimates of each input parameter's variability and will consider this variability in its calculation of consumer impacts.

DOE will determine the impact on consumer subgroups using the LCC Spreadsheet Model. The standard LCC analysis (described in chapter 8) focuses on the consumers that use dishwashers. DOE can use the LCC Spreadsheet Model to analyze the LCC for any subgroup by sampling only that subgroup. (Chapter 8 explains in detail the inputs to the model used in determining LCC and PBPs.)

CHAPTER 12. PRELIMINARY MANUFACTURER IMPACT ANALYSIS

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CHAPTER 12. ANOPR MANUFACTURER IMPACT ANALYSIS

12.1 INTRODUCTION

The purpose of the manufacturer impact analysis (MIA) is to identify and quantify the impacts of any potential new and/or amended energy conservation standards on manufacturers. The Process Rule[1] provides guidance for conducting this analysis with input from manufacturers and other interested parties. The U.S. Department of Energy (DOE) will apply this methodology to its evaluation of amended energy conservation standards for dishwashers. DOE will consider a wide range of quantitative and qualitative industry impacts. For example, a particular standard level could require changes to manufacturing practices, production equipment, raw materials, *etc*. DOE will identify and analyze these manufacturer impacts during the notice of proposed rulemaking (NOPR) stage of the analysis.

DOE announced changes to the MIA format through a report issued to Congress in January 2006 entitled "Energy Conservation Standards Activities." (as required by section 141 of the Energy Policy Act of 2005 (EPACT 2005))[2] Previously, DOE did not report any MIA results before the NOPR phase; however, under this new format, DOE collects, evaluates, and reports preliminary information and data.

12.2 METHODOLOGY

DOE conducts the MIA in three phases, and further tailors the analytical framework based on the comments it receives. In Phase I, DOE creates an industry profile to characterize the industry and identify important issues that require consideration. In Phase II, DOE prepares an industry cash-flow model and considers what information it might gather in manufacturer interviews. In Phase III, DOE interviews manufacturers and assesses the impacts of standards both quantitatively and qualitatively. DOE assesses industry and subgroup cash flows and industry net present value (INPV) using the Government Regulatory Impact Model (GRIM). DOE then assesses impacts on competition, manufacturing capacity, employment, and cumulative regulatory burden (CRB).

12.2.1 Phase I: Industry Profile

In Phase I of the MIA, DOE collects pertinent qualitative and quantitative information about the market and manufacturer financials. This includes research and development (R&D) expenses; selling, general, and administrative (SG&A) expenses; capital expenditures; property, plant, and equipment expenses; tax rate; and depreciation rate for dishwasher manufacturers, as

[1] On December 13, 2021 the Department of Energy published a Process Rule clarifying the procedures used to evaluate the economic justification of new or amended energy conservation standards. 86 FR 70892.

[2] This report is available on the DOE website at https://www1.eere.energy.gov/buildings/appliance_standards/pdfs/congressional_report_013106.pdf

well as wages, employment, and industry costs for dishwashers. Sources of information include reports published by industry groups, trade journals, the U.S. Census Bureau, and Securities Exchange Commission (SEC) 10-K filings, and publications from prior DOE dishwasher rulemakings. The initial estimates of financial parameters are presented in section 12.3.1.

In addition, DOE develops a comprehensive manufacturer list, develops market share estimates, and evaluates consolidation trends, as presented in the preliminary market and technology assessment. Characterizations of the current product offerings and market efficiency distributions are presented in the preliminary engineering analysis and shipment analysis.

12.2.2 Phase II: Industry Cash Flow Analysis and Interview Guide

Phase II activities occur after publication of the preliminary analysis. In Phase II, DOE performs a draft industry cash-flow analysis and prepares an interview guide for manufacturer interviews.

12.2.2.1 Industry Cash Flow Analysis

DOE uses the GRIM to analyze the financial impacts of potential new and/or amended energy conservation standards. The implementation of these standards may require manufacturer investments (e.g., conversion costs), raise manufacturer production costs (MPCs), and/or affect revenue possibly through higher prices and lower shipments. The GRIM uses a suite factors to determine annual cash flows for the years leading up to the compliance date of new and/or amended energy conservation standards and for 30 years after the compliance date. These factors include industry financial parameters, manufacturer production costs, conversion costs, shipment forecasts, and price forecasts. DOE compares the GRIM results for potential standard levels against the results for the no-new-standards case, in which energy conservation standards are not amended. The financial impact of analyzed amended energy conservation standards is the difference between the two sets of discounted annual cash flows.

12.2.2.2 Interview Guide

DOE conducts interviews with manufacturers to gather information on the effects new and/or amended energy conservation standards could have on revenues and finances, direct employment, capital assets, and industry competitiveness. In Phase II, before the interviews, DOE drafts and distributes an interview guide that will help identify the impacts of potential standard levels on individual manufacturers or subgroups of manufacturers within the dishwasher industry. The interview guide covers financial parameters, MPCs, shipment projections, market share, product mix, conversion costs, markups and profitability, assessment of the impact on competition, manufacturing capacity, and other relevant topics.

12.2.3 Phase III: Industry and Subgroup Analysis

Phase III activities occur after publication of the preliminary analysis. These activities include manufacturer interviews; revision of the industry cash flow analysis; manufacturer subgroup analyses, where appropriate; an assessment of the impacts on industry competition, manufacturing capacity, direct employment, and the cumulative regulatory burden; and other qualitative impacts.

12.2.3.1 Manufacturer Interviews

DOE supplements the information gathered in Phase I and the cash-flow analysis constructed in Phase II with information gathered through interviews with manufacturers and written comments from stakeholders during Phase III.

DOE conducts detailed interviews with manufacturers to gain insight into the potential impacts of any amended energy conservation standards on sales, direct employment, capital assets, and industry competitiveness. Generally, interviews are scheduled well in advance to provide every opportunity for key individuals to be available for comment. Although a written response to the questionnaire is acceptable, DOE prefers interactive interviews, if possible, which help clarify responses and provide the opportunity to identify additional issues.

Non-disclosure agreements allow DOE contractors to consider confidential or sensitive information in the decision-making process. Confidential information, however, is not made available in the public record. At most, sensitive or confidential information may be aggregated and presented in the form of industry-wide representations.

12.2.3.2 Revised Industry Cash Flow Analysis

During interviews, DOE requests information about profitability, necessary plant changes, and other manufacturing impacts. Following any such interviews, DOE revises the preliminary cash-flow prepared in Phase II based on the feedback it receives during interviews.

12.2.3.3 Manufacturer Subgroup Analysis

The use of average cost assumptions to develop an industry cash flow estimate may not adequately assess differential impacts of potential amended energy conservation standards among manufacturer subgroups. Smaller manufacturers, niche players, and manufacturers exhibiting a cost structure that differs largely from the industry average could be more negatively or positively affected. DOE customarily uses the results of the industry characterization to group manufacturers with similar characteristics. When possible, DOE discusses the potential subgroups that have been identified for the analysis in manufacturer interviews. DOE asks manufacturers and other interested parties to suggest what subgroups or characteristics are most appropriate for the analysis. One subgroup commonly identified is small business manufacturers.

12.2.3.4 Competitive Impact Assessment

EPCA directs DOE to consider the impact of any lessening of competition, as determined in writing by the Attorney General, that is likely to result from a proposed standard. (42 U.S.C. 6295(o)(2)(B)(i)(V)) It also directs the Attorney General to determine the impact, if any, of any lessening of competition likely to result from a proposed standard and to transmit such determination to the Secretary within 60 days of the publication of a proposed rule, together with an analysis of the nature and extent of the impact. (42 U.S.C. 6295(o)(2)(B)(ii)) Furthermore, as part of the MIA, DOE evaluates the potential impact of standards to create asymmetric cost increases for manufacturer sub-groups, shifts in competition due to proprietary technologies, and business risks due to limited supplier availability or raw material constraints.

12.2.3.5 Manufacturing Capacity Impact

One of the potential outcomes of new and/or amended energy conservation standards is the obsolescence of existing manufacturing assets, including tooling and other investments. The manufacturer interview guide has a series of questions to help identify impacts on manufacturing capacity, specifically capacity utilization and plant location decisions in the United States with and without amended energy conservation 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 restructuring or other charges, where applicable.

12.2.3.6 Direct Employment Impacts

The impact of potential new and/or amended energy conservation standards on direct employment is considered in DOE's analysis. Manufacturer interviews aid in assessing how domestic employment patterns might be impacted by new and/or amended energy conservation standards. Typically, the interview guide contains a series of questions that are designed to explore current employment trends in the industry and to solicit manufacturers' views on changes in direct employment patterns that may result from increased standard levels. These questions focus on current employment levels at production facilities, expected future direct employment levels with and without changes in energy conservation standards, differences in workforce skills, and employee retraining.

12.2.3.7 Cumulative Regulatory Burden

DOE seeks to mitigate the overlapping effects on manufacturers of potential new and/or amended energy conservation standards and other Federal regulatory actions affecting the same products or companies within a short timeframe. DOE analyzes and considers the impact of multiple, product-specific, Federal regulatory actions on manufacturers.

12.3 PRELIMINARY FINDINGS

The following section summarizes information gathered for the preliminary MIA that are not already presented in the MTA, engineering analysis, or shipments analysis.

12.3.1 Initial Financial Parameters

For dishwashers, DOE identified a one domestic, publicly-listed manufacturer of the covered product. The company manufactures a range of home appliances, with dishwashers accounting for approximately 8% of net sales. The company sells product into domestic and foreign markets.

Given the limited number of companies from which to aggregate financial data, DOE chose to begin the analysis of industry financial parameters with values presented in the December 2016 Final Rule. The 2016 Final Rule financial parameters were vetted by multiple manufacturers in confidential interviews and went through public notice and comment. The results are the most robust product-specific estimates that are publicly available for dishwashers.

DOE compared those values with the current financial parameters of the two domestic, publicly listed company to confirm that the parameters were still relevant. DOE noted that tax rates estimates from before 2018 were not relevant for modeling future cash-flows due to the Tax Cuts and Jobs Act (TCJA), which was signed into law in December 2017 and changed the Federal corporate tax rate from 35% to 21%. Table 12.3.1 below shows DOE's initial financial parameter estimates. DOE will further refine these values using feedback from manufacturer interviews and public comments.

Table 12.3.1 Initial Financial Parameters

Financial Parameters	Estimate
Tax Rate ***(% of Taxable Income)***	23.3
Working Capital ***(% of Revenue)***	7.0
SG&A ***(% of Revenue)***	13.3
R&D ***(% of Revenues)***	2.3
Depreciation ***(% of Revenues)***	5.0
Capital Expenditures ***(% of Revenues)***	5.0
Net Property, Plant, and Equipment ***(% of Revenues)***	16.7

The manufacturer selling price (MSP) is the price manufacturers charge their first customers. The MSP equals the MPC multiplied by the manufacturer markup. The manufacturer markup covers all manufacturer non-production costs (*e.g.,* SG&A, R&D, and interest) and profit. The MSP is different from the cost the end-user pays because there are additional markups from entities along the distribution chain between the manufacturer and the end-user.

DOE considered the average manufacturer markup from the December 2016 Final Rule to be the most robust product-specific data available. DOE estimated the industry average manufacturer markup to be 1.24.

12.3.2 Manufacturers and Manufacturer Subgroups

DOE relied on a review of the Certification Compliance Database, the California Energy Commission's Modernized Appliance Efficiency Database System (MAEDbS), retailer websites, and manufacturer information to identify companies that distribute the covered product into commerce. DOE identified 51 companies that import, private label, produce, or manufacture dishwashers. DOE notes that it can be difficult to differentiate between companies that import, private label, produce, and manufacture based on public information. Some companies may offer a mix of imported, private labeled, and in-house manufactured product. Using available information from manufacturer websites, manufacturer specifications and product literature, bill of lading information, site images, and basic model numbers, DOE estimates fourteen of these companies are original equipment manufacturers (OEMs) of covered products. Of the fourteen, DOE estimates five companies have manufacturing facilities in the United States producing covered products.

DOE performed a preliminary investigation into small business manufacturers as a subgroup for consideration in subsequent stages of the dishwashers rulemaking. DOE relied on the Small Business Association (SBA) size standards for determining the threshold for a firm to be a "small business". The SBA size standards are set based on the North American

Classification System (NAICS) code. For NAICS code 335220, described as "Major Household Appliance Manufacturing," the size threshold is 1,500 employees for an entity to be a small business. The size threshold is based on enterprise-wide employment, which includes enterprise subsidiaries and branches, as well as unrelated establishments of the parent company.

DOE identified 28 small companies that import, private label, produce, or manufacture dishwashers. As noted earlier in this section, there is limited information to enable DOE to differentiate between companies that import, private label, produce, and manufacture. Based on review of public information, DOE understands that none of these small companies are OEMs of dishwashers.

12.3.3 Cumulative Regulatory Burden

While any one regulation may not impose a significant burden on manufacturers, the combined effects of several impending regulations may have significant consequences for individual manufacturers, groups of manufacturers, or entire industries. In the cumulative regulatory burden (CRB) analysis, DOE considers expenditures associated with meeting other Federal, product-specific regulations that occur within the CRB timeframe. The CRB timeframe is the seven-year period that covers with three years before the compliance year, the compliance year, and the three years after the compliance year of the proposed standard.

In the MIA's Phase III (as described in section 12.2.3 of this TSD), which is conducted after the preliminary analysis notice is published, manufacturer interviews help DOE identify potential opportunities to coordinate regulatory actions in a manner that mitigates cumulative impacts, such as multiple successive redesigns of the same product with a short period of time. Many of the dishwasher manufacturers produce other home appliances and products that are regulated by DOE efficiency standards. Dishwasher manufacturers are subject to efficiency standard for other regulated products, such as cooking products; clothes washers; clothes dryers; central air conditioners; residential furnaces; consumer refrigerators, refrigerator-freezers, and freezers; and miscellaneous refrigeration products. The exact regulations contributing to CRB will be determined once a compliance date is proposed in the NOPR phase of the ECS rulemaking.

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13.1 OVERVIEW

The U.S. Department of Energy (DOE) conducts an emissions analysis for the notice of proposed rulemaking (NOPR) stage should DOE determine to issue a NOPR. In the emissions analysis, DOE estimates the reduction in power sector combustion emissions of carbon dioxide (CO_2), nitrogen oxides (NO_X), sulfur dioxide (SO_2), mercury (Hg), methane (CH_4) and nitrous oxide (N_2O) from potential energy conservation standards for the considered products, as well as emissions at the building site if applicable. In addition, DOE estimates emissions impacts in production activities (extracting, processing, and transporting fuels) that provide the energy inputs to power plants and for site combustion. 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 (August 18, 2011)), the FFC analysis includes impacts on emissions of methane and nitrous oxide, both of which are recognized as greenhouse gases.

DOE conducts the emissions analysis using marginal emissions factors that are primarily derived from data in the latest version of the Energy Information Administration's (EIA's) *Annual Energy Outlook* (*AEO)*, supplemented by data from other sources. EIA prepares the *AEO* using the National Energy Modeling System (NEMS).[a] Each annual version of NEMS incorporates the projected impacts of existing air quality regulations on emissions.

Site emissions of CO_2 and NO_X are estimated using emissions intensity factors from a publication of the Environmental Protection Agency (EPA).[1] Combustion emissions of CH_4 and N_2O are estimated using emissions intensity factors published by the EPA GHG Emissions Factors Hub.[b] The FFC upstream emissions are estimated based on the methodology developed by Coughlin (2013).[2] 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.

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[a] For more information about NEMS, please refer to the U.S. Department of Energy, Energy Information Administration documentation. A useful summary is National Energy Modeling System: An Overview 2009, DOE/EIA-0581 (October 2009), available at: https://www.eia.gov/outlooks/aeo/nems/overview/pdf/0581(2009).pdf
[b] https://www.epa.gov/sites/production/files/2016-09/documents/emission-factors_nov_2015_v2.pdf

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2. Coughlin, K. *Projections of Full-Fuel-Cycle Energy and Emissions Metrics*. 2013. Lawrence Berkeley National Laboratory: Berkeley, CA. Report No. LBNL-6025E. (Last accessed March 31, 2021.) https://eta-publications.lbl.gov/sites/default/files/lbnl6025e_ffc.pdf.

CHAPTER 14. MONETIZATION OF EMISSIONS REDUCTIONS BENEFITS

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CHAPTER 14. MONETIZATION OF EMISSIONS REDUCTIONS BENEFITS

14.1 OVERVIEW

The U.S. Department of Energy (DOE) estimates the monetary benefits associated with the reduced emissions of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), sulfur dioxide (SO_2), and nitrogen oxides (NO_X) that are expected to result from the considered standard levels in the notice of proposed rulemaking (NOPR) stage, should DOE determine to issue a NOPR. To make this calculation similar to the calculation of the net present value of consumer benefit, DOE considers the reduced emissions expected to result over the lifetime of products shipped in the projection period for each standard level.

DOE estimates the monetized benefits of the reductions in emissions of CO_2, CH_4, and N_2O by using a measure of the social cost ("SC") of each pollutant. These estimates represent the monetary value of the net harm to society associated with a marginal increase in emissions of these pollutants in a given year, or the benefit of avoiding that increase. These estimates are intended to include (but are not limited to) climate-change-related changes in net agricultural productivity, human health, property damages from increased flood risk, disruption of energy systems, risk of conflict, environmental migration, and the value of ecosystem services.

DOE uses the estimates for the social cost of greenhouse gases ("SC-GHG") from the most recent update of the Interagency Working Group on Social Cost of Greenhouse Gases, United States Government ("IWG") working group, from "Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide Interim Estimates under Executive Order 13990." (February 2021 TSD). DOE has determined that the estimates from the February 2021 TSD, as described more below, are based upon sound analysis and provide well founded estimates for DOE's analysis of the impacts of related to the reductions of emissions anticipated from the proposed rule.

The SC-GHG estimates in the February 2021 TSD are interim values developed under Executive Order (E.O.) 13990 for use until an improved estimate of the impacts of climate change can be developed based on the best available science and economics. The SC-GHG estimates used in this analysis were developed over many years, using a transparent process, peer-reviewed methodologies, the best science available at the time of that process, and with input from the public. Specifically, an IWG that included DOE, the EPA and other executive branch agencies and offices used three integrated assessment models ("IAMs") to develop the SC-CO_2 estimates and recommended four global values for use in regulatory analyses. Those estimates were subject to public comment in the context of dozens of proposed rulemakings as well as in a dedicated public comment period in 2013.

The SC-CO_2 estimates were first released in February 2010 and updated in 2013 using new versions of each IAM. In 2015, as part of the response to public comments received to a 2013 solicitation for comments on the SC-CO_2 estimates, the IWG announced a National Academies of Sciences, Engineering, and Medicine review of the SC-CO_2 estimates to offer advice on how to approach future updates to ensure that the estimates continue to reflect the best available science and methodologies. In January 2017, the National Academies released their final report, Valuing Climate Damages: Updating Estimation of the Social Cost of Carbon Dioxide, and recommended specific criteria for future updates to the SC-CO_2 estimates, a modeling framework to satisfy the specified criteria, and both near-term updates and longer-term research needs pertaining to various components of the estimation process (National Academies 2017). On January 20, 2021, President Biden issued Executive Order 13990, which directed the IWG to ensure that the U.S. Government's (USG) estimates of the SC-CO_2 social cost of carbon and other greenhouse gases reflect the best available science and the recommendations of the National Academies (2017). The IWG was tasked with first reviewing the estimates currently used by the USG and publishing interim estimates within 30 days of E.O. 13990 that reflect the full impact of GHG emissions, including taking global damages into account, which resulted in the issuance of the February 2021 TSD. More information on the basis for the IWG's interim values may be found in the IWG's Technical Support Document.[a]

To estimate the monetary value of reduced NO_X and SO_2 emissions from electricity generation attributable to the standard levels it considers, DOE uses benefit-per-ton estimates derived from analysis conducted by the EPA. For NO_X and SO_2 emissions from combustion at the site of product use, DOE uses another set of benefit-per-ton estimates published by the EPA.

[a] See Interagency Working Group on Social Cost of Greenhouse Gases, Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide. Interim Estimates Under Executive Order 13990, Washington, D.C., February 2021.
https://www.whitehouse.gov/wpcontent/uploads/2021/02/TechnicalSupportDocument_SocialCostofCarbonMethaneNitrousOxide.pdf?source=email

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CHAPTER 15. UTILITY IMPACT ANALYSIS

15.1 OVERVIEW

The U.S. Department of Energy (DOE) analyzes the changes in electric installed capacity and power generation that result for each considered trial standard level for the notice of proposed rulemaking (NOPR) stage should DOE determine to issue a NOPR.

The utility impact analysis is based on output of the DOE/Energy Information Administration (EIA)'s National Energy Modeling System (NEMS).[1] NEMS is a public domain, multi-sectored, partial equilibrium model of the U.S. energy sector. Each year, DOE/EIA uses NEMS to produce an energy forecast for the United States, the Annual Energy Outlook (AEO). The EIA publishes a reference case, which incorporates all existing energy-related policies at the time of publication, and a variety of side cases which analyze the impact of different policies, energy price and market trends.

DOE's methodology is based on results published for the most recent *Annual Energy Outlook (AEO)* Reference case, as well as a number of side cases that estimate the economy-wide impacts of changes to energy supply and demand. DOE estimates the marginal impacts of reduction in energy demand on the energy supply sector. In principle, marginal values should provide a better estimate of the actual impact of energy conservation standards. DOE uses the side cases to estimate the marginal impacts of reduced energy demand on the utility sector. These marginal factors are estimated based on the changes to electricity sector generation, installed capacity, fuel consumption and emissions in the *AEO* Reference case and various side cases. The methodology is described in more detail in K. Coughlin, "Utility Sector Impacts of Reduced Electricity Demand."[2,3]

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

REFERENCES

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3. Coughlin, K. *Utility Sector Impacts of Reduced Electricity Demand: Updates to Methodology and Results*. 2019. Lawrence Berkeley National Laboratory: Berkeley, CA. Report No. LBNL-2001256. (Last accessed May 24, 2021.) https://www.osti.gov/servlets/purl/1580427/.

CHAPTER 16. EMPLOYMENT IMPACT ANALYSIS

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CHAPTER 16. EMPLOYMENT IMPACT ANALYSIS

16.1 OVERVIEW

Energy conservation standards can impact employment both directly and indirectly. Direct employment impacts are changes in the number of employees at the plants that produce the covered dishwashers resulting from standards, and are evaluated in the manufacturer impact analysis, as described in chapter 12 of this Technical Support Document. The employment impact analysis described in this chapter covers indirect employment impacts which 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 the implementation of standards. The U.S. Department of Energy (DOE) conducts this analysis in the notice of proposed rulemaking (NOPR) stage should DOE determine to issue a NOPR.

DOE expects new or amended energy conservation standards to decrease energy consumption and, therefore, reduce expenditures for energy. In turn, savings in energy expenditures may be redirected for new investment and other items. Notwithstanding, energy conservation standards may potentially increase the purchase price of dishwashers, including the retail price plus sales tax, and may increase installation costs.

Using an input-output model of the U.S. economy, the employment impact analysis seeks to estimate the year-to-year effect of these expenditure impacts on net national employment. DOE intends the employment impact analysis to quantify the indirect employment impacts of these expenditure changes.

To investigate the indirect employment impacts, DOE uses the Pacific Northwest National Laboratory's (PNNL's) "Impact of Sector Energy Technologies" (ImSET 3.1.1) model.[1] PNNL developed ImSET, a spreadsheet model of the U.S. economy that focuses on 187 sectors most relevant to industrial, commercial, and residential building energy use, for DOE's Office of Energy Efficiency and Renewable Energy. ImSET is a special-purpose version of the U.S. Benchmark National Input-Output (I-O) model, which has been designed to estimate the national employment and income effects of energy saving technologies that are deployed by DOE's Office of Energy Efficiency and Renewable Energy. In comparison with the previous versions of the model used in earlier rulemakings, this version allows for more complete and automated analysis of the essential features of energy efficiency investments in buildings, industry, transportation, and the electric power sectors.

The ImSET software includes a computer-based I-O model with structural coefficients to characterize economic flows among the 187 sectors. ImSET's national economic I-O structure is based on the 2002 Benchmark U.S. table, specially aggregated to 187 sectors.[2]

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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. (Last accessed March 31, 2021.) http://www.pnl.gov/main/publications/external/technical_reports/PNNL-15273.pdf.

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CHAPTER 17. REGULATORY IMPACT ANALYSIS

17.1 INTRODUCTION

Under appendix A to subpart C of Title 10 of the Code of Federal Regulations, Part 430, *Procedures for Consideration of New or Revised Energy Conservation Standards for Consumer Products* (Process Rule) the U.S. Department of Energy (DOE) is committed to explore non-regulatory alternatives to energy conservation standards. Accordingly, DOE will prepare a draft regulatory impact analysis pursuant to Executive Order 12866, "Regulatory Planning and Review," which will be subject to review by the Office of Management and Budget's Office of Information and Regulatory Affairs for the notice of proposed rulemaking (NOPR). Pursuant to the Process Rule, DOE has identified five major alternatives to standards that represent feasible policy options to reduce the energy consumption of dishwashers. It will evaluate each alternative in terms of its ability to achieve significant energy savings at a reasonable cost, and will compare the effectiveness of each alternative to the effectiveness of the proposed standard.

Table 17.1.1 lists the non-regulatory means of achieving energy savings that DOE proposes to analyze. The technical support document (TSD) prepared in support of DOE's NOPR will include a complete quantitative analysis of each alternative, the methodology for which is briefly addressed below.

Table 17.1.1 Non-Regulatory Alternatives to Standards

No New Regulatory Action
Consumer Rebates
Consumer Tax Credits
Manufacturer Tax Credits
Voluntary Energy Efficiency Targets
Bulk Government Purchases

17.2 METHODOLOGY

DOE will use the national impact analysis (NIA) spreadsheet model for dishwashers to calculate the national energy savings and the net present value (NPV) corresponding to each candidate standard. The NIA model is discussed in chapter 10 of the TSD. To compare each alternative quantitatively to the proposed energy conservation standards, DOE will need to quantify the effect of each alternative on the purchase of energy efficient dishwashers. DOE will create an integrated NIA-RIA model, built upon the NIA model, where DOE will make the appropriate revisions to the inputs in the NIA models. Key inputs that DOE may revise in the NIA-RIA model are:

- Dishwasher market shares of products meeting target efficiency levels (identical to the trial standard levels for the mandatory standards)

- Shipments of dishwashers, when those are affected by the proposed energy conservation standards.

The following are the key measures of the impact of each alternative:

- *National energy savings*: Cumulative national energy use from the no-new-standards case projection minus the alternative-policy-case projection.
- *Net present value*: The value of future operating cost savings from the equipment bought during the period from the required compliance date of the new standard (2027-2065). DOE will calculate the NPV as the difference between the present value of equipment and operating expenditures (including energy) in the no-new-standards case, and the present value of expenditures under each alternative-policy case. DOE will calculate operating expenses (including energy costs) for the life of the equipment. It will discount future operating and equipment expenditures to 2021 using a 7-percent and 3-percent real discount rate.

APPENDIX 6A. INCREMENTAL MARKUPS: THEORY AND EVIDENCE

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APPENDIX 6A. INCREMENTAL MARKUPS: THEORY AND EVIDENCE

6A.1 INTRODUCTION

Since 2004, the Department of Energy (DOE) has applied the incremental markup approach to estimate the increase in final product price of high-efficiency products as a function of the increase in manufacturing cost.[1] Under this approach, DOE applies a lower markup than the average markup to the incremental cost of higher-efficiency products, relative to the baseline product. The approach is described in detail in chapter 6.

DOE's incremental markup approach is based on the widely accepted economic view that prices closely reflect marginal costs in competitive markets and in those with some degree of concentration. Evaluating industry data in IBISWorld suggests that most of the industries relevant to appliance wholesalers and appliance retailers are considered to have low to moderate market concentration, high and increasing market competition and medium barriers to entry (see Table 6A.1.1 and Table 6A.1.2).[2,3]

Table 6A.1.1 Competitive Environment of Appliance Wholesalers

Sector	Industry Concentration	Competition	Barriers to Entry
TV & appliance wholesaling	Low	High and steady	Medium and steady
Refrigeration equipment wholesaling	Low	Medium and increasing	Medium and increasing
Heating & air-conditioning wholesaling	Low	High and steady	Medium and increasing

Table 6A.1.2 Competitive Environment of Appliance Retailers

Sector	Industry Concentration	Competition	Barriers to Entry
TV & appliance retailers	Low	High and steady	Medium and steady
Consumer electronics stores	Medium	High and increasing	Medium and steady
Department stores	High	High and increasing	Medium and steady
Home improvement stores	High	Medium and steady	Medium and steady

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

Examining gross margin and price data in the appliance retail industry over time, DOE finds that both gross margins and prices did not demonstrate any persistent trend. Similarly, appliance wholesale gross margins and prices have both been effectively constant in past two decades. Thus, these sets of historical data have no bearing on firm markup behavior under product price increases, such as may occur as a result of standards.

To investigate markup behavior under product price increases, DOE evaluated time series gross margin data from three industries with rapidly changing input prices – the LCD television retail market, the U.S. oil and gasoline market, and the U.S. housing market. Additionally, LBNL conducted an in-depth interview with an HVAC consultant who represents many individual contractors in the industry.

6A.2 MARGIN TRENDS UNDER PRICE VOLATILITY

The market data on appliance wholesalers handling household appliances are not available at this point. Since the heating and air-conditioning wholesale industry has similar competition landscape as appliance wholesale industry (Table 6A.1.1), DOE turns to analyze the publicly available market data for heating and air-conditioning wholesaler and assumes that the results are generally applicable for appliance wholesalers as well. Heating, Air-Conditioning and Refrigeration Distributors International (HARDI) published annual profit report with aggregated financial and operating data of its participating firms in HVAC wholesale industry. DOE evaluated the percent gross margins[a] and sales revenue per shipment received (as a proxy for average HVAC wholesale prices) reported from 1999 to 2012 for typical HARDI distributors.[b] As shown in Figure 6A.2.1, average HVAC wholesaler prices have experienced some fluctuations during this period of time, but the overall wholesale price trend is relatively stable, with a price increase of four percent from 1999 to 2012.

The U.S. Census Annual Retail Trade Survey (ARTS) provides gross margin data for electronics and appliance stores (NAICS 443) for 1993 to 2008. DOE calculated the shipments weighted average price of major household appliances (i.e. refrigerators, freezers, clothes washers, dishwashers, and room air-conditioners) for the same time period from AHAM shipments and value of shipments data.[c] As seen in HVAC wholesaling, percent gross margins for appliance retailers and average appliance prices have been fairly stable (Figure 6A.2.2).

However, the existence of constant percent margin over time is not sufficient to identify an industry's markup practice without considering the underlying input price changes during the same period. If the prices have been relatively constant, the incremental markup approach will arrive at the same result as applying constant margin. In fact, the average prices have been relatively stable over time; [d] hence, the historically constant percent margins do not necessarily imply a constant percent margin in the future, especially in the case of increased input prices due to standards.

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[a] Percent gross margin is defined as gross margin in percentage of sales revenue.
[b] The typical distributors are the firms with median financial results among all participating firms.
[c] AHAM Annual Trends - Industry Shipments of Major Appliances; AHAM History of Dollar Value Report.
[d] In 2005 the HVAC market experienced a brief 15% price rise. The HVAC price increase may be attributed to the 2006 Central Air-Conditioner and Heat Pump Standard. Gross margins declined slightly at this time.

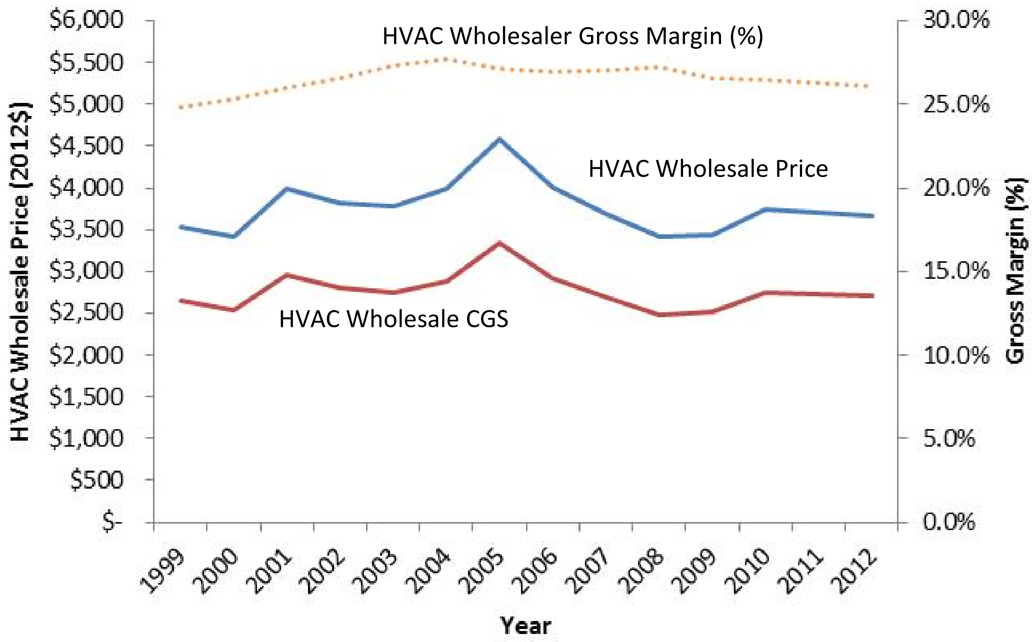

Figure 6A.2.1 HVAC Wholesale Prices, Cost of Goods Sold and Gross Margins

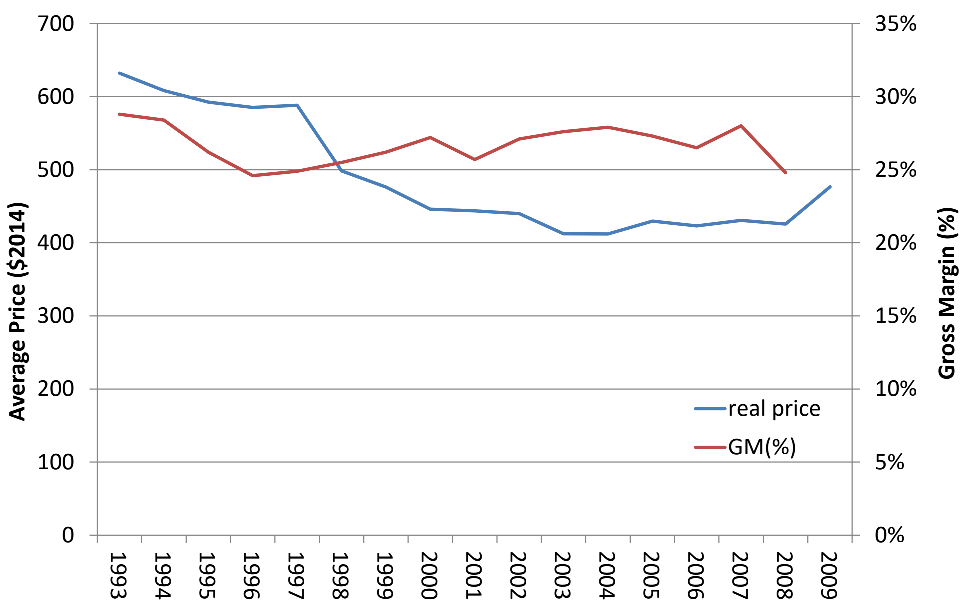

Figure 6A.2.2 Retail Appliance Prices and Gross Margins

As historical data in HVAC wholesale and appliance retail markets cannot be used to address the question of margins under a standards-induced price shock, we look to other publicly available data for markets of products that have experienced noticeable price changes, evaluating the prevalence of fixed percent gross margins.

To replicate the theorized conditions of efficiency standard implementation, DOE would ideally analyze a household durable that has experienced a consistent rise in price, such as may occur as a result of standards. The LCD television retail market, on the other hand, is a market with a consistently downward price trend since 2007. The material costs and retail prices of LCD televisions have both dropped substantially over this period. At the same time, average retailer gross margins have decreased from 25 percent in 2007 to only 6 percent in late 2014. Under the input price change (CGS), retailers did not maintain constant percent gross margins (Figure 6A.2.3).[e]

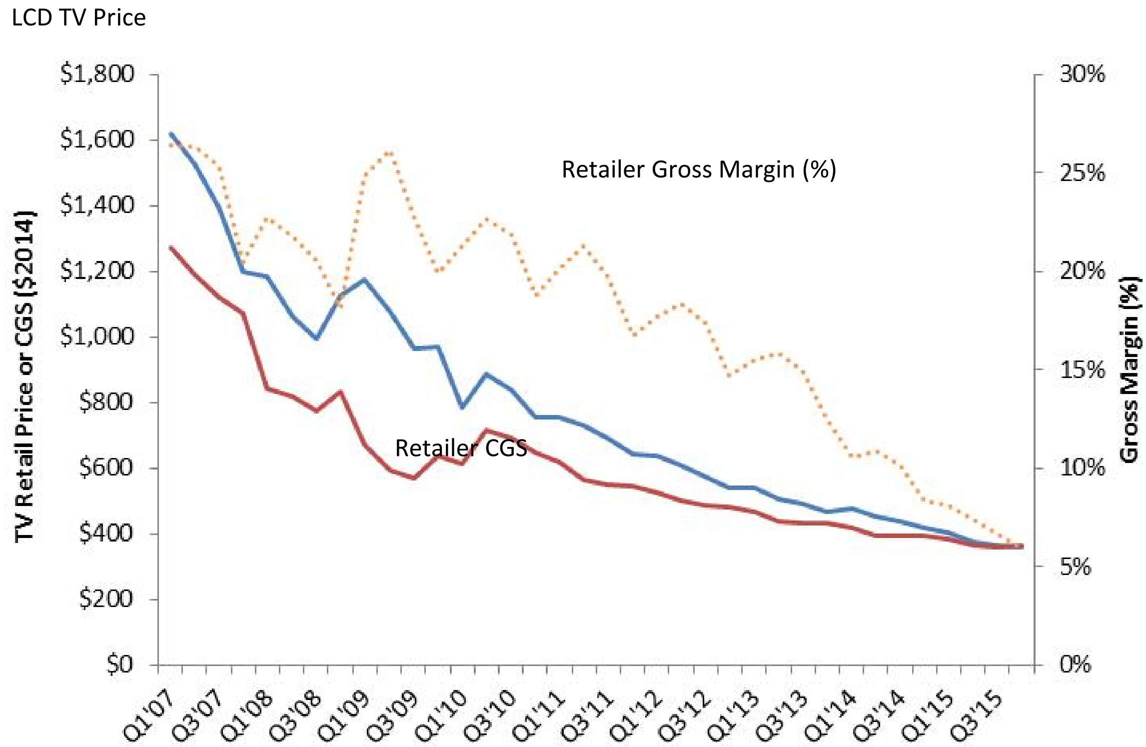

Figure 6A.2.3 LCD TV Prices, Cost of Goods Sold and Gross Margins

DOE also analyzed margin behavior in markets with upward price trends in order to test the prevalence of fixed percent gross margins. U.S. imported crude oil prices rose by $2.50 per gallon from 1995 to 2008, but the percent retail gross margins have decreased during the same period of time (Figure 6A.2.4).[4]

[e] LCD television data from DisplaySearch, a market research company affiliated with NPD Group.

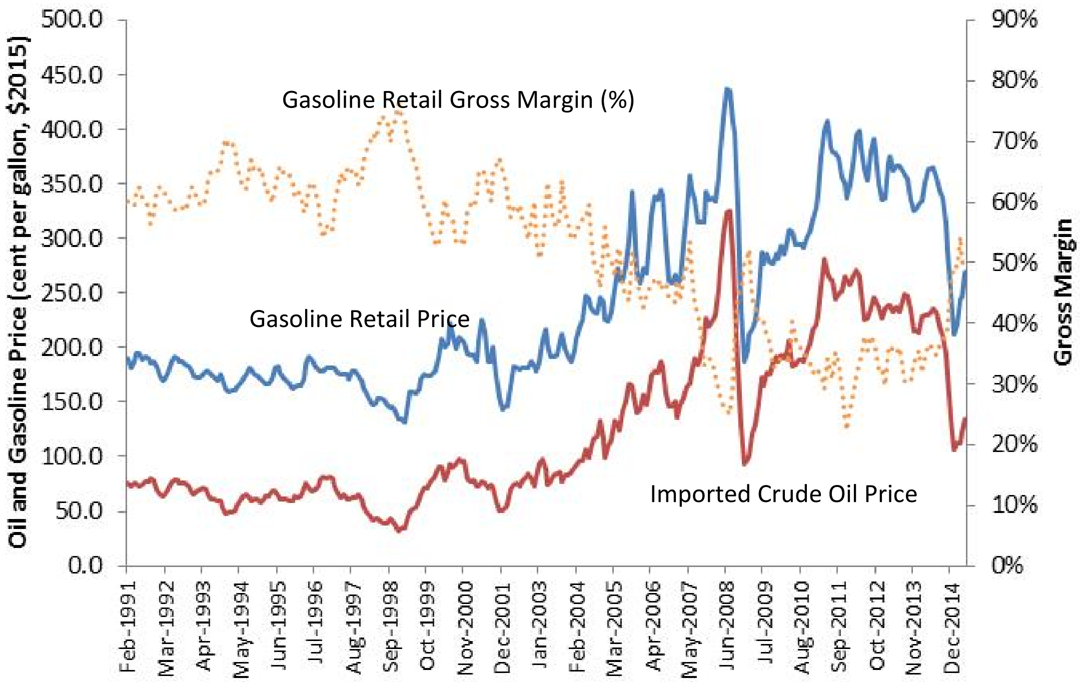

Figure 6A.2.4 Oil and Gasoline Price, Gross Margin

The U.S. inflation-adjusted median home sales prices and the costs of selling, measured by home sales price minus agent's commission fee, have increased substantially from 1991 to 2005. The percent gross margin in the housing market (i.e., commission rate), however, has declined by 15 percent over this period (Figure 6A.2.5).[5,6,7,8f] In short, we do not observe fixed percent gross margins in this market with increasing costs.

[f] Federal Trade Commission and the U.S. Department of Justice published a report, titled "Competition in the Real Estate Brokerage Industry", which provides extensive literature review on the topic of housing prices and brokerage commission fee, and the empirical evidences are consistent with our findings. Access to the full report: www.ftc.gov/reports/competition-real-estate-brokerage-industry-report-federal-trade-commission-us-department

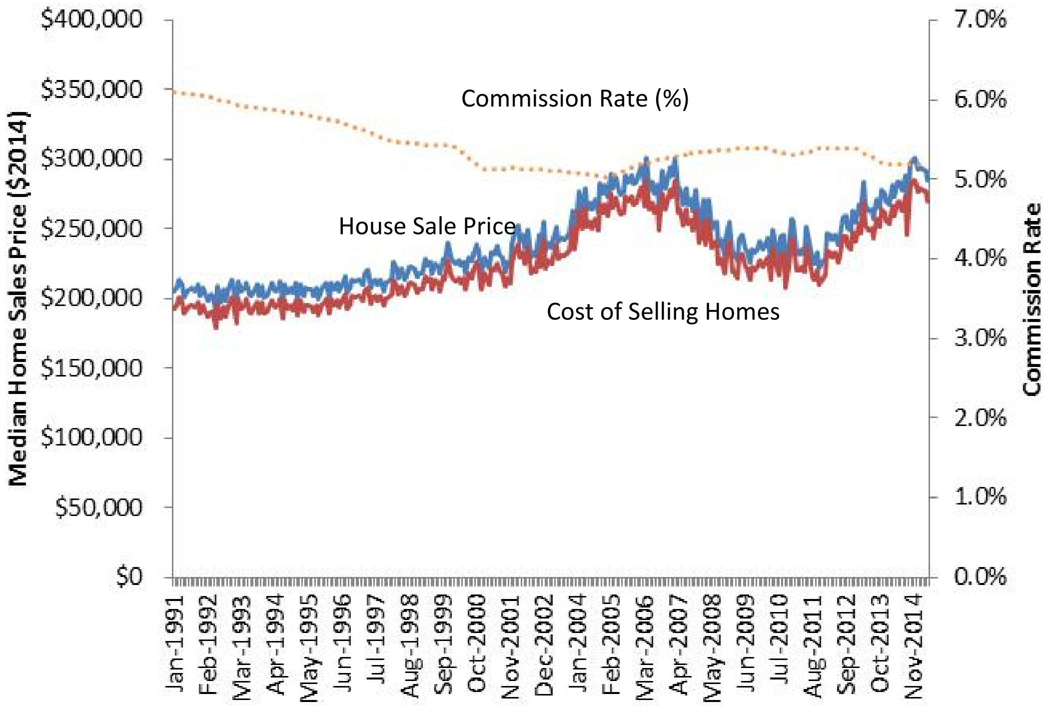

Figure 6A.2.5 House Sales Price, Costs of Selling Homes, and Realtor Commission (%)

After examining price and gross margin data in various markets, the results indicate that prices could go up or down in different of time, but in no case do we see the percent gross margins remain fixed over time. Hence, DOE does not expect that firms can sustain on applying constant markups on incremental costs of more efficient products after standards.

6A.3 SUMMARY OF CONSULTANT INTERVIEW

To gain insight into real-world markup practice, LBNL interviewed an experienced consultant who specializes in the HVAC contracting field.[9] Since the incremental markup is applied in a very specific analytical situation where the input cost increases due to the standard while other costs remain the same, it was necessary to carefully craft the interview to accurately convey the concept. The list of key questions asked of the consultant includes the following points:

1. *Assuming the HVAC equipment price increases while the other costs remain constant (no change in labor, material, and operating costs), are contractors still able to keep the same markup over time as before?*
2. *Keeping a fixed markup when the equipment price goes up implies that the contractor's profitability would increase, assuming no other cost changes. Is this increase in profitability viable over time?*
3. *If contractors would have to adjust their markup in this situation due to competition, how long does it take for them to revisit their markup values and adjust the firm's profitability to a competitive level?*

The consultant responded as follows:

1. *Initially, contractors will attempt to use the same markup after the increase in input cost occurs, but, assuming there is no increase in other costs, "they'll eventually either have to lower their markup based on market pressures, or they'll choose to lower their markup when it's reviewed and recalculated."*
2. *Any increase in profit following an input cost increase is likely to be short-lived. "There are too many pressures on contractors to lower their prices for various reasons… We'll guess this isn't the first time over the past 40 years that equipment prices have increased because of regulatory changes rather than inflationary or commodity price increases. Construction today is not a more profitable industry than it was decades ago."*
3. *Contractor profit margins and markups are typically reevaluated every three to six months; this limits the timeframe in which higher-than-sustainable profits are likely to persist.*

The consultant's responses provide real-world evidence indicating that HVAC contractors aim to maintain fixed percent markups, but market pressures force them to reevaluate and adjust markups over time to stay competitive. This empirical phenomenon reinforces the underlying theory and assumptions inherent in the incremental markup approach used in DOE's post-standard price projections. While the consultant speaks specifically to the practices of HVAC contractors, his descriptions of firms' response to cost increase over time in a competitive environment can be logically extended to wholesalers and retailers and general contractors as well. DOE concludes that the combined evidence of changing percent gross margins across industries with cost changes and the support of the industry consultant justify the use of the incremental markup approach.

6A.4 CONSULTANT INTERVIEW REPORT

In this section, the original responses from consultant regarding markup practice in construction industry is presented as a supplementary material supporting the use of incremental markup when estimating the consumer product price of more efficient products.

To: Lawrence Berkeley National Laboratory
From: Michael Stone, Construction Programs & Results, Inc.
Date: January 26, 2015
Re: Supplementary questions on contractor markups

After a new energy efficiency standard is in place, the equipment prices generally go up as less efficient (cheaper) ones are eliminated on the market by new standard. The questions below are intended to help us understand the impact of increased equipment prices on contractors' markup practices and profitability. That is, how contractors react to this change in equipment price while the other costs remain constant.

(1) Assuming the equipment price increases while the other costs remain constant (no change in labor, material and operating costs), are contractors still able to keep the same markup over time as before?

Michael Stone (Michael): *Yes and no. The contractors will attempt to use the same markup over time, but, assuming no increase in other costs, they'll eventually either have to lower their markup based on market pressures, or they'll choose to lower their markup when it's reviewed and recalculated.*

Keep in mind the numbers and our answer assume a "pure" company; one that currently only installs the lower efficiency units and that in the future will only install the higher efficiency units. They don't perform any other service work or install any other equipment. Those companies don't exist in real life. So it's most likely that on individual sales, if under pressure, the contractor might choose to reduce their markup because they recognize the equipment price increase without other related cost increases. The markup change will happen when the company's finances are reviewed, and the equipment cost increase will be only one factor in the adjustment.

(2) Keeping a fixed markup when the equipment price goes up implies that the contractor's profitability would increase, assuming no other cost changes. Is this increase in profitability viable over time?

Michael: *Probably not. There are too many pressures on contractors to lower their prices for various reasons. Unless building owners suddenly have more money to spend and consider the work on their building valuable enough to pay what it's worth, profitability will stay the same.*

We'll guess this isn't the first time over the past 40 years that equipment prices have increased because of regulatory changes rather than inflationary or commodity price increases. Construction today is not a more profitable industry than it was decades ago.

(3) If contractors would have to adjust their markup in this situation due to competition, how long does it take for them to revisit their markup values and adjust the firm's profitability to a competitive level?

Michael: *Generally speaking, 3-6 months.*

(4) For commercial contractors, is the market as competitive as for residential contractors? Is there a significant difference in their ability to maintain a fixed markup between commercial and residential contractors? If so, please elaborate the differences.

Michael: *There are so many variations in how commercial contractors operate, and the market is considerably different than residential. But it is as competitive.*
Many of them get jobs because of their connections. They do a lot of marketing and schmoozing, promoting themselves to buyers. This enables them to get jobs easier. If they have long-time relationships with general contractors who are primarily concerned with getting a job well-built with few problems, they can have an easier time maintaining a fixed markup. If they have long-time relationships with general contractors who are more concerned about getting the job built at the lowest possible price, they might choose to cut their price to get jobs.
Others get jobs by competing to be the lowest price. If they have relationships and can influence the bid process, they might have a bid that's written with them in mind, making it easier for them to be low bid and still maintain a reasonable markup on the job. Other contractors just shoot to be the lowest bid and have a tough time being profitable (ie, no, they don't maintain a fixed markup).

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APPENDIX 8A. USER INSTRUCTIONS FOR THE LIFE-CYCLE COST ANALYSIS SPREADSHEET

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APPENDIX 8A. USER INSTRUCTIONS FOR THE LIFE-CYCLE COST ANALYSIS SPREADSHEET

8A.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 dishwashers by using Microsoft Excel spreadsheets available on DOE's website at http://energy.gov/eere/buildings/appliance-and-equipment-standards-program.
To fully execute the spreadsheets requires both Microsoft Excel and Crystal Ball software. Both applications are commercially available. Crystal Ball is available at www.decisioneering.com.

The latest version of the workbook, which is posted on the DOE website, was tested using Microsoft Excel 2010. The LCC and PBP workbook for dishwashers comprises the following worksheets.

Summary	The *Summary* worksheet contains LCC simulation and simple payback results for each design option and product class.
LCC & Payback	The *LCC & Payback* worksheet shows LCC calculation results for different efficiency levels for single Residential Energy Consumption Survey (RECS) households.
Rebuttable PB	The *Rebuttable PB* worksheet contains the total and incremental manufacturer costs, retail prices, installation costs, repair and maintenance costs, energy use calculations, and rebuttable payback period calculations for each efficiency level.
RECS Samples	The *RECS Samples* worksheet contains the RECS 2015 household data for each dishwasher product type.
Equipment & Installation Cost	Develops total installed cost for dishwashers in 2020$. This sheet provides baseline and incremental manufacturer costs, retail price, sales tax, and installation cost for all product classes and each efficiency level. Includes the assumptions used about markups and sales tax.
Base Case Eff Dist	The *Base Case Eff Dist* worksheet determines the efficiency of the no-new-standards case unit.
Energy & Water Use	The *Energy & Water Use* worksheet calculates annual energy use by fuel type, depending on product class.
Energy & Water Prices	The *Energy & Water Prices* worksheet calculates energy and water prices, depending on a number of variables.

Energy Price Trends	The *Energy Price Trends* worksheet shows the future price trends of the different heating fuels.
Discount Rate	The *Discount Rate* worksheet contains the distributions of discount rates for replacement and new units.
Lifetime	The *Lifetime* worksheet presents the average lifetime, in years, for all product classes, the Weibull parameters used for the survival function, and a graph of the Weibull retirement function for dishwashers.

8A.2 BASIC INSTRUCTIONS FOR OPERATING THE LIFE-CYCLE COST SPREADSHEETS

Basic instructions for operating the LCC spreadsheet are as follows:

1. Once the LCC spreadsheet has been downloaded, open the file using Excel. Click "Enable Macro" when prompted and then click on the tab for the *Summary* worksheet.

2. Use Excel's View/Zoom commands at the top menu bar to change the size of the display to fit your monitor.

3. The user can change the parameters listed under USER INPUT on the *Summary* worksheet. There are five drop-down boxes and one command button. The default parameters are:

    a. Energy Price Trend: Defaults to "AEO 2021 - Reference." To change the input, use the drop-down menu and select the desired trend (Reference, High, or Low).

    b. # of Trials: Defaults to "10,000." To change the value, use the drop-down menu and select the desired number of trials (100, 1,000, 2,000, 5,000, 10,000 or 50,000).

    c. Analysis Group: Defaults to "National." To analyze a subgroup, use the drop-down menu and select the desired subgroup.

    d. Learning Curve: Defaults to "Default." To change the input, use the drop-down menu and select the desired trend (Default, High, or Low).

4. To run the Crystal Ball simulation, click the "run" button (you must re-run after changing any parameters). The spreadsheet will then be minimized. You can monitor the progress of the simulation by watching the count of iterations in the left bottom corner of the screen. When the simulation is finished, the spreadsheet will re-open.

5. Additional information can be found in the *Summary* worksheets.

APPENDIX 8B. UNCERTAINTY AND VARIABILITY IN LCC ANALYSIS FOR DISHWASHERS

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APPENDIX 8B. UNCERTAINTY AND VARIABILITY IN LCC ANALYSIS

8B.1 INTRODUCTION

This appendix discusses uncertainty and variability and describes how the U.S. Department of Energy (DOE) incorporated these into the life-cycle cost (LCC) and payback period (PBP) analysis in this technical support document (TSD) for the dishwasher energy conservation standards (ECS) rulemaking. The two key approaches are (1) to use distributions to capture uncertainties and variations in input variables when such distributions are reasonably well defined, and (2) to use scenarios that capture the bounds of uncertainty when the bounds are less well defined.

8B.2 UNCERTAINTY AND VARIABILITY

DOE develops mathematical models to analyze the impacts of proposed ECS. The models generate outputs (e.g., the LCC impact of proposed standards) based on inputs that are often uncertain, variable, or both.

Variability means that the quantity of interest takes on different values at different times or under different conditions. Variability may be caused by many factors. For example, the hours of use of a lamp depend on environmental factors (e.g., diurnal variations in light) and behavioral factors (e.g., the schedules and preferences of the inhabitants of a house). Manufacturing irregularities can also cause variability. For example, 10 lamps of the same model may each have slightly different power consumptions. DOE attempts to account for major sources of variability in its analyses.

Uncertainty has many sources. Variability may lead to uncertainty in model inputs, because analysts frequently must estimate the values of interest based on samples of a variable quantity (for example, the hours of use of lighting in a home). Measurement uncertainty is another source of uncertainty, which may result from instrumental uncertainties (resulting, for example, from drift, bias, and precision of resolution) and human factors (e.g., variations in experimental setup, errors in instrument readings or recordings). Uncertainty can also arise when there is limited data available to estimate a particular parameter. DOE attempts to address the major sources of uncertainties in its analyses.

8B.2.1 APPROACHES TO UNCERTAINTY AND VARIABILITY

This section describes two approaches to address uncertainty and variability in numerical modeling that in practice are often used in tandem, as they are in this rulemaking: (1) probability analysis and (2) scenario analysis.

Probability analysis considers the probability that a variable has a given value over its range of possible values. For quantities with variability (e.g., electricity rates in different households), data from surveys or other forms of measurement can be used to generate a frequency distribution of numerical values to estimate the probability that the variable takes a given value. By sampling values from the resulting distribution, it is possible to quantify the impact of known variability in a particular variable on the outcome of the analysis. In this analysis, DOE used probability distributions to estimate dishwasher lifetime, discount rates, and other variables.

Unlike probability analysis, which considers the impact of known variability, scenario analysis estimates the sensitivity of an analysis to sources of uncertainty and variability whose probability distribution is not well known. Certain model inputs are modified to take a number of different values, and models are re-analyzed, in a set of different model scenarios. Because only selected inputs are changed in each scenario, the variability in the results for each scenario helps to quantify the impact of uncertainty in the input parameters. Whereas it is relatively simple to perform scenario analyses for a range of scenarios, scenario analyses provide no information regarding the likelihood of any given scenario's actually occurring.

Scenario and probability analysis provide some indication of the robustness of the policy given the uncertainties and variability. A policy is robust when the impacts are acceptable over a wide range of possible conditions.

8B.3 PROBABILITY ANALYSIS AND THE USE OF CRYSTAL BALL

To quantify the uncertainty and variability that exist in inputs to the LCC and PBP analyses, DOE used Monte Carlo simulation and probability distributions to conduct probability analyses.

Simulation refers to any analytical method meant to imitate a real-life system, especially when other analyses are too mathematically complex or too difficult to reproduce. Without the aid of simulation, a model will only reveal a single outcome, generally the most likely or average scenario. Probabilistic risk analysis uses both a spreadsheet model and simulation to automatically analyze the effect of varying inputs on the outputs of a modeled system. One type of simulation is Monte Carlo simulation, which repeatedly generates random values for uncertain variables, drawn from a probability distribution, to simulate a model.

For each uncertain variable, the range of possible values is controlled by a probability distribution. The type of distribution selected is based on the conditions surrounding that variable. Probability distribution types include normal, triangular, uniform, and Weibull distributions, as well as custom distributions where needed. Example plots of these distributions are shown in Figure 8B.3.1.

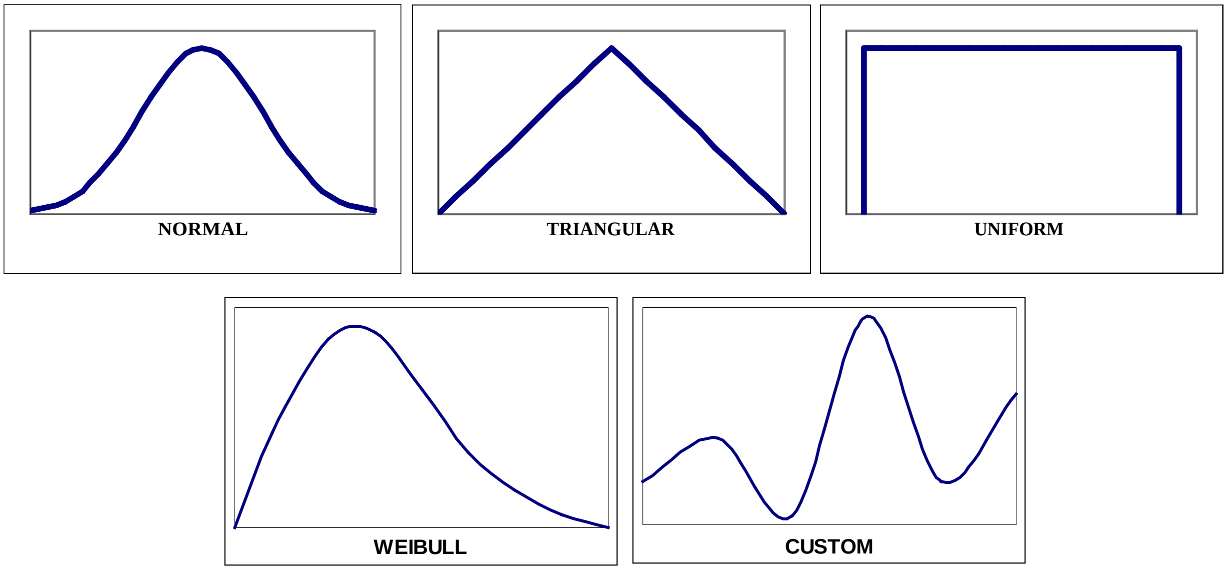

Figure 8B.3.1 Normal, Triangular, Uniform, Weibull, and Custom Probability Distributions

APPENDIX 8C. ENERGY PRICE CALCULATIONS FOR DISHWASHERS

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APPENDIX 8C. Energy Price Calculations for dishwashers

8C.1 INTRODUCTION

Figure 8C.1.1 depicts the energy price calculation process, which also encompasses average energy price, seasonal marginal price factor, and monthly price factor calculations.

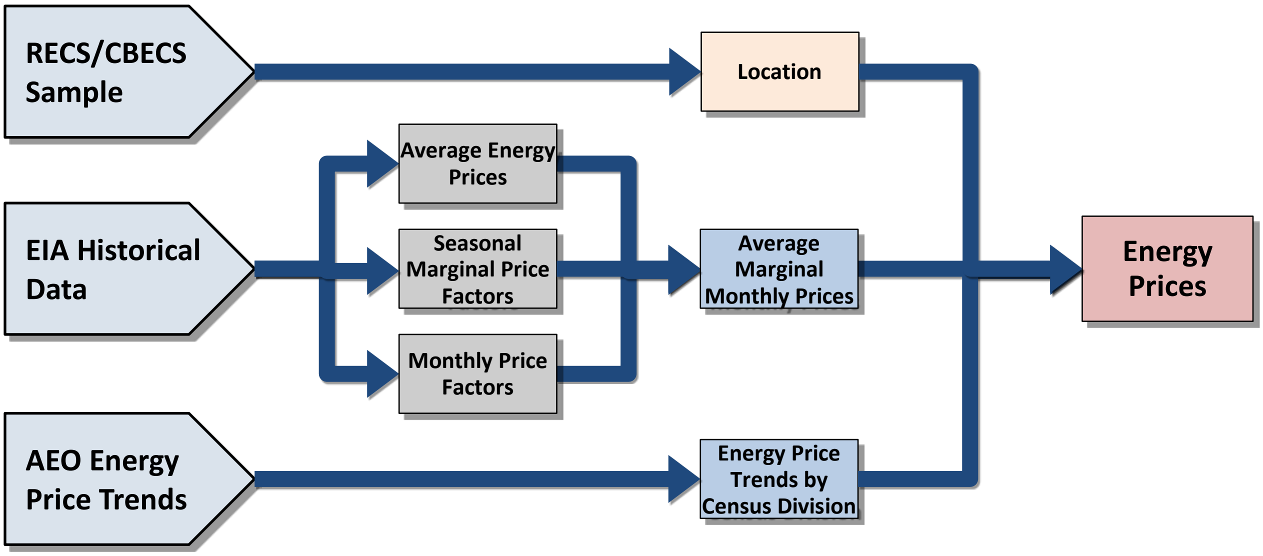

Figure 8C.1.1 Energy Price Calculation Process

8C.2 RECS/CBECS SAMPLE MAPPING PROCESS

To match the regional data from the Energy Information Administration's (EIA's) *2015 Residential Energy Consumption Survey* (RECS 2015)[1] building samples by geographic area, DOE used population by state to appropriately weight the EIA energy price data.[2] RECS 2015 utilizes 10 regions.

8C.3 AVERAGE MARGINAL MONTHLY PRICES

8C.3.1 Average Annual Prices Determination

8C.3.1.1 Annual Electrical Prices

DOE derived 2020 annual electricity prices from EIA's Form 861M.[3] The EIA Form 861M data include residential and commercial energy prices by state. Table 8C.3.1 shows the monthly residential electricity prices for each state reported in the EIA Form 861M.

Table 8C.3.1 Monthly Residential Electricity Prices by State from EIA (2020¢/kWh)

Geographical Area	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg. 2020
United States	12.79	12.85	13.08	13.28	13.15	13.27	13.25	13.31	13.54	13.70	13.35	12.80	13.20
Alabama	22.59	22.17	22.33	22.29	23.16	23.90	23.99	23.75	23.49	23.44	22.53	21.93	22.96
Alaska	12.38	12.39	12.76	12.87	12.68	12.92	12.68	12.75	13.18	13.17	12.99	11.39	12.68
Arizona	9.83	9.89	10.13	10.66	10.50	10.67	10.74	10.47	10.84	10.76	10.58	9.87	10.41
Arkansas	11.68	11.88	12.16	12.78	12.99	12.77	12.70	12.37	12.53	12.26	11.69	12.18	12.33
California	19.93	21.70	20.49	20.47	18.69	19.78	20.10	20.76	21.21	20.85	22.26	20.45	20.56
Colorado	11.74	11.89	12.04	12.13	12.06	12.96	12.84	12.84	13.20	12.49	12.38	12.14	12.39
Connecticut	22.10	23.70	23.30	23.50	23.96	21.73	22.05	22.13	23.68	22.69	21.41	20.39	22.55
Delaware	12.38	12.80	13.03	12.41	12.77	12.78	11.81	12.12	12.55	13.61	13.35	12.96	12.71
District of Columbia	12.17	12.59	12.95	12.98	13.58	13.22	11.90	12.15	12.09	14.06	13.63	12.51	12.82
Florida	11.72	11.76	11.63	11.71	9.84	11.53	11.71	11.61	11.97	11.71	12.00	11.86	11.59
Georgia	10.87	11.06	11.38	11.38	11.81	12.68	12.64	12.86	12.10	11.88	11.36	10.80	11.74
Hawaii	31.70	33.37	33.10	32.77	30.94	29.03	28.87	28.87	29.99	29.01	28.84	29.14	30.47
Idaho	11.72	11.90	12.40	12.74	14.35	13.50	14.74	14.62	13.15	13.02	12.34	11.31	12.98
Illinois	9.91	9.45	9.64	9.51	9.90	10.50	10.81	10.39	10.07	10.33	9.67	9.92	10.01
Indiana	12.63	12.81	13.19	13.76	14.12	12.74	12.01	12.35	12.41	13.75	13.41	12.32	12.96
Iowa	11.91	11.84	12.19	12.60	12.65	12.61	12.23	12.32	13.04	13.65	13.23	12.69	12.58
Kansas	11.82	12.18	12.67	13.02	13.77	12.88	12.88	12.97	12.43	13.03	12.98	12.22	12.74
Kentucky	10.62	10.43	10.76	11.13	11.13	10.84	10.55	10.67	11.03	11.50	11.43	10.53	10.89
Louisiana	9.05	8.87	9.07	9.25	9.67	9.49	9.34	9.41	9.76	10.28	9.94	9.54	9.47
Maine	22.90	23.05	22.78	23.22	22.25	20.99	21.32	21.68	21.51	21.64	22.10	21.54	22.08
Maryland	13.42	13.35	13.59	13.22	13.23	12.84	12.24	12.48	12.95	13.86	13.27	12.73	13.10
Massachusetts	16.81	17.04	16.56	16.80	16.82	16.91	16.84	16.82	17.21	16.84	16.47	16.51	16.80
Michigan	15.74	15.92	16.05	16.14	16.32	16.72	16.34	16.60	16.99	16.92	16.43	16.47	16.39
Minnesota	12.49	12.75	12.85	13.19	13.71	14.20	13.82	14.16	14.44	13.87	12.92	12.87	13.44
Mississippi	9.52	9.37	9.99	10.29	12.12	12.74	12.58	12.40	10.93	10.65	10.07	9.30	10.83
Missouri	11.33	11.12	11.54	11.68	11.82	11.20	10.90	10.77	10.84	11.58	11.98	11.25	11.33
Montana	11.15	11.30	11.32	11.23	11.67	12.00	12.09	11.94	12.04	11.84	11.22	11.02	11.57
Nebraska	11.01	11.47	11.67	11.99	11.74	11.44	11.25	11.55	12.15	12.16	11.63	10.60	11.56
Nevada	9.01	9.28	10.00	10.20	11.27	12.09	11.89	11.91	12.37	10.70	10.26	9.39	10.70
New Hampshire	9.59	10.01	10.55	11.04	11.70	11.42	11.67	11.94	12.03	11.49	10.73	10.13	11.03
New Jersey	19.90	19.71	18.97	19.38	19.34	19.00	18.33	18.28	19.03	19.34	19.20	18.74	19.10
New Mexico	15.43	15.73	16.14	15.93	15.63	15.85	16.60	16.48	16.34	15.96	15.69	15.99	15.98
New York	12.08	12.48	12.47	12.61	12.24	13.48	13.83	13.97	14.33	13.48	12.94	12.27	13.02
North Carolina	11.98	12.03	12.12	11.79	11.42	11.19	10.72	10.79	11.97	11.41	11.61	11.20	11.52
North Dakota	17.55	17.42	17.17	17.33	18.53	19.11	18.73	18.41	18.98	19.28	18.92	18.23	18.31
Ohio	11.72	11.58	11.91	12.40	12.44	12.06	12.09	12.06	12.09	12.76	12.35	11.80	12.11
Oklahoma	9.05	9.32	9.84	10.27	9.89	10.24	10.11	10.29	10.87	10.69	10.27	8.88	9.98
Oregon	10.69	10.86	10.95	11.02	11.41	11.32	11.30	11.28	11.39	11.34	11.12	10.89	11.13
Pennsylvania	13.63	13.70	13.75	13.76	13.99	13.61	13.30	13.25	13.56	13.89	13.52	13.15	13.59
Rhode Island	24.23	22.64	23.25	23.37	21.20	19.28	19.52	22.13	21.98	22.43	23.58	22.59	22.18
South Carolina	12.26	12.27	12.78	13.06	12.77	12.57	12.35	12.52	12.91	12.90	12.68	11.78	12.57
South Dakota	10.67	11.11	11.17	11.56	12.12	12.17	12.31	12.70	12.69	12.53	12.02	11.39	11.87
Tennessee	10.84	10.59	10.81	10.84	10.99	10.92	10.77	10.55	10.60	11.06	11.10	10.41	10.79
Texas	11.73	11.96	12.08	12.29	12.02	11.99	11.81	11.73	12.00	12.09	12.19	11.87	11.98
Utah	10.09	10.17	10.16	10.35	10.56	10.91	11.09	11.32	10.93	10.41	10.29	10.19	10.54

Geographical Area	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg. 2020
Vermont	11.68	12.12	12.26	12.73	12.37	12.37	12.28	12.34	12.10	12.49	11.65	11.21	12.13
Virginia	19.27	19.39	19.60	19.53	19.75	19.67	19.01	19.17	19.79	20.09	19.68	19.04	19.50
Washington	9.43	9.42	9.60	9.67	9.87	9.92	9.85	9.92	10.04	9.90	9.83	9.77	9.77
West Virginia	14.31	14.71	14.73	14.89	15.24	15.00	14.53	14.72	15.38	15.23	14.77	14.52	14.84
Wisconsin	10.89	11.27	12.05	11.89	12.12	11.98	11.69	11.73	12.23	13.00	12.46	11.41	11.89
Wyoming	10.49	10.59	10.71	11.04	11.52	11.81	11.89	11.72	11.91	11.76	11.12	10.66	11.27

DOE calculated residential annual electricity prices for each RECS 2015 geographical area by averaging monthly electricity prices by State to get State electricity prices in 2020. For areas with more than one State, DOE weighted each state's average price by its number of people in each state. Table 8C.3.2 shows the shipment-weighted average residential electricity prices in 2020 for each adjusted RECS 2015 geographic areas.

Table 8C.3.2 DOE Average Residential Electricity Prices by Region in 2020

	Geographic Area	2020$/kWh
1	New England	$0.183
2	Middle Atlantic	$0.145
3	East North Central	$0.126
4	West North Central	$0.126
5	South Atlantic	$0.129
6	East South Central	$0.139
7	West South Central	$0.116
8a	Mountain (North)	$0.119
8b	Mountain (South)	$0.113
9	Pacific	$0.183
10	U.S. Average	$0.132

8C.3.1.2 Annual Natural Gas Prices

DOE obtained the data for natural gas prices from EIA's Natural Gas Navigator,[4] which includes monthly natural gas prices by state for residential, commercial, and industrial customers. Table 8C.3.3 shows the monthly residential natural gas prices for each state.

Table 8C.3.3 2020 Monthly Residential Natural Gas Prices by State from EIA (2020$/tcf)

Geographical Area	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg. 2020
United States	9.51	9.12	9.85	10.66	11.85	15.37	17.63	18.42	16.99	12.36	11.07	9.81	12.72
Alabama	14.77	14.33	14.52	17.21	17.93	20.44	22.46	22.74	22.93	21.24	18.58	14.23	18.45
Alaska	10.55	10.76	10.79	11.36	12.34	13.47	14.19	13.78	12.27	11.10	10.61	10.59	11.82
Arizona	10.85	11.17	11.92	13.74	16.74	17.77	19.19	20.43	19.95	17.34	13.51	11.16	15.31
Arkansas	11.18	10.39	10.69	11.35	12.63	16.31	19.03	21.17	20.79	16.74	12.44	11.05	14.48
California	15.02	14.57	13.70		14.56	14.58	14.34	14.34	14.75	14.74	14.38	15.32	14.57
Colorado	5.92	5.80	6.44	6.59	8.78	11.46	13.25	13.37	10.31	8.05	7.44	6.94	8.70
Connecticut	12.80	12.84	13.40	14.28	15.55	19.67	21.91	23.68	23.03	18.31		13.44	17.17
Delaware	11.38				14.26	19.40	24.51	26.11	25.29	19.98	14.66	11.82	18.60

Geographical Area	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg. 2020
District of Columbia	11.38	10.63	10.50	12.26	12.64	16.09	19.77	20.63	20.78	16.93	13.48	11.17	14.69
Florida		18.61		19.91		22.19	25.14		26.23	25.26	23.47	20.24	22.63
Georgia		12.06	13.48	15.71		23.81	27.70	29.48	28.22	24.88	21.71	11.71	20.88
Hawaii	43.17	43.98			35.00	38.30	38.17	37.36	37.28	37.84	37.96	38.60	38.77
Idaho	6.26	6.22	6.54	6.90	7.57	8.19	10.12	9.71	8.48	7.30	6.42	6.24	7.50
Illinois	6.36	6.25	6.99	7.50	9.18	12.65	18.97	19.53	16.59	8.85	7.99	6.79	10.64
Indiana	7.06	6.63	7.61	8.01	10.72	18.66	21.00	22.18	18.25	10.42	8.90	6.91	12.20
Iowa	6.17	5.99	7.00	7.12	10.69	13.70		18.15	15.76	9.72	8.16	6.51	9.91
Kansas	7.22	6.99	8.34	9.80	13.99	20.74	21.05		18.40	10.25	9.58	8.24	12.24
Kentucky	9.59	8.73	10.64	11.07	15.59	21.44	25.01	26.22	24.27	13.76	11.21	8.79	15.53
Louisiana		10.33	11.01	12.89	13.74	15.13	15.98	17.68	17.64	15.82	14.16	10.45	14.08
Maine	13.70	14.84	13.24	13.41	14.47	20.02	25.39	28.00	22.85		14.87	13.75	17.69
Maryland	11.70	12.14	12.51	11.92	14.19	18.61	19.29	22.03	20.87	17.43	14.55	11.89	15.59
Massachusetts	14.19	14.14	14.25	14.52	13.57	13.23	15.30	15.71	15.04			15.40	14.54
Michigan	7.28	7.25	7.70	8.28	9.27	12.43	13.97	14.31	11.24	8.66	8.31	7.72	9.70
Minnesota			7.04	7.26	9.29		12.76	11.36	10.94	8.04	8.37	7.89	9.22
Mississippi	9.40	9.47	11.21		14.61	16.49	17.38	18.76	19.05	15.43	12.49	9.89	14.02
Missouri	8.49	8.26	9.04	10.06	12.52	18.86	23.85		24.04	15.17	10.98	8.98	13.66
Montana	6.52	6.54	6.59	6.61	7.19	8.47	9.78	11.43	10.94		7.64	7.16	8.08
Nebraska	6.35	6.17	6.46	6.90	8.56	11.61	14.35	15.99	15.38	12.43	8.75	7.91	10.07
Nevada	9.59	9.91	10.23	10.98	12.24	13.21	13.66	13.84	13.44	11.76	9.20	8.18	11.35
New Hampshire	14.24	13.94	13.16	13.07	11.95	15.40	20.38	23.22	22.60	19.20	16.09	15.56	16.57
New Jersey	9.56	9.15	9.09	9.55	9.95	12.43	12.99	13.29	13.14	11.48	10.19	9.39	10.85
New Mexico	6.00		5.66	5.70	7.47	10.32	10.54	12.74	11.93	11.16	7.81	7.21	8.78
New York	11.39	11.64	11.95	12.10	11.58	16.06	19.36	19.85	19.27	16.13	13.70	12.17	14.60
North Carolina	11.80	11.62	14.41	14.05				20.42	19.24	21.55	15.36	11.27	15.52
North Dakota	5.56	5.51	5.67	6.08	7.99	12.54	20.23	20.62	15.16	8.64	6.43	5.74	10.01
Ohio	7.30	6.99	7.82	8.50	11.12		27.01	28.61	23.14	13.20	9.60	7.49	13.71
Oklahoma	6.70	6.29	6.87	8.41	11.48	16.93	23.22	25.43	23.14	18.64	9.44	8.02	13.71
Oregon	10.88	10.39	9.84	10.01	12.15		13.67	15.58	14.93	11.37	10.38	10.05	11.75
Pennsylvania	10.38	10.57	10.90	11.14	11.72	16.44	19.99	20.65	18.82	13.72	10.98	10.20	13.79
Rhode Island	13.52	13.79	13.91	14.38	15.09	17.58	19.88	21.54	21.54	18.98	16.15	15.45	16.82
South Carolina	11.44	10.84	14.10	16.27	17.16		26.07	26.27	24.85	20.83	15.85	10.32	17.64
South Dakota	6.00	6.27	6.83	6.62	7.79	9.91	14.67	15.32	12.68	8.40	7.12	6.44	9.00
Tennessee	8.01	7.61		9.15		13.36	17.40	20.02	17.08	12.92	9.49	7.52	12.26
Texas	8.32	8.13	9.34	13.23	15.96	18.88	19.91	21.59	21.75		14.12	10.41	14.69
Utah	8.17	8.20	8.37		8.72	8.89	9.12	10.08	9.71	9.48	7.41	8.34	8.77
Vermont	11.62	11.29	11.98	12.25	13.18	17.59	22.06	23.80	21.69	17.19	13.87	12.60	15.76
Virginia	11.90	10.94	11.55	12.42		16.18	19.42	20.45	19.15	16.55	14.60	11.54	14.97
Washington	10.23	10.20	10.28	11.26	12.09	12.99	14.44	14.99	14.40	10.89	10.59	10.57	11.91
West Virginia	9.10	9.17	9.39	10.04	11.12	13.78	18.59	20.14	15.35	11.67	9.96	9.03	12.28
Wisconsin	6.78	6.87	7.03	6.71	7.81	11.56	13.28	14.06	12.16	6.99	7.85	7.12	9.02
Wyoming	7.04	7.09	7.47	8.01	9.22	12.12	16.08		16.45	12.14	8.42	7.98	10.18

Note: tcf = thousand cubic feet

DOE calculated residential annual natural gas prices for each RECS 2015 geographical area by averaging monthly natural gas prices by state to get State natural gas prices in 2020. For areas with more than one State, DOE weighted each State's average price by its population in 2019. DOE also used a conversion factor (1.023) to convert cubic feet of natural gas to MMBtu.[a] Table 8C.3.4 displays the 2020 shipment-weighted average residential natural gas prices by adjusted RECS 2015 geographic region.

Table 8C.3.4 Calculated Average Residential Natural Gas Prices by Region in 2020

	Geographic Area	2020$/MMBtu
1	New England	$15.27
2	Middle Atlantic	$13.05
3	East North Central	$10.83
4	West North Central	$10.67
5	South Atlantic	$18.17
6	East South Central	$14.31
7	West South Central	$14.01
8a	Mountain (North)	$8.25
8b	Mountain (South)	$12.83
9	Pacific	$14.02
10	U.S. Average	$12.27

8C.3.1.3 Annual LPG Prices

DOE collected 2019 average LPG prices from EIA's 2019 State Energy Consumption, Price, and Expenditures Estimates (SEDS).[5] SEDS includes annual LPG prices for residential, commercial, industrial, and transportation consumers by state. Table 8C.3.5 shows the annual residential LPG prices for each state.

Table 8C.3.5 2019 Residential Average LPG Prices by State from EIA (2019$/MMBtu)

Geographical Area	Avg. 2019
United States	22.72
Alabama	23.81
Alaska	28.91
Arizona	27.23
Arkansas	22.58
California	26.89
Colorado	20.92
Connecticut	32.05
Delaware	27.42
District of Columbia	30.32
Florida	36.98
Georgia	27.89
Hawaii	44.27
Idaho	22.85
Illinois	16.69
Indiana	19.92
Iowa	13.86

[a] www.eia.gov/tools/faqs/faq.cfm?id=45&t=7

Geographical Area	Avg. 2019
Kansas	16.22
Kentucky	23.2
Louisiana	26.41
Maine	28.96
Maryland	30.57
Massachusetts	34.79
Michigan	19.15
Minnesota	16.61
Mississippi	25.45
Missouri	16.78
Montana	19.23
Nebraska	13.82
Nevada	27.16
New Hampshire	28.7
New Jersey	34.2
New Mexico	23.69
New York	30
North Carolina	28.81
North Dakota	15.29
Ohio	24.86
Oklahoma	17.37
Oregon	24.87
Pennsylvania	26.1
Rhode Island	35.73
South Carolina	31.59
South Dakota	15.47
Tennessee	21.78
Texas	24.78
Utah	21.84
Vermont	28.9
Virginia	29.88
Washington	23.02
West Virginia	31.23
Wisconsin	15.38
Wyoming	21.13

For areas with more than one state, DOE weighted each state's average price by its shipments. All prices in 2019$ were converted to 2020$ using the CPI to be consistent with the prices used in the rest of the analysis.[b] Table 8C.3.6 shows the 2019 population-weighted average residential LPG prices for each adjusted RECS 2015 geographic area. DOE escalated the prices to 2020 using EIA's 2020 Annual Energy Outlook (AEO" 2020).[6]

[b] www.bls.gov/cpi/

Table 8C.3.6 Average Residential LPG Prices by Region in 2020

	Geographic Area	2020$/MMBtu
1	New England	$33.29
2	Middle Atlantic	$30.05
3	East North Central	$19.80
4	West North Central	$16.04
5	South Atlantic	$32.37
6	East South Central	$23.45
7	West South Central	$24.41
8a	Mountain (North)	$21.57
8b	Mountain (South)	$26.99
9	Pacific	$26.95
10	U.S. Average	$33.29

8C.3.1.1 Annual Fuel Oil Prices

DOE collected 2019 average fuel oil prices from EIA's 2019 State Energy Consumption, Price, and Expenditures Estimates (SEDS).[5] SEDS includes annual fuel oil prices for residential, commercial, industrial, and transportation consumers by state. Table 8C.3.7 shows the annual residential fuel oil prices for each state.

Table 8C.3.7 2019 Residential Average Fuel Oil Prices by State from EIA (2019$/MMBtu)

Geographical Area	Avg. 2019
United States	19.34
Alabama	16.29
Alaska	20.16
Arizona	21.28
Arkansas	16.68
California	21.61
Colorado	18.63
Connecticut	18.81
Delaware	19.92
District of Columbia	21.15
Florida	18.78
Georgia	18.43
Hawaii	—
Idaho	19.19
Illinois	18.57
Indiana	18.92
Iowa	18.06
Kansas	18.62
Kentucky	18.92
Louisiana	16.36
Maine	18.83
Maryland	21.48
Massachusetts	18.97
Michigan	18.39
Minnesota	19.79

Geographical Area	Avg. 2019
Mississippi	16.76
Missouri	18.22
Montana	18.1
Nebraska	17.95
Nevada	21.53
New Hampshire	17.89
New Jersey	20.41
New Mexico	16.46
New York	19.25
North Carolina	18.45
North Dakota	18.35
Ohio	18.42
Oklahoma	18.27
Oregon	20.15
Pennsylvania	20.61
Rhode Island	19.18
South Carolina	18.78
South Dakota	18.27
Tennessee	18.7
Texas	16.64
Utah	19.2
Vermont	19.24
Virginia	18.78
Washington	21.46
West Virginia	18.78
Wisconsin	17.99
Wyoming	18.83

For areas with more than one state, DOE weighted each state's average price by its shipments. All prices in 2019$ were converted to 2020$ using the CPI to be consistent with the prices used in the rest of the analysis.[c] Table 8C.3.8shows the 2019 population-weighted average residential LPG prices for each adjusted RECS 2015 geographic area. DOE escalated the prices to 2020 using EIA's 2020 Annual Energy Outlook (AEO" 2020).[6]

[c] www.bls.gov/cpi/

Table 8C.3.8 Average Residential Fuel Oil Prices by Region in 2020

	Geographic Area	2020$/MMBtu
1	New England	$19.07
2	Middle Atlantic	$20.17
3	East North Central	$18.70
4	West North Central	$18.88
5	South Atlantic	$19.18
6	East South Central	$18.07
7	West South Central	$16.97
8a	Mountain (North)	$19.05
8b	Mountain (South)	$20.85
9	Pacific	$21.70
10	U.S. Average	$19.07

8C.3.2 Seasonal Marginal Price Factors Determination

Marginal energy prices are the prices consumers pay for the last unit of energy used. DOE used the marginal energy prices for each building to determine the cost of saved energy associated with the use of higher-efficiency products. Because marginal prices reflect a change in a consumer's bill associated with a change in energy consumed, such prices are appropriate for determining energy cost savings associated with possible changes to efficiency standards.

EIA provides historical monthly electricity and natural gas consumption and expenditures by state. This data was used to determine 10-year average marginal prices for the RECS 2015 geographical areas, which are then used to convert average monthly energy prices into marginal monthly energy prices. Because a pool heater can operate during year round, DOE determined summer and winter marginal price factors.

For LPG and fuel oil, DOE used the average LPG and fuel oil prices for each sampled dishwasher for both base case products and higher-efficiency products, as the data necessary for estimating marginal prices were not available.

8C.3.2.1 Marginal Price Factor Calculation for Electricity and Natural Gas

Table 8C.3.9 and Table 8C.3.10 show the resulting electricity and natural gas marginal price factors.

Table 8C.3.9 Residential Marginal Electricity Price Factors using EIA 2011-2020 Data

Geographical Area	Summer	Winter
New England	0.91	0.97
Middle Atlantic	1.04	0.93
East North Central	1.00	0.85
West North Central	1.06	0.80
South Atlantic	1.02	0.92
East South Central	0.97	0.86
West South Central	0.97	0.85
Mountain (North)	1.14	0.90
Mountain (South)	1.02	0.84
Pacific	1.18	0.97
United States	1.04	0.84

Table 8C.3.10 Residential Marginal Natural Gas Price Factors using EIA 2011-2020 Data

Geographical Area	Summer	Winter
New England	0.83	0.96
Middle Atlantic	0.64	0.91
East North Central	0.55	0.85
West North Central	0.57	0.85
South Atlantic	0.58	0.79
East South Central	0.58	0.84
West South Central	0.52	0.73
Mountain (North)	0.71	0.87
Mountain (South)	0.59	0.77
Pacific	0.87	1.01
United States	0.60	0.86

8C.3.3 Results

To aggregate the State level energy prices into the RECS 2015 regions, DOE weighted each State's average energy price by the State's population in 2019.[2] Table 8C.3.11 shows the resulting annual average and marginal energy prices for residential.

Table 8C.3.11 Residential Energy Prices by RECS 2015 Regions for 2020

	Census Division	Electricity (2020$/kWh)		Natural Gas (2020$/MMBtu)		LPG (2020$/MMBtu)	Fuel Oil (2020$/MMBtu)
		Average	Marginal	Average	Marginal	Average*	Average*
1	New England	$0.183	$0.171	$15.27	$13.54	$33.29	$19.07
2	Middle Atlantic	$0.145	$0.144	$13.05	$9.80	$30.05	$20.17
3	East North Central	$0.126	$0.117	$10.83	$7.29	$19.80	$18.70
4	West North Central	$0.126	$0.120	$10.67	$7.34	$16.04	$18.88
5	South Atlantic	$0.129	$0.126	$18.17	$12.11	$32.37	$19.18
6	East South Central	$0.139	$0.128	$14.31	$9.85	$23.45	$18.07
7	West South Central	$0.116	$0.106	$14.01	$8.53	$24.41	$16.97
8a	Mountain (North)	$0.119	$0.123	$8.25	$6.42	$21.57	$19.05
8b	Mountain (South)	$0.113	$0.107	$12.83	$8.54	$26.99	$20.85
9	Pacific	$0.183	$0.201	$14.02	$12.97	$26.95	$21.70

* Average and marginal energy prices for LPG and fuel oil are the same.

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APPENDIX 8D. WATER AND WASTEWATER PRICE DETERMINATIONS

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APPENDIX 8D. WATER AND WASTEWATER PRICE DETERMINATIONS

8D.1 INTRODUCTION

Consumers pay a range of prices for residential water and wastewater services depending on several factors, including whether those services are provided by a public utility or a private well and septic system. This appendix summarizes the considerations and methodology the DOE applied to determine water and wastewater prices when examining lifetime savings associated with new performance standards for dishwashers.

8D.2 PRICES FOR PUBLIC WATER AND WASTEWATER SERVICES

DOE calculated prices for water and wastewater systems operated by public utilities based on data in the *2016 Water and Wastewater Rate Survey*[1] conducted by the American Water Works Association (AWWA) and Raftelis Financial Consultants, Inc. (RFC). AWWA/RFC collected data from 262 water utilities and 181 wastewater utilities. The survey identifies prices for residential and non-residential customers separately. DOE's analysis used only the residential categories of the survey to estimate the prices consumers pay. For each water utility, the survey provides the cost to consumers of purchasing a given volume of water. The data are divided into fixed and volumetric charges. DOE uses only the volumetric charges to calculate water prices, because only those charges would be affected by a change in water consumption. The survey format is similar for wastewater utilities, except the price represents the charge for collecting a given volume of wastewater.

The size of the AWWA/RFC sample is sufficient to calculate geographically distinct prices for the four U.S. census regions, but not for the smaller census divisions.[a] DOE took the following steps to calculate average prices per unit volume of water or wastewater for the Northeast, South, Midwest, and West census regions.

1. For each water or wastewater utility, calculate the price per unit volume by dividing the total volumetric charges by the volume of water delivered or wastewater collected.
2. Calculate a state-level average price by weighting each utility in a given state by the number of customers it serves.
3. Calculate a regional average price by combining the appropriate state-level averages, weighting each by the population of the associated state. This third step helps reduce any bias in the sample that may occur because of the relative under-sampling of large States.

[a] For comparison, the U.S. Energy Information Administration's Form 861 collects data from more than 3,000 utilities.

4. Calculate a national average based on all regional averages.

Table 8E.2.1 presents the results of DOE's calculations in terms of 2020 dollars per 1,000 gallons of water delivered or wastewater collected (2020$/1,000 gal).

Table 8D.2.1 Average 2016 Prices for Public Utility Residential Water and Wastewater Services

Region	**Average Water Price** *2020$/1,000 gal*	**Average Wastewater Price** *2020$/1,000 gal*	**Marginal Water Price** *2020$/1,000 gal*	**Marginal Wastewater Price** *2020$/1,000 gal*
Northeast	$4.84	$6.91	$4.10	$5.28
Midwest	$4.46	$6.71	$3.42	$5.72
South	$4.75	$6.38	$4.60	$5.37
West	$6.99	$6.78	$5.41	$4.20
National Average	$5.23	$6.61	$4.45	$5.14

8D.3 WATER COSTS FOR HOUSEHOLDS USING PRIVATE WELLS

This section outlines DOE's calculation of the water costs incurred by users of private residential wells.

8D.3.1 Number of Residential Water Well Users

In 2020, the National Groundwater Association (NGWA) published an estimate that 13,100,000 American households[b] are served by privately owned individual wells[2] (149,000 less than the 13,249,000 in 2009). The American Housing Survey (AHS) collects data on the primary source of water households rely on, including private wells. To determine the current percentage of the U.S. population served by private wells, DOE used historical AHS data from 1970 to 2019 to develop a projection for 2027, the effective year of potential new standards for dishwashers.[3] Table 8D.3.1 lists the percentages of consumers served by public water systems and by private wells by census region for all occupied housing units[c] in the United States for the most recent (2019) AHS survey.

[b] NGWA sites the U.S. Census, American Housing Survey, 2013.

[c] DOE's calculations incorporated values for "all occupied housing units" when available; some older AHS surveys simply extrapolated the water source for all units.

Table 8D.3.1 Distribution of Users of Public Supply and Private Well Water

Year	Nation		Northeast		Midwest		South		West	
	Public	Well	Public	Well	Public	Well	Public	Well	Public	Well
	%		%		%		%		%	
2019	88.9	11.1	84.3	15.7	84.9	15.1	90.7	9.3	93.4	6.6
2027	90.3	9.7	84.2	15.8	86.2	13.8	93.2	6.8	93.5	6.5

Except for the Northeast, which is projected to experience a slight increase in private well use, all census regions are expected to observe a decline in users of private wells and an increase in users of public water systems. A 2020 paper[4] produced by the U.S. Geological Survey found that the percentage of people using domestic wells has been falling nationally given population increases in urban areas relative to rural areas without public supply access. Additionally, household size is decreasing resulting in fewer people served by a single well.

8D.3.2 Determining Costs for Well Water

DOE considered several factors when developing consumer prices for water supplied by private wells. Initial costs to install a well include well siting, well drilling, pump purchase and installation, water testing, and sometimes a water treatment system. Ongoing costs include pump maintenance; pump fuel to lift water to the surface and to the point of use or storage; plus any required maintenance of the treatment system (water-softening chemicals, filters, etc.). Information about the prevalence and cost of treatments used for well water, however, was unavailable. DOE followed three steps to calculate the average cost per unit volume for private well water.

1. For each household that uses a private well, divide the total annual economic value of pumped water by the number of people in the household. Further divide by 360 days for a daily economic value of pumped water per person.
2. Calculate a value per gallon by assuming a daily water usage of 100 gallons per person.
3. Calculate a value per thousand gallons to compare with prices of publically supplied water.

Table 8D.3.2 summarizes the values DOE used to determine a residential well water price of $1.93 per thousand gallons in 2009$.

Table 8D.3.2 Calculation of Costs for Well Water in 2009

Measure	2009$
Annual economic value of pumped water for all well-using households	3,090,000,000
Annual economic value per user	69.64 [a]
Daily economic value per person	0.19
Value per gallon	0.002[b]
Value per thousand gallons	1.93

[a] Based on 13,249,000 households comprising 3.35 persons per household.
[b] Based on NGWA assumption that each individual uses 100 gallons daily.

For this rulemaking, DOE scaled the 2009 values for well water to 2020 dollars using the consumer price index. In 2020$ the value per thousand gallons of well water is $2.80.

8D.3.3 Weighted-Average Residential Water Prices

Table 8D.3.3 shows regional water prices for both the public supply system (calculated from AWWA/RFC's *2016 Water and Wastewater Rate Survey*) and the adjusted regional costs for well water. Estimated prices per thousand gallons are given in 2020 dollars (2020$/1,000 gal). The top row shows the percent of the U.S. population that resides in each census region based on 2020 projection from the U.S. Census Bureau.[d] DOE used those percentages to develop prices for each census region.

Table 8D.3.3 National and Regional Water Prices

	National	Northeast	Midwest	South	West
Regional population *%*	—	17.0	20.7	38.0	24.3
Public supply price *2020$/1,000 gal*	5.23	4.84	4.46	4.75	6.99
Well water population *%*	9.7	15.8	13.8	6.8	6.5
Well water cost *2020$/1,000 gal*	2.80	2.64	2.78	2.63	3.19

DOE applied each regional cost for well water in Table 8D.3.3 to the percentage of well users in the associated region (using projections in Table 8D.3.1 for the 2027 standards year). DOE then applied each regional price for public supply water in Table 8D.3.3 to the percentage of public supply users in that region (using projections in Table 8D.3.1). Prices for both public supply and private well water then were summed for each region to arrive at overall average water prices by region. Table 8D.3.4 shows the final weighted-average regional and national

[d] http://www.census.gov/popest/.

water prices for residential consumers. DOE used those weighted-average water prices in its analysis.

Table 8D.3.4 Weighted-Average 2016 Residential Water Prices (2020$/1000 gal)

Region	Average Water Price *2020$/1,000 gal*	Average Wastewater Price *2020$/1,000 gal*	Marginal Water Price *2020$/1,000 gal*	Marginal Wastewater Price *2020$/1,000 gal*
Northeast	$4.53	$6.91	$3.91	$5.28
Midwest	$4.26	$6.71	$3.37	$5.72
South	$4.62	$6.38	$4.49	$5.37
West	$6.76	$6.78	$5.28	$4.20
National Average	$5.02	$6.61	$4.32	$5.14

8D.4 WASTEWATER PRICES FOR CONSUMERS USING SEPTIC SYSTEMS

Two studies indicate that the costs for private septic systems are similar to the prices charged for public wastewater services. A study conducted by the Ohio Department of Health found costs for septic operation and maintenance to be similar to prices for public wastewater services. [5] The study, which asked local health districts to collect cost data from nearly 6,000 sewage treatment systems, concluded that “annual system costs (system installation plus operation and maintenance) amortized over 30 years were calculated and ranged from $336 (conventional system) to $1,172 (drip distribution) which is very similar to the state average sewer rate prices of $442 annually, and 30 year annual costs of $504 to $1,272 with the addition of connection fees and costs.”

The Montana Department of Environmental Quality estimated monthly costs for various types of septic systems and for municipal wastewater services. The monthly price for municipal wastewater service was found to be close to monthly septic system costs.[6]

Given the similarity in operating costs between private septic systems and public sewer services, as well as the lack of national data on costs for private septic systems, for this dishwasher rulemaking DOE assumed that the costs residential consumers incur from maintaining and operating a septic system are equal to the prices charged by public wastewater systems. DOE applied the nationwide price calculated for publically owned wastewater services, which is $6.15 per thousand gallons as derived by the *2016 Water and Wastewater Rate Survey*, to consumers who utilize residential septic systems.

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APPENDIX 8E. LIFETIME DISTRIBUTIONS

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APPENDIX 8E. LIFETIME DISTRIBUTIONS

8E.1 INTRODUCTION

The U.S. Department of Energy (DOE) characterized the lifetimes of both product classes of dishwashers (standard-sized 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]

8E.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,
α = scale, and
β = 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.

8E.3 LIFETIME DISTRIBUTION FOR DISHWASHERS

The Energy Information Administration's Residential Energy Consumption Survey (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, 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 and 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. Table 8E.3.1 shows the average lifetimes used to determine the Weibull distribution parameters α and β for dishwashers.

Table 8E.3.1 Distribution Parameters for Dishwashers

Value	Weibull Parameters	
Average (years)	**Alpha - α (scale)**	**Beta - β (shape)**
15.19	15.88	1.82

Figure 8E.3.1 shows the Weibull distribution for the lifetime of both standard and compact dishwashers. DOE used an average lifetime of 15.19 years in its analyses.

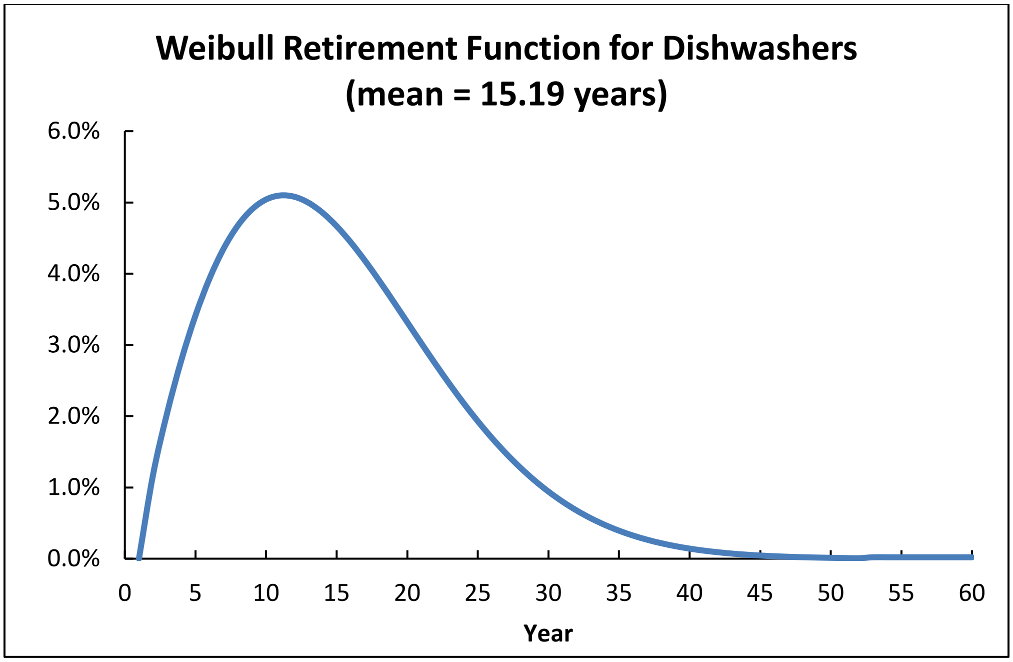

Figure 8E.3.1 Weibull Retirement Probability Distribution for Dishwashers

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APPENDIX 8F. DISTRIBUTIONS USED FOR DISCOUNT RATES

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APPENDIX 8F. Distributions Used for Discount Rates

8F.1 INTRODUCTION: DISTRIBUTIONS USED FOR RESIDENTIAL CONSUMER DISCOUNT RATES

The Department of Energy (DOE) derived consumer discount rates for the life-cycle cost (LCC) analysis using data on interest or return rates for various types of debt and equity to calculate a real effective discount rate for each household in the Federal Reserve Board's *Survey of Consumer Finances* (*SCF)* in 1995, 1998, 2001, 2004, 2007, 2010, 2013, and 2016.[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.

8F.1.1 Distribution of Rates for Equity Classes

Figure 8F.1.1 through Figure 8F.1.6 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 (1990-2019). The rates for stocks are the annual returns on the Standard and Poor's 500 for 1990-2019.[2] The interest rates associated with AAA corporate bonds were collected from Moody's time-series data for 1990-2019.[3] Rates on Certificates of Deposit (CDs) accounts came from Cost of Savings Index (COSI) data covering 1990-2019.[4,a] The interest rates associated with state and local bonds (20-bond municipal bonds) were collected from Federal Reserve Board economic data time-series for 1990-2019.[9,b] The interest rates associated with treasury bills (30-Year treasury constant maturity rate) were collected from Federal Reserve Board economic data time-series for 1990-2019.[10,c] Rates for money market accounts are based on three-month money market account rates reported by Organization for Economic Cooperation and Development (OECD) from 1990-2019.[12] Rates for savings accounts are assumed to be half the average real money market rate. Rates for mutual funds are a weighted average of the stock rates and the bond rates.[d] The 30-year average nominal interest rates are shown in Figure 8F.1.1. DOE adjusted the nominal rates to real rates using the annual inflation rate in each year (see Figure 8F.1.7). In addition, DOE adjusted the nominal rates to real effective rates by accounting for the fact that interest on such equity types is taxable. The capital gains marginal tax rate varies for each household based on income as shown in chapter 8 (the impact of this is not shown in Figure 8F.1.1 through Figure 8F.1.6, which are only adjusted for inflation).

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[a] The Wells COSI is based on the interest rates that the depository subsidiaries of Wells Fargo & Company pay to individuals on CDs, also known as personal time deposits. Wells Fargo COSI started in November 2009.[5] From July 2007 to October 2009 the index was known as Wachovia COSI[6] and from January 1984 to July 2007 the index was known as GDW (or World Savings) COSI.[7,8]

[b] This index was discontinued in 2016. To calculate the 2017 and 2018 values, DOE compared 1977-2018 data for 30-Year Treasury Constant Maturity Rate[10] and Moody's AAA Corporate Bond Yield[3] to the 20-Bond Municipal Bond Index data.[9]

[c] From 2003-2005 there are no data. For 2003-2005, DOE used 20-Year Treasury Constant Maturity Rate.[11]

[d] SCF reports what type of mutual funds the household has (e.g. stock mutual fund, savings bond mutual fund, etc.). For mutual funds with a mixture of stocks and bonds, the mutual fund interest rate is a weighted average of the stock rates (two-thirds weight) and the savings bond rates (one-third weight).

Table 8F.1.1 30-Year Average Nominal Interest Rates for Household Equity Type

Type of Equity	30 Year Average Nominal Rate (%)
Savings accounts	2.95
Money market accounts	3.32
Certificate of deposit	3.59
Treasury Bills (T-bills)	5.25
State/Local bonds	4.96
AAA Corporate Bonds	6.11
Stocks (S&P 500)	11.34
Mutual funds	10.07

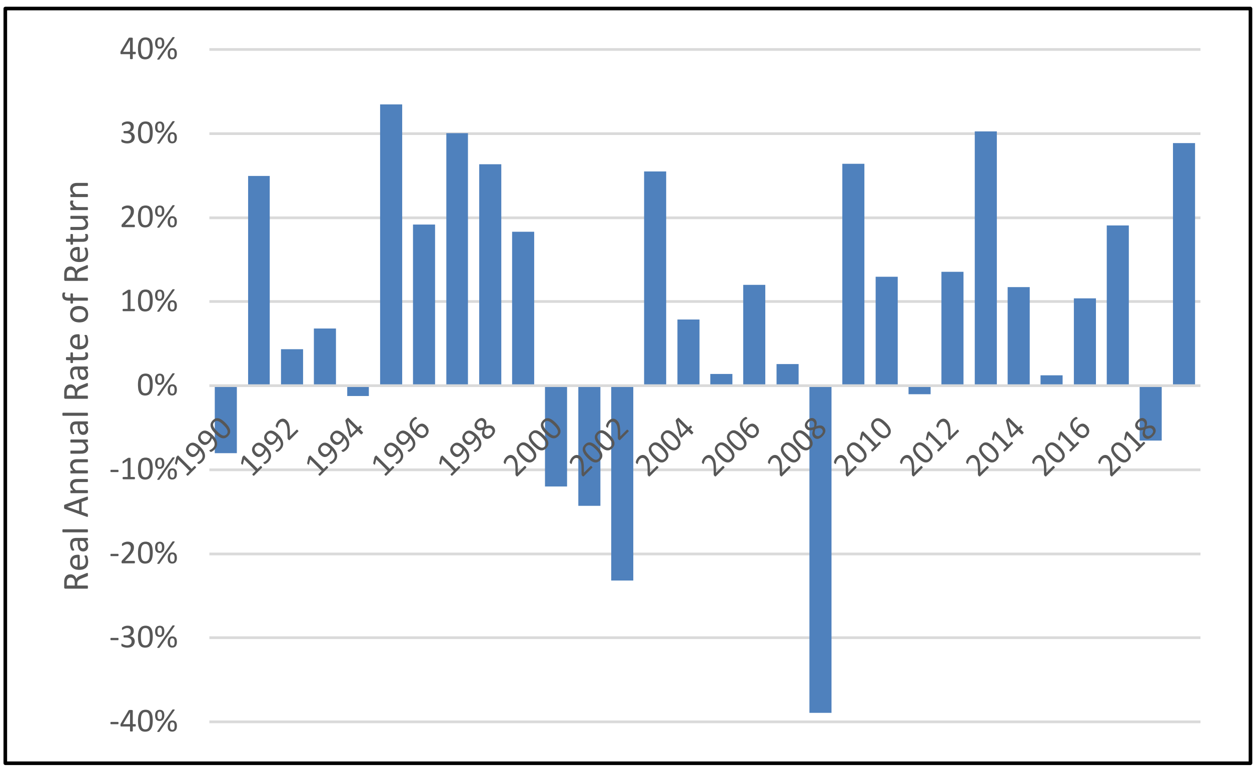

Figure 8F.1.1 Distribution of Annual Rate of Return on S&P 500

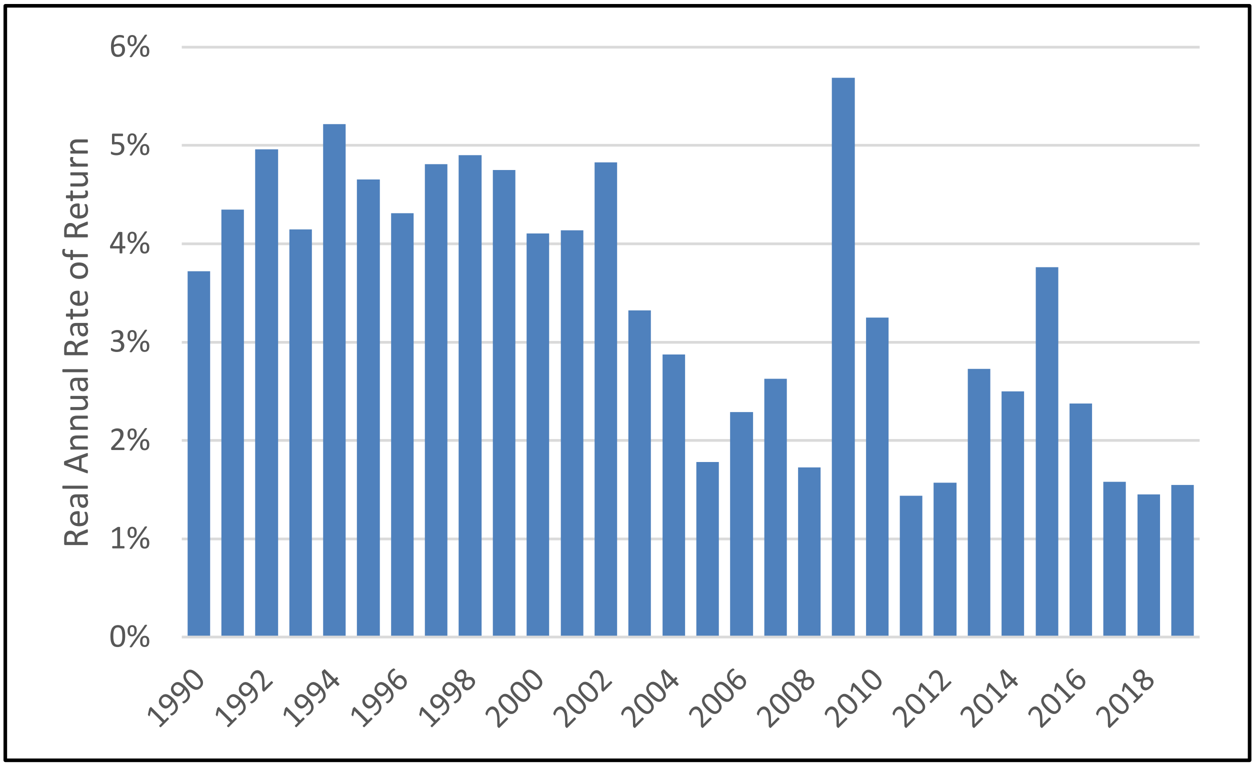

Figure 8F.1.2 Distribution of Annual Rate of Return on Corporate AAA Bonds

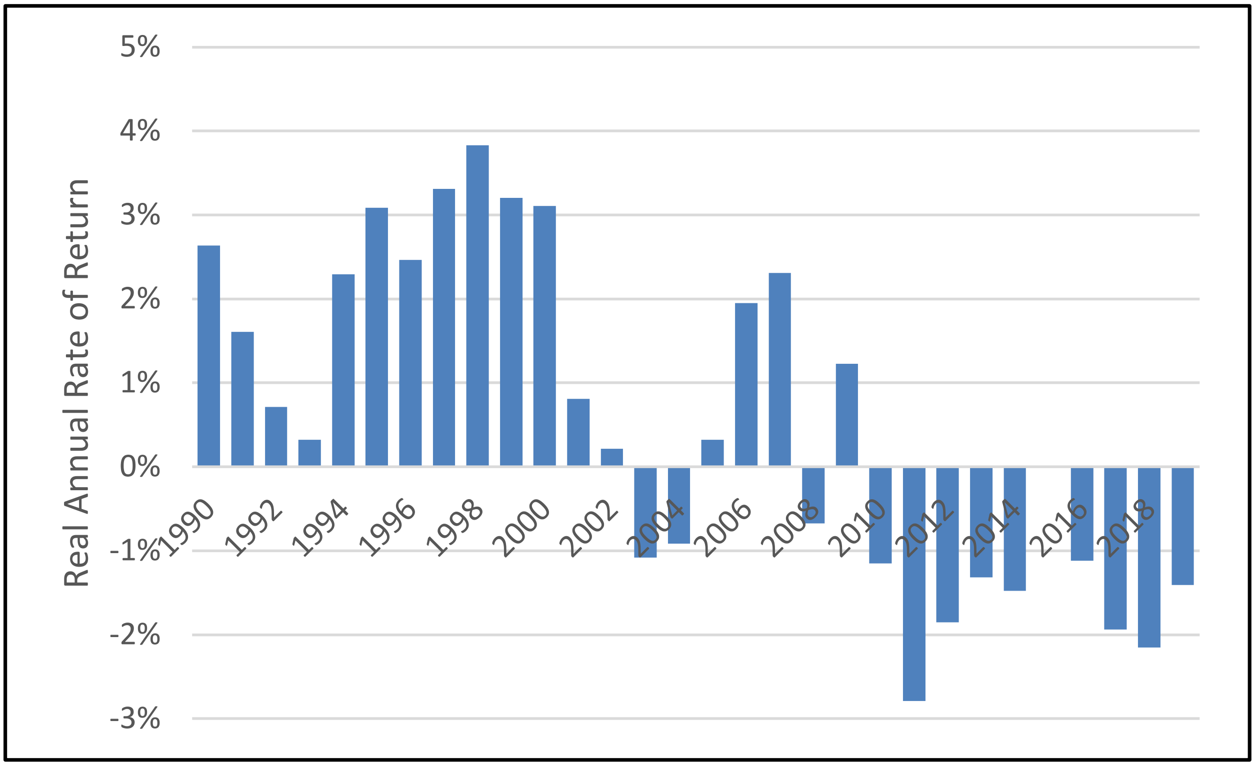

Figure 8F.1.3 Distribution of Annual Rate of Return on CDs

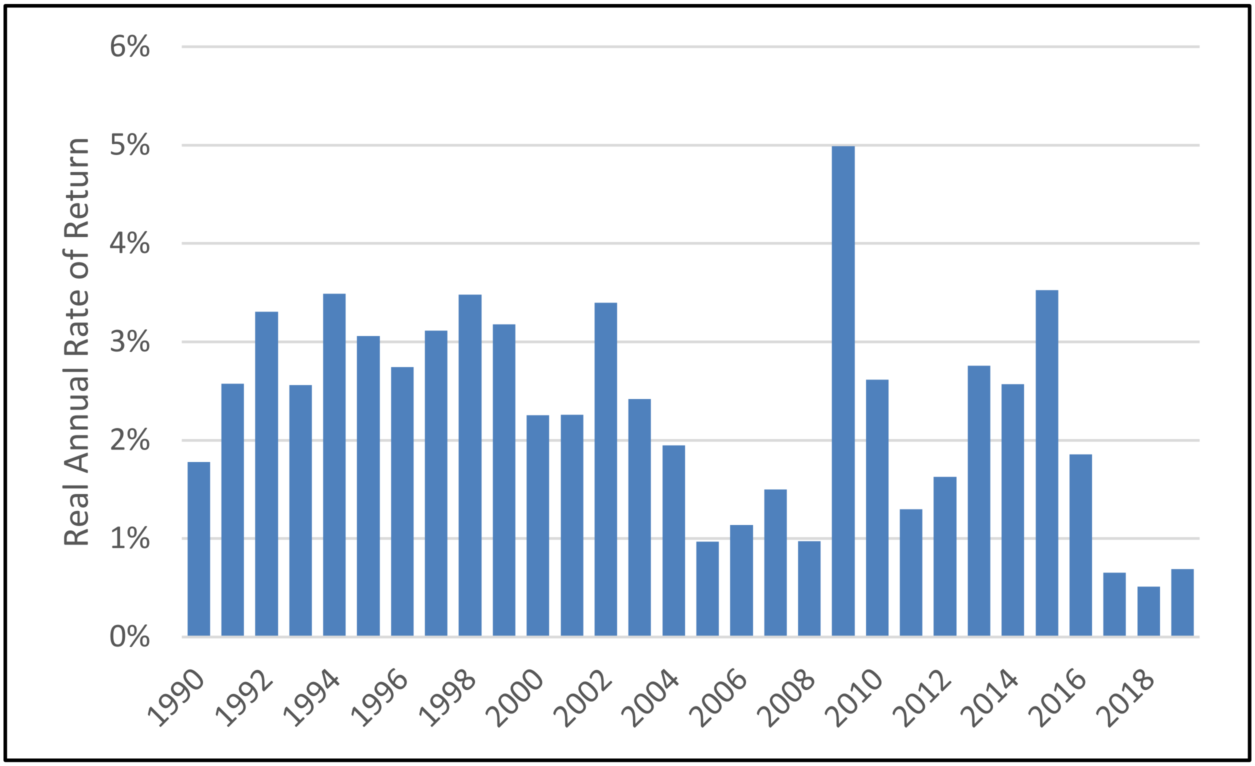

Figure 8F.1.4 Distribution of Annual Rate of State and Local Bonds

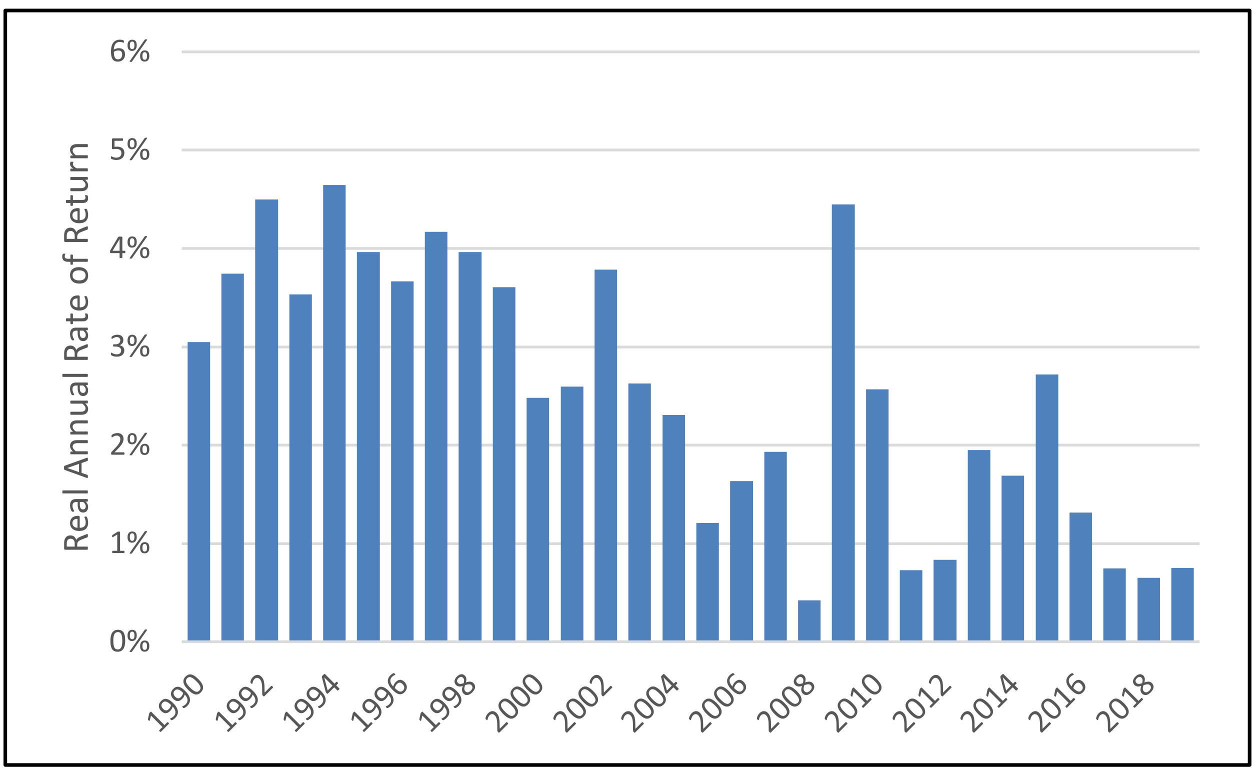

Figure 8F.1.5 Distribution of Annual Rate of Return on Savings Bonds (30 Year Treasury Bills)

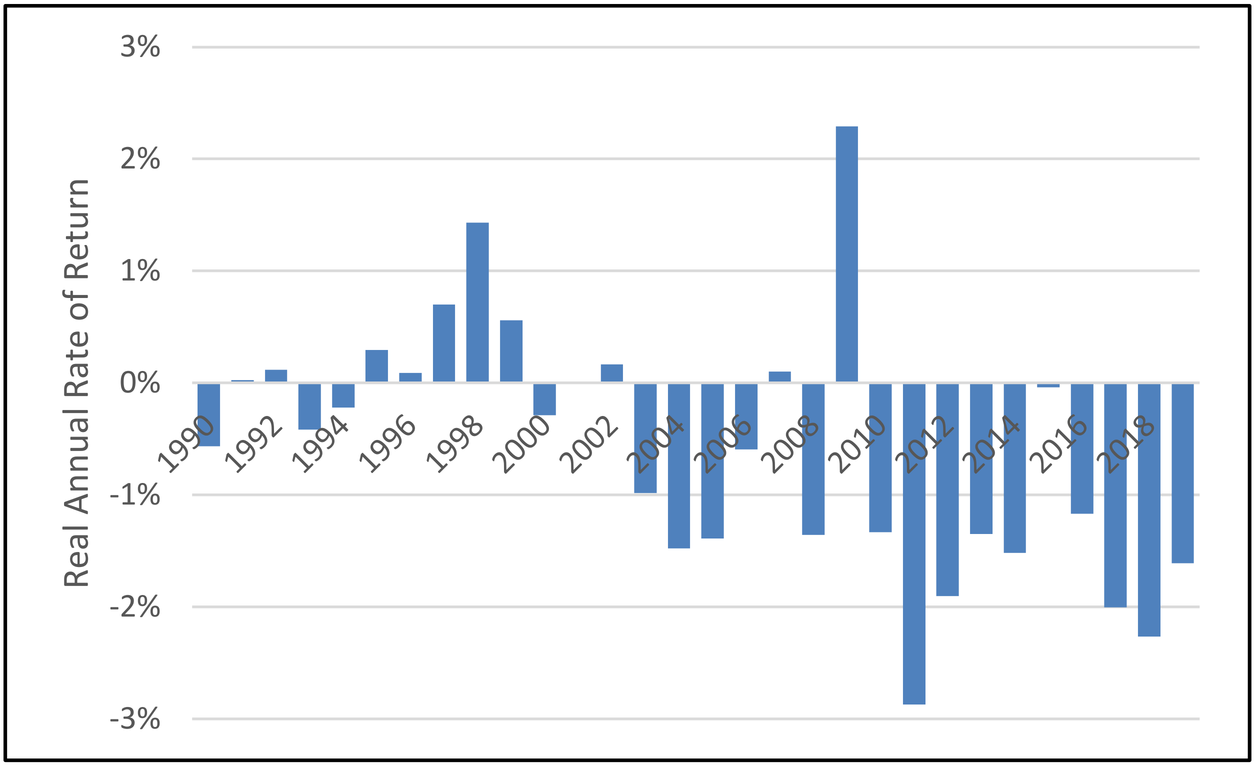

Figure 8F.1.6 Distribution of Annual Rate of Money Market Accounts

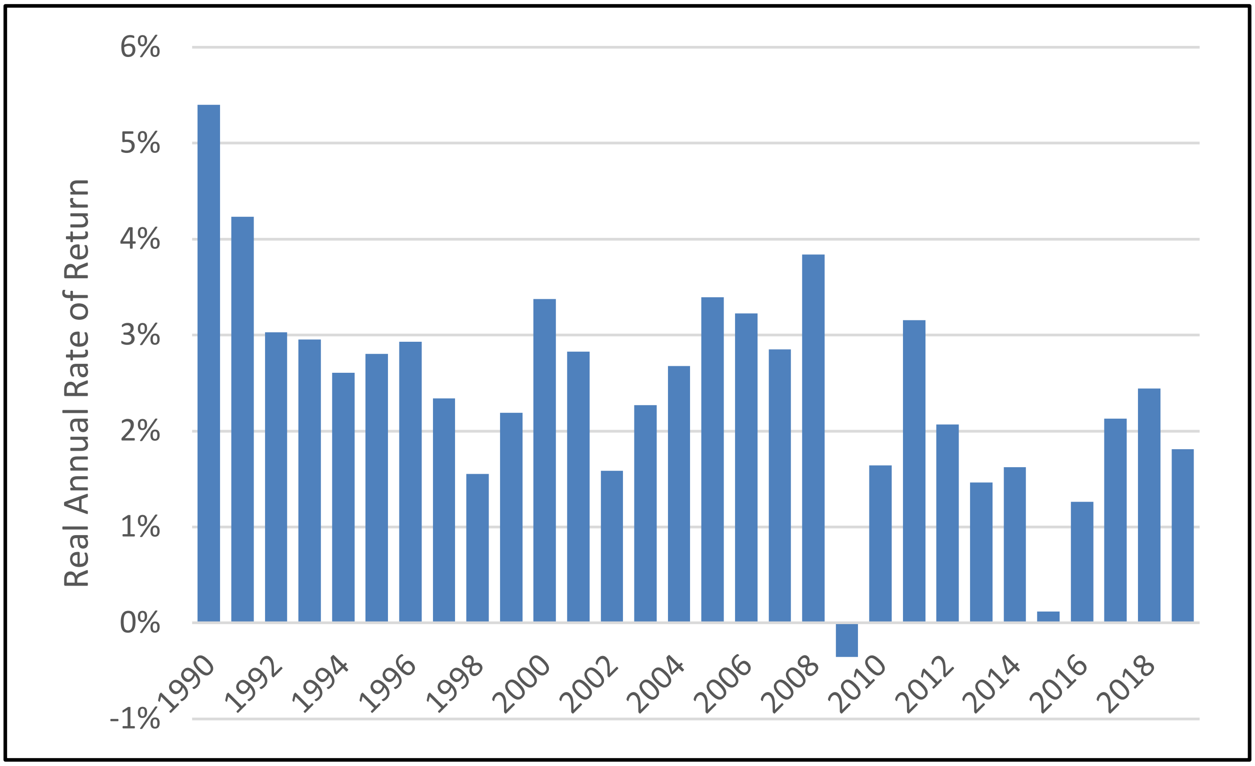

Figure 8F.1.7 Annual Consumer Price Index (CPI) Rate

8F.2 DISTRIBUTION OF REAL EFFECTIVE DISCOUNT RATES BY INCOME GROUP

Real effective discount rates were calculated for each household of the SCF using the method described in Chapter 8. Interest rates for asset types were as described in Table 8F.1.1. The data source for the interest rates for mortgages, home equity loans, credit cards, installment loans, other residence loans, and other lines of credit is the Federal Reserve Board's *SCF* in 1995, 1998, 2001, 2004, 2007, 2010, 2013, and 2016. 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 8F.2.1 provides a graphical representation of the real effective discount rate distributions by income group, while Table 8F.1.1 provides the full distributions as used in the LCC analysis.

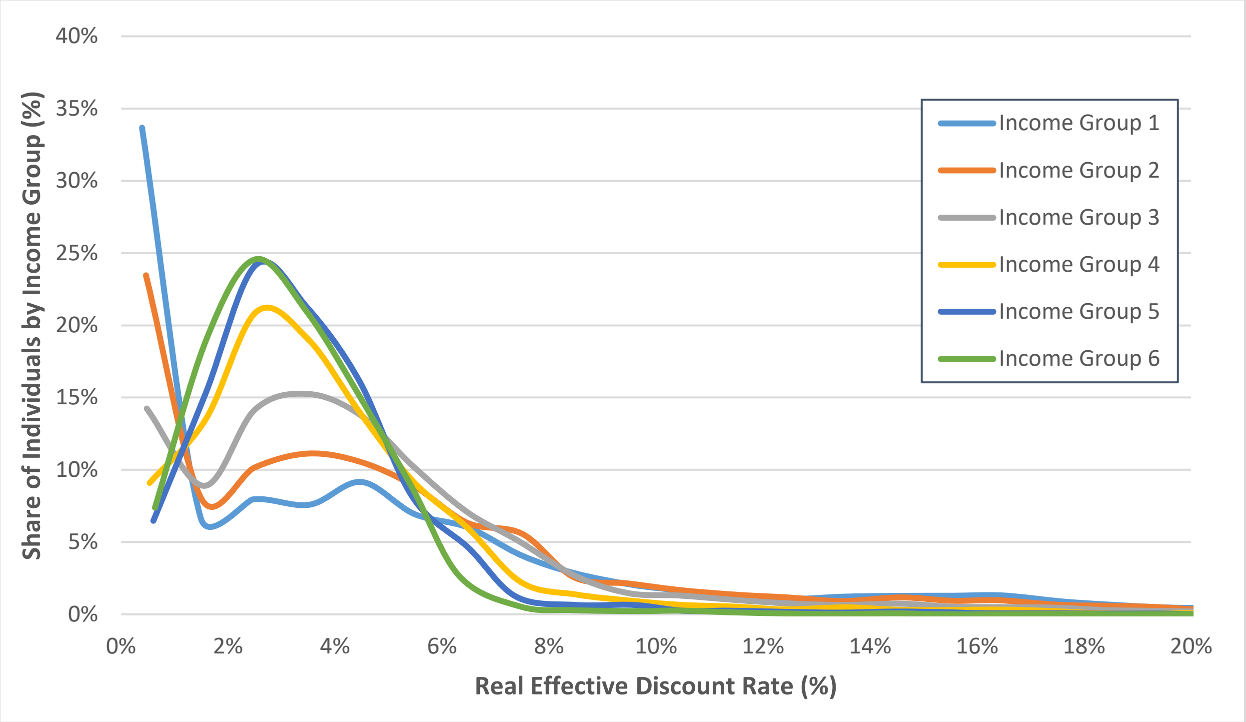

Figure 8F.2.1 Distribution of Real Discount Rates by Income Group

Table 8F.2.1 Distribution of Real Discount Rates by Income Group

DR Bin (%)	Income Group 1 (1-20 percentile)		Income Group 2 (21-40 percentile)		Income Group 3 (41-60 percentile)		Income Group 4 (61-80 percentile)		Income Group 5 (81-90 percentile)		Income Group 6 (90-99 percentile)	
	Rate %	Weight %	Rate %	Weight %	Rate %	Weight %	Rate %	Weight %	Rate %	Weight %	Rate %	Weight %
0-1	0.39	33.68	0.46	23.46	0.48	14.24	0.53	9.09	0.60	6.47	0.63	7.38
1-2	1.49	6.63	1.51	7.96	1.55	8.89	1.58	13.47	1.58	15.27	1.59	19.02
2-3	2.46	7.96	2.50	10.16	2.50	14.17	2.53	20.95	2.52	24.19	2.51	24.57
3-4	3.53	7.59	3.50	11.13	3.49	15.25	3.49	19.08	3.47	21.26	3.47	20.93
4-5	4.49	9.16	4.48	10.55	4.47	13.79	4.46	13.99	4.46	16.10	4.47	15.02
5-6	5.48	6.95	5.47	8.89	5.45	10.26	5.46	9.21	5.44	8.14	5.45	8.71
6-7	6.49	6.01	6.47	6.33	6.46	7.09	6.47	6.02	6.50	4.57	6.32	2.64
7-8	7.49	4.07	7.50	5.57	7.42	5.09	7.48	2.22	7.39	1.22	7.46	0.54
8-9	8.46	2.86	8.47	2.56	8.50	2.65	8.51	1.37	8.51	0.65	8.44	0.29
9-10	9.55	2.05	9.48	2.14	9.49	1.46	9.50	0.96	9.58	0.65	9.66	0.23
10-11	10.52	1.61	10.47	1.67	10.43	1.31	10.45	0.66	10.50	0.25	10.45	0.26
11-12	11.47	1.11	11.51	1.36	11.51	0.99	11.52	0.53	11.37	0.26	11.45	0.14
12-13	12.52	1.05	12.47	1.17	12.51	0.75	12.43	0.34	12.41	0.18	12.35	0.07
13-14	13.52	1.23	13.49	0.92	13.48	0.65	13.54	0.49	13.44	0.12	13.28	0.01
14-15	14.53	1.28	14.58	1.17	14.59	0.74	14.49	0.32	14.49	0.20	14.45	0.07
15-16	15.55	1.29	15.52	0.94	15.49	0.53	15.45	0.30	15.45	0.15	15.19	0.01
16-17	16.47	1.31	16.41	0.97	16.43	0.50	16.44	0.33	16.17	0.07	16.33	0.01
17-18	17.58	0.89	17.51	0.66	17.50	0.46	17.45	0.22	17.54	0.07	17.93	0.04
18-19	18.37	0.70	18.47	0.59	18.40	0.30	18.32	0.08	18.34	0.05	18.50	0.01
19-20	19.45	0.48	19.39	0.50	19.43	0.23	19.60	0.07	19.42	0.06	19.18	0.01
20-21	20.57	0.44	20.42	0.27	20.36	0.18	20.36	0.08	20.13	0.01	20.13	0.02
21-22	21.44	0.53	21.40	0.26	21.26	0.13	21.37	0.08	21.38	0.07	0.00	0.00
22-23	22.47	0.22	22.45	0.19	22.58	0.09	22.72	0.03	0.00	0.00	0.00	0.00
23-24	23.34	0.14	23.48	0.11	23.41	0.10	23.44	0.02	0.00	0.00	23.89	0.03
24-25	24.58	0.20	24.41	0.09	24.71	0.02	24.09	0.01	0.00	0.00	0.00	0.00
25-26	25.32	0.15	25.36	0.07	25.32	0.03	25.33	0.03	25.80	0.00	0.00	0.00
26-27	26.48	0.11	26.38	0.02	26.45	0.03	0.00	0.00	0.00	0.00	0.00	0.00
27-28	27.49	0.08	27.37	0.01	27.41	0.03	27.27	0.04	27.14	0.01	0.00	0.00
28-29	28.14	0.10	28.29	0.05	28.38	0.01	0.00	0.00	0.00	0.00	0.00	0.00
29-30	29.87	0.01	29.37	0.02	29.31	0.00	0.00	0.00	0.00	0.00	0.00	0.00
>30	76.74	0.12	143.68	0.20	105.26	0.02	53.87	0.00	0.00	0.00	0.00	0.00
Total	4.74	100.00	5.01	100.00	4.51	100.00	3.87	100.00	3.50	100.00	3.18	100.00

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APPENDIX 10A. USER INSTRUCTIONS FOR SHIPMENTS AND NATIONAL IMPACT ANALYSIS SPREADSHEET

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APPENDIX 10A. USER INSTRUCTIONS FOR SHIPMENTS AND NATIONAL IMPACT ANALYSIS SPREADSHEETS

10A.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 dishwashers using Microsoft Excel spreadsheets that are available on DOE's website http://www.eere.energy.gov/buildings/appliance_standards/.

The latest version of the shipments and NIA spreadsheet model was developed using Microsoft Excel 2016. The spreadsheet can be accessed using Microsoft Excel 2016 or a later version. The NIA spreadsheet model performs calculations to forecast the change in national energy and water use and the net present value attributable to a potential energy conservation standard. The energy and water use, and associated costs and savings attributable to a potential 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 potential standard. The differences between results under a potential standards case and the no-new-standards case can be compared and the nationwide energy and water savings and net present values (NPVs) determined.

The shipments and NIA spreadsheet model for both standard-sized and compact dishwashers comprises the following worksheets.

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 2056. 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 (-0.45 or no impact); efficiency levels to be considered; 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) 2021*.
Efficiency Distributions	Provides efficiency distributions through 2056 in terms of shipment-weighted annual energy use (SWAEU), under the no-new-standards case and each EL being considered for both standard-sized and compact dishwashers.

Historical Shipments	Contains data regarding historical shipments of dishwashers, 1972–2018.
Price Forecasting	Contains the forecasts for default, low, and high product price trends.
Shipments No-New Standards Case	Provides data and a graph related to annual historical and projected shipments of dishwashers through 2056 under the no-new-standards 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 regarding annual historical and projected shipments of dishwashers through 2056 under the chosen EL. Also, 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 worksheet 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 efficiency level. 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 *AEO2021* economic scenarios (reference, low growth, and high growth).
Energy & Water Prices	Contains projected average energy (electricity, gas, and oil) and water prices to 2100 under each of the three *AEO2021* economic growth scenarios.
Conversion Factors	Contains the marginal site-to-source conversion factors for electricity and full-fuel-cycle conversion factors for electricity, gas and fuel that DOE used in calculating source and full-fuel-cycle energy savings, respectively.
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.

10A.2 BASIC INSTRUCTIONS

Basic instructions for operating the NIA spreadsheet 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 (-0.45 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. Efficiency Level: To change the standard level, click on the drop-down arrow and select an efficiency level.

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.

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APPENDIX 10B. FULL-FUEL-CYCLE ANALYSIS

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APPENDIX 10B. FULL-FUEL-CYCLE ANALYSIS

10B.1 INTRODUCTION

This appendix summarizes the methods the U.S. Department of Energy (DOE) used to calculate the estimated full-fuel-cycle (FFC) energy savings from potential energy conservation standards. The FFC measure includes point-of-use (site) energy; the energy losses associated with generation, transmission, and distribution of electricity; and the energy consumed in extracting, processing, and transporting or distributing primary fuels. DOE's method of analysis previously encompassed only site energy and the energy lost through generation, transmission, and distribution of electricity. In 2011 DOE announced its intention, based on recommendations from the National Academy of Sciences, to use FFC measures of energy use and emissions when analyzing proposed energy conservation standards.[1] This appendix summarizes the methods DOE used to incorporate impacts of the full fuel cycle into the analysis.

In the national energy savings calculation, DOE estimates the site, primary and FFC energy consumption for each standard level, for each year in the analysis period. DOE defines these quantities as follows:

- Site energy consumption is the physical quantity of fossil fuels or electricity consumed at the site where the end-use service is provided.[a] The site energy consumption is used to calculate the energy cost input to the net present value calculation.
- Primary energy consumption is defined by converting the site fuel use from physical units, for example cubic feet for natural gas, or kWh for electricity, to common energy units (million Btu or MMBtu). For electricity the conversion factor is a marginal heat rate that incorporates losses in generation, transmission and distribution, and depends on the sector, end use and year.
- The FFC energy use is equal to the primary energy use plus the energy consumed "upstream" of the site in the extraction, processing and distribution of fuels. The FFC energy use was calculated by applying a fuel-specific FFC energy multiplier to the primary energy use.

For electricity from the grid, site energy is measured in terawatt-hours (TWh). The primary energy of a unit of grid electricity is equal to the heat content of the fuels used to generate that electricity, including transmission and distribution losses.[b] DOE typically measures the primary energy associated with the power sector in quads (quadrillion Btu). Both primary fuels and electricity are used in upstream activities. The treatment of electricity in full-fuel-cycle analysis must distinguish between electricity generated by fossil fuels and electricity generated from renewable sources (wind, solar, and hydro). For the former, the upstream fuel cycle relates

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[a] For fossil fuels, this is the site of combustion of the fuel.
[b] For electricity sources like nuclear energy and renewable energy, the primary energy is calculated using the convention described below.

to the fuel consumed at the power plant. There is no upstream component for the latter, because no fuel *per se* is used.

10B.2 SITE-TO-PRIMARY ENERGY FACTORS

DOE uses heat rates to convert site electricity savings in TWh to primary energy savings in quads. The heat rates are developed as a function of the sector, end-use and year of the analysis period. For this analysis DOE uses output of the DOE/Energy Information Administration (EIA)'s National Energy Modeling System (NEMS).[2] EIA uses the NEMS model to produce the *Annual Energy Outlook* (*AEO*). DOE's approach uses the most recently available edition, in this case *AEO 2021*.[3] The *AEO* publication includes a reference case and a series of side cases incorporating different economic and policy scenarios. DOE calculates marginal heat rates as the ratio of the change in fuel consumption to the change in generation for each fossil fuel type, where the change is defined as the difference between the reference case and the side case. DOE calculates a marginal heat rate for each of the principal fuel types: coal, natural gas and oil. DOE uses the EIA convention of assigning a heat rate of 10.5 Btu/Wh to nuclear power and 9.5 Btu/Wh to electricity from renewable sources.

DOE multiplied the fuel share weights for sector and end-use, described in appendix 15A of this TSD, by the fuel specific marginal heat rates, and summed over all fuel types, to define a heat rate for each sector/end-use. This step incorporates the transmission and distribution losses. In equation form:

$$h(u,y) = (1 + TDLoss) * \sum_{r,f} g(r,f,y)\, H(f,y)$$

Where:

TDLoss = the fraction of total generation that is lost in transmission and distribution, equal to 0.07037
u = an index representing the sector/end-use (e.g. commercial cooling)
y = the analysis year
f = the fuel type
H(f,y) = the fuel-specific heat rate
g(r,f,y) = the fraction of generation provided by fuel type *f* for end-use *u* in year *y*
h(u,y) = the end-use specific marginal heat rate

The sector/end-use specific heat rates are shown in Table 10B.2.1. These heat rates convert site electricity to primary energy in quads; i.e., the units used in the table are quads per TWh.

Table 10B.2.1 Electric Power Heat Rates (MMBtu/MWh) by Sector and End-Use

	2025	2030	2035	2040	2045	2050+
Residential						
Clothes Dryers	9.484	9.258	9.257	9.205	9.153	9.133
Cooking	9.473	9.246	9.245	9.193	9.142	9.122
Freezers	9.496	9.267	9.264	9.211	9.159	9.138

	2025	2030	2035	2040	2045	2050+
Residential						
Lighting	9.511	9.289	9.290	9.238	9.186	9.167
Refrigeration	9.496	9.267	9.264	9.212	9.159	9.138
Space Cooling	9.397	9.146	9.133	9.080	9.026	9.001
Space Heating	9.526	9.306	9.308	9.256	9.204	9.185
Water Heating	9.493	9.270	9.271	9.219	9.168	9.149
Other Uses	9.484	9.259	9.258	9.206	9.154	9.134
Commercial						
Cooking	9.409	9.184	9.185	9.135	9.085	9.065
Lighting	9.426	9.200	9.200	9.150	9.100	9.079
Office Equipment (Non-Pc)	9.374	9.145	9.145	9.095	9.046	9.026
Office Equipment (Pc)	9.374	9.145	9.145	9.095	9.046	9.026
Refrigeration	9.476	9.250	9.249	9.197	9.146	9.126
Space Cooling	9.378	9.125	9.111	9.058	9.005	8.979
Space Heating	9.532	9.313	9.314	9.262	9.210	9.191
Ventilation	9.478	9.253	9.252	9.200	9.149	9.129
Water Heating	9.409	9.184	9.186	9.136	9.087	9.067
Other Uses	9.389	9.161	9.162	9.111	9.062	9.042
Industrial						
All Uses	9.389	9.161	9.162	9.111	9.062	9.042

10B.3 FFC METHODOLOGY

The methods used to calculate FFC energy use are summarized here. The mathematical approach to determining FCC is discussed in Coughlin (2012).[4] Details related to the modeling of the fuel production chain are presented in Coughlin (2013).[5]

When all energy quantities are normalized to the same units, FFC energy use can be represented as the product of the primary energy use and an FFC multiplier. Mathematically the FFC multiplier is a function of a set of parameters that represent the energy intensity and material losses at each stage of energy production. Those parameters depend only on physical data, so the calculations require no assumptions about prices or other economic factors. Although the parameter values may differ by geographic region, this analysis utilizes national averages.

The fuel cycle parameters are defined as follows.

- a_x is the quantity of fuel x burned per unit of electricity produced for grid electricity. The calculation of a_x includes a factor to account for losses incurred through the transmission and distribution systems.
- b_y is the amount of grid electricity used in producing fuel y, in MWh per physical unit of fuel y.
- c_{xy} is the amount of fuel x consumed in producing one unit of fuel y.

- q_x is the heat content of fuel *x* (MBtu/physical unit).

All the parameters are calculated as functions of an annual time step; hence, when evaluating the effects of potential new standards, a time series of annual values is used to estimate the FFC energy and emissions savings in each year of the analysis period and cumulatively.

The FFC multiplier is denoted μ (mu). A separate multiplier is calculated for each fuel used on site. Also calculated is a multiplier for electricity that reflects the fuel mix used in its generation. The multipliers are dimensionless numbers applied to primary energy savings to obtain the FFC energy savings. The upstream component of the energy savings is proportional to (μ-1). The fuel type is denoted by a subscript on the multiplier μ.

The method for performing the full-fuel-cycle analysis utilizes data and projections published in the *AEO 2021*. Table 10B.3.1 summarizes the data used as inputs to the calculation of various parameters. The column titled "*AEO* Table" gives the name of the table that provided the reference data.

Table 10B.3.1 Dependence of FFC Parameters on *AEO* Inputs

Parameter(s)	Fuel(s)	*AEO* Table	Variables
q_x	All	Conversion factors	MMBtu per physical unit
a_x	All	Electricity supply, disposition, prices, and emissions Energy consumption by sector and source	Generation by fuel type Electric energy consumption by the power sector
b_c, c_{nc}, c_{pc}	Coal	Coal production by region and type	Coal production by type and sulfur content
b_p, c_{np}, c_{pp}	Petroleum	Refining industry energy consumption Liquid fuels supply and disposition International liquids supply and disposition Oil and gas supply	Refining-only energy use Crude supply by source Crude oil imports Domestic crude oil production
c_{nn}	Natural gas	Oil and gas supply Natural gas supply, disposition, and prices	U.S. dry gas production Pipeline, lease, and plant fuel
z_x	All	Electricity supply, disposition, prices, and emissions	Power sector emissions

The *AEO 2021* does not provide all the information needed to estimate total energy use in the fuel production chain. Coughlin (2013) describes the additional data sources needed to complete the analysis. The time dependence in the FFC multipliers, however, arises exclusively from variables taken from the *AEO*.

10B.4 ENERGY MULTIPLIERS FOR THE FULL FUEL CYCLE

FFC energy multipliers for selected years are presented in Table 10B.4.1. The 2050 value was held constant for the analysis period beyond 2050, which is the last year in the *AEO 2021* projection. The multiplier for electricity reflects the shares of various primary fuels in total electricity generation throughout the forecast period.

Table 10B.4.1 Energy Multipliers for the Full Fuel Cycle (Based on *AEO 2021*)

	2025	2030	2035	2040	2045	2050+
Electricity	1.042	1.039	1.038	1.037	1.038	1.037
Natural gas	1.099	1.098	1.098	1.098	1.100	1.099
Petroleum fuels	1.171	1.171	1.173	1.179	1.180	1.185

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APPENDIX 10C. NATIONAL ENERGY SAVINGS AND NET PRESENT VALUE USING ALTERNATIVE GROWTH SCENARIOS

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APPENDIX 10D. NATIONAL ENERGY SAVINGS AND NET PRESENT VALUE USING ALTERNATIVE GROWTH SCENARIOS

10C.1 INTRODUCTION

This appendix presents national energy savings (NES) and net present value (NPV) results using inputs from alternative economic growth scenarios. The scenarios use the energy price and housing starts forecasts in the High Economic Growth case and the Low Economic Growth case from EIA's *Annual Energy Outlook 2021* (*AEO 2021*).[1]

Figure 10C.1.1 shows the projection for new housing starts.
Figure 10C.1.2 and Figure 10C.1.3 show residential electricity prices and natural gas prices under the different economic growth scenarios, respectively.

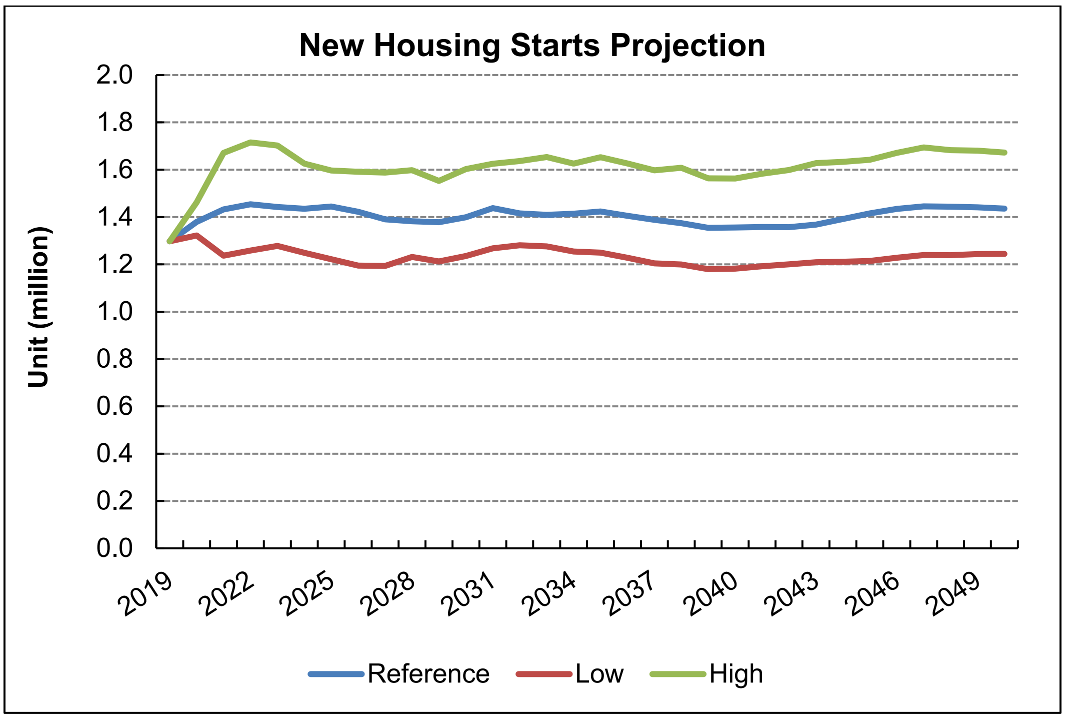

Figure 10C.1.1 New Housing Starts Projection under Alternative AEO2021 Economic Growth Scenarios

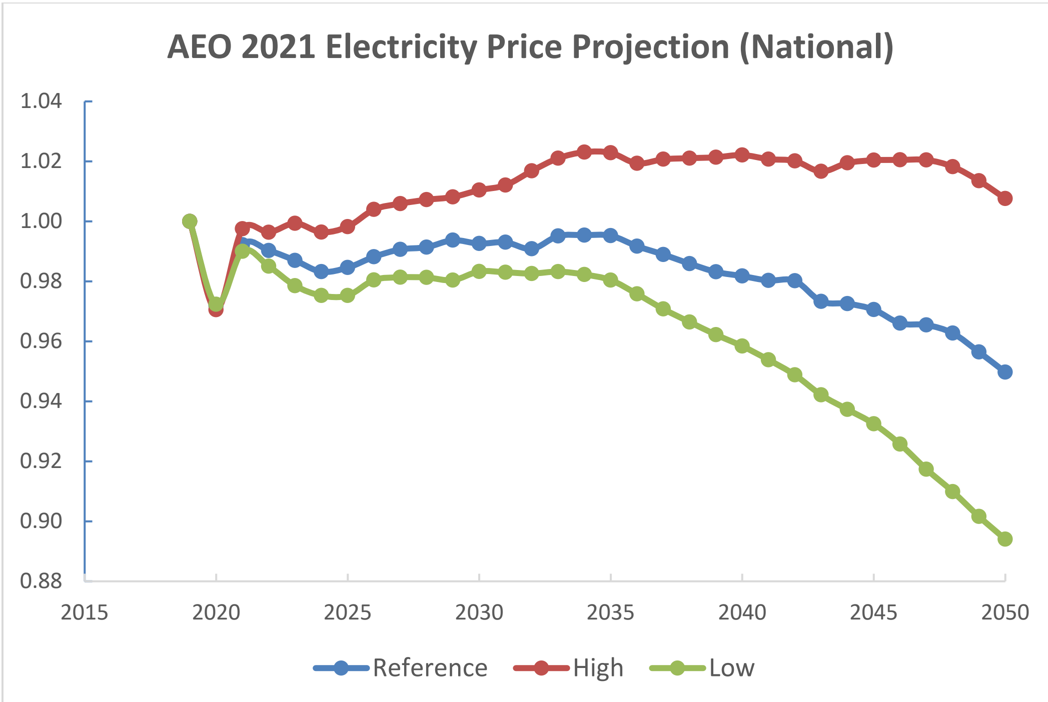

Figure 10C.1.2 Average Residential Electricity Price Projection under Alternative AEO2021 Economic Growth Scenarios

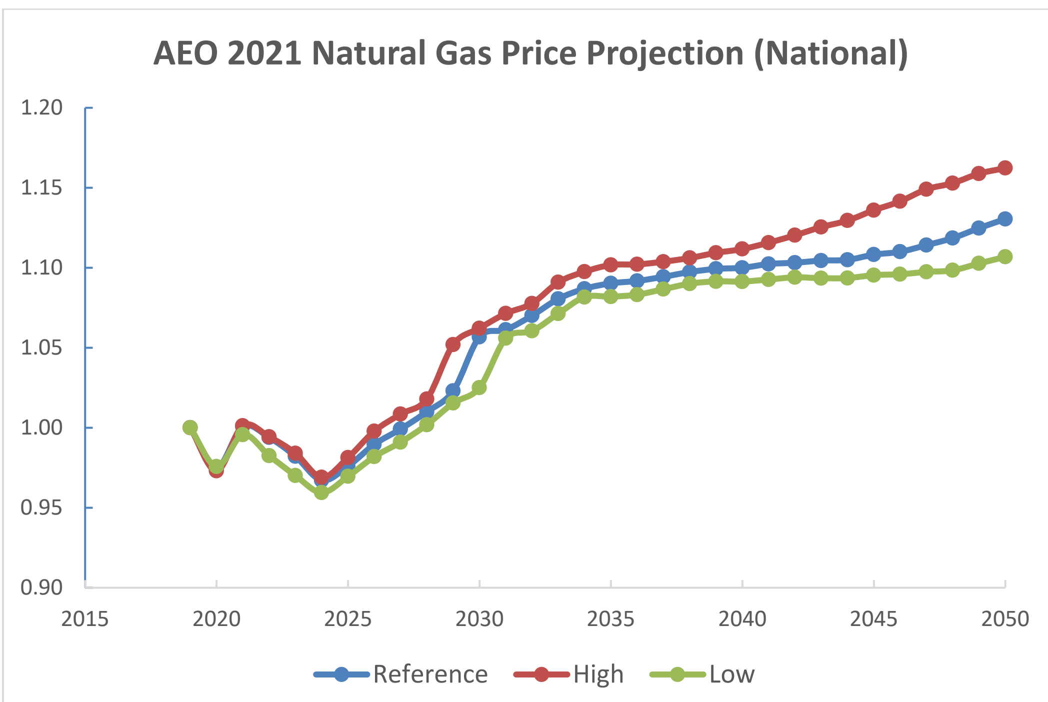

Figure 10C.1.3 Average Residential Natural Gas Price Forecasts under Alternative AEO2021 Economic Growth Scenarios

10C.2 NIA RESULTS FOR HIGH ECONOMIC GROWTH SCENARIO

Table 10C.2.1 Cumulative Full-Fuel Cycle Energy Savings in Quads, High Economic Growth Scenario

Product Class	Efficiency Level			
	1	**2**	**3**	**4**
Standard	0.004	0.056	0.489	0.650
Compact	0.000	0.056		
All	**0.004**	**0.112**	**0.489**	**0.650**

Table 10C.2.2 Cumulative Water Savings in Trillion Gallons, High Economic Growth Scenario

Product Class	Efficiency Level			
	1	**2**	**3**	**4**
Standard	0.007	0.035	0.055	0.570
Compact	0.000	0.044		
All	**0.007**	**0.080**	**0.055**	**0.570**

Table 10C.2.3 Cumulative Net Present Value of Consumer Benefits, High Economic Growth Scenario (billion, 2020$)

Discount Rates	Product Class	EL 1	EL 2	EL 3	EL 4
3% (billion 2020$)	Standard	0.049	0.160	(3.005)	(6.093)
	Compact	0.001	0.304		
	All	**0.050**	**0.464**	**(3.005)**	**(6.093)**
7% (billion 2020$)	Standard	0.023	0.007	(2.048)	(4.163)
	Compact	0.001	0.082		
	All	**0.023**	**0.088**	**(2.048)**	**(4.163)**

10C.3 NIA RESULTS FOR LOW ECONOMIC GROWTH SCENARIO

Table 10C.3.1 Cumulative Full-Fuel Cycle Energy Savings in Quads, Low Economic Growth Scenario

Product Class	Efficiency Level			
	1	2	3	4
Standard	0.004	0.052	0.446	0.592
Compact	0.000	0.051		
All	**0.004**	**0.103**	**0.446**	**0.592**

Table 10C.3.2 Cumulative Water Savings in Trillion Gallons, Low Economic Growth Scenario

Product Class	Efficiency Level			
	1	2	3	4
Standard	0.006	0.033	0.050	0.518
Compact	0.000	0.040		
All	**0.007**	**0.074**	**0.050**	**0.518**

Table 10C.3.3 Cumulative Net Present Value of Consumer Benefits, Low Economic Growth Scenario (billion, 2020$)

Discount Rates	Product Class	EL 1	EL 2	EL 3	EL 4
3% (billion 2020$)	Standard	0.045	0.129	(2.986)	(5.836)
	Compact	0.001	0.257		
	All	**0.046**	**0.386**	**(2.986)**	**(5.836)**
7% (billion 2020$)	Standard	0.021	(0.003)	(1.973)	(3.924)
	Compact	0.001	0.068		
	All	**0.022**	**0.064**	**(1.973)**	**(3.924)**

REFERENCES

1. U.S. Department of Energy-Energy Information Administration. *Annual Energy Outlook 2021 with Projections to 2050,* 2021. Washington, DC. Report Number: DOE/EIA-0383(2021). http://www.eia.gov/forecasts/aeo/