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

Commercial Water Heating Equipment

April 18, 2016

U.S. Department of Energy
Assistant Secretary
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CHAPTER 1. INTRODUCTION

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CHAPTER 1. INTRODUCTION

1.1 PURPOSE OF THE DOCUMENT

This technical support document (TSD) is a stand-alone report that provides the technical analyses and results supporting the notice of proposed rulemaking (NOPR) for commercial water heaters, hot water supply boilers, and unfired hot water supply tanks (herein referred to as commercial water heating equipment or CWH equipment). This NOPR TSD reports on the activities and analyses conducted in support of the NOPR.

1.2 SUMMARY OF NATIONAL BENEFITS

DOE's analyses indicate that the proposed standards for CWH equipment would save a significant amount of energy. The lifetime savings for CWH equipment purchased in the 30-year period that begins in the expected year of compliance with amended standards (2019–2048) amount to 1.798 quadrillion British thermal units (quads)[a] of cumulative full-fuel-cycle energy.[b] This represents a savings of 8 percent relative to the energy use of this equipment in the case where no amended standards are proposed.

The cumulative national net present value (NPV) of total costs and savings to commercial consumers of CWH equipment resulting from the proposed standards ranges from $2.26 billion (at a 7-percent discount rate) to $6.75 billion (at a 3-percent discount rate) in 2014$. This NPV expresses the estimated total value of future operating cost savings minus the estimated increased installed costs for equipment purchased in 2019–2048, discounted to 2015.

DOE also studied the potential impact on the CWH equipment manufacturers. The industry net present value (INPV) is the sum of the discounted cash flows to the industry from the base year (2015) through the end of the analysis period (2048). Using a real discount rate of 9.1 percent,[c] DOE estimates that the INPV of CWH manufacturers is $176.2 million in 2014$ using DOE's current standards as a baseline. Under the proposed standards, DOE expects that the INPV for CWH equipment manufacturers would change by approximately -13.3 percent to 5.0 percent, which is approximately equivalent to an increase of $8.8 million to a reduction of $23.4 million.

The proposed standards are expected to have significant environmental benefits. The estimated energy savings from equipment purchased over the period of 2019–2048 would result

[a] A quad is equal to 10^{15} British thermal units (Btu). The quantity refers to full-fuel-cycle (FFC) energy savings. FFC energy savings include the energy consumed in extracting, processing, and transporting primary fuels (*i.e.*, coal, natural gas, petroleum fuels), and thus present a more complete picture of the impacts of energy efficiency standards. For more information on the FFC metric, see chapter 10 of this TSD.
[b] The standards analysis period for national benefits covers the 30-year period 2019–2048 plus the life of equipment purchased during the period. In the calculation of economic impacts, DOE considered operating cost savings measured over the entire lifetime of equipment purchased in the 30-year period.
[c] This is the rate used to discount future cash flows in the manufacturer impact analysis. A discount rate of 8.5 percent was calculated based on SEC filings and feedback from manufacturer interviews about the current cost of capital in the industry. For more information, refer to chapter 12 of the NOPR TSD.

in cumulative greenhouse gas emission reductions of 98 million metric tons[d] of carbon dioxide (CO_2), 1,172 thousand tons of methane (CH_4), 0.2 thousand tons of nitrous oxide (N_2O), 1.6 thousand tons of sulfur dioxide (SO_2), 316 thousand tons of nitrogen oxides (NO_X), and 0.004 tons of mercury (Hg).[e] DOE estimates that the net present monetary value of the CO_2 emissions reduction would be between $0.63 and $9.11 billion, expressed in 2014$ and discounted to 2015. The value of the CO_2 reductions is calculated using a range of values per metric ton of CO_2 (otherwise known as the Social Cost of Carbon, SCC) developed by a Federal interagency process.[f] The monetary costs and benefits of cumulative emissions reductions are reported in 2014$ to permit straightforward comparisons with the other costs and benefits. The derivation of the values of the SCC is discussed in appendices 14A and 14B. DOE also estimates the present monetary value of the NO_X emissions reduction would be $373 million at a 7-percent discount rate and $970 million at a 3-percent discount rate.[g]

The benefits and costs of the proposed standards, for CWH equipment purchased between 2019 and 2048, can also be expressed in terms of annualized values. The monetary values for the total annualized net benefits are the (1) sum of the national economic value of the benefits in reduced operating costs, (2) minus the increase in product purchase prices and installation costs, and (3) plus the value of the benefits of CO_2 and NO_X emission reductions, all annualized.[h]

The national operating savings are domestic private U.S. consumer monetary savings that occur as a result of purchasing these equipment. The national operating cost savings is measured for the lifetime of CWH equipment shipped in 2019–2048. The CO_2 reduction is a benefit that

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[d] A metric ton is equivalent to 1.1 U.S. short tons. Results for NO_X and Hg are presented in short tons.

[e] DOE calculated emissions reductions relative to the *Annual Energy Outlook 2015* (*AEO2015*) Reference case. *AEO2015* generally represents current legislation and environmental regulations for which implementing regulations were available as of October 31, 2014.

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

[g] DOE estimated the monetized value of NO_X emissions reductions using benefit per ton estimates from the Regulatory Impact Analysis titled, "Proposed Carbon Pollution Guidelines for Existing Power Plants and Emission Standards for Modified and Reconstructed Power Plants," published in June 2014 by EPA's Office of Air Quality Planning and Standards. (Available at: www3.epa.gov/ttnecas1/regdata/RIAs/111dproposalRIAfinal0602.pdf.) Note that the agency is presenting a national benefit-per-ton estimate for particulate matter emitted from the Electricity Generating Unit sector based on an estimate of premature mortality derived from the ACS study (Krewski et al., 2009). If the benefit-per-ton estimates were based on the Six Cities study (Lepuele et al., 2011), the values would be nearly two-and-a-half times larger. Because of the sensitivity of the benefit-per-ton estimate to the geographical considerations of sources and receptors of emissions, DOE intends to investigate refinements to the agency's current approach of one national estimate by assessing the regional approach taken by EPA's Regulatory Impact Analysis for the Clean Power Plan Final Rule. Note that DOE is currently investigating valuation of avoided SO_2 and Hg emissions..

[h] To convert the time-series of costs and benefits into annualized values, DOE calculated a present value in 2015, the year used for discounting the NPV of total consumer costs and savings. For the benefits, DOE calculated a present value associated with each year's shipments in the year in which the shipments occur (*e.g.*, 2020 or 2030), and then discounted the present value from each year to 2015. The calculation uses discount rates of 3 and 7 percent for all costs and benefits except for the value of CO_2 reductions, for which DOE used case-specific discount rates, as shown in Table 1.2.1. Using the present value, DOE then calculated the fixed annual payment over a 30-year period starting in the compliance year that yields the same present value.

accrues globally due to decreased domestic energy consumption that is expected to result from this rule. Because CO_2 emissions have a very long residence time in the atmosphere,[i] the SCC values in future years reflect future CO_2-emissions impacts that continue beyond 2100 through 2300.

Table 1.2.1 shows the annualized benefits and costs of the proposed standards. In addition to the primary analysis scenario, DOE analyzed low and high net benefit sensitivity scenarios to account for the variability in shipments, projected electricity prices, and capital equipment costs over the analysis period. In the primary estimate, the operating cost savings were calculated using the *Annual Energy Outlook 2015* (*AEO2015*)[j] reference case forecast of future electricity prices and default price learning.

DOE also estimated the low net benefits and high net benefits by calculating the operating cost savings and shipments at the *AEO2015* low economic growth case and high economic growth case scenarios, respectively. The net benefits and costs for low and high net benefits estimates were calculated in the same manner as the primary estimate by using the corresponding values of operating cost savings and incremental installed costs.

At a 7-percent discount rate for benefits and costs, the primary estimate results in $144.0 million per year in increased equipment costs at the proposed standard level. The annualized benefits from the proposed standard level are (1) $367.4 million per year in reduced equipment operating costs; (2) $166.4 million in CO_2 reductions (note that DOE used a 3-percent discount rate, along with the corresponding SCC series that uses a 3-percent discount rate, to calculate the monetized value of CO_2 emissions reductions); and (3) $36.8 million in reduced NO_X emissions. In this case, the annualized net benefit amounts to $426.7 million.

At a 3-percent discount rate for all benefits and costs, the cost in the primary estimate of the amended standards proposed in this NOPR is $140.5 million per year in increased equipment costs. The benefits are $516.9 million per year in reduced operating costs, $166.4 million in CO_2 reductions, and $54.1 million in reduced NO_X emissions, resulting in an overall net benefit of $596.8 million per year. See chapter 10 and 14 of the NOPR TSD for more detailed information regarding the NPV and emissions valuation results, respectively.

[i] The atmospheric lifetime of CO_2 is estimated to be on the order of 30–95 years. Jacobson, MZ. Correction to "Control of fossil-fuel particulate black carbon and organic matter, possibly the most effective method of slowing global warming". July 2005. *J. Geophys. Res.* 110(D14): p. D14105. DOI: 10.1029/2005JD005888.
[j] U.S. Department of Energy–Energy Information Administration. *Annual Energy Outlook 2015*. 2015. Washington D.C. DOE/EIA-0383(2015).

Table 1.2.1 Annualized Benefits and Costs of Proposed Standards for Analyzed CWH Equipment (TSL 3)

	Discount Rate	Primary Estimate*	Low Net Benefits Estimate*	High Net Benefits Estimate*
		million 2014$/year		
Benefits				
Commercial Consumer Operating Cost Savings*	7%	367	336	411
	3%	517	465	588
CO_2 Reduction Monetized Value (using mean SCC at 5% discount rate)**	5%	48	46	50
CO_2 Reduction Monetized Value using mean SCC at 3% discount rate)**	3%	166	159	176
CO_2 Reduction Monetized Value (using mean SCC at 2.5% discount rate) **	2.5%	245	234	259
CO_2 Reduction Monetized Value (using 95th percentile SCC at 3% discount rate) **	3%	508	485	536
NO_X Reduction†	7%	37	35	86
	3%	54	52	126
Total Benefits‡	7% plus CO_2 range	452 to 912	417 to 855	547 to 1,033
	7%	571	530	673
	3% plus CO_2 range	619 to 1,079	563 to 1,001	765 to 1,251
	3%	737	676	890
Costs				
Incremental Equipment Costs	7%	144	147	142
	3%	141	144	138
Net Benefits				
Total‡	7% plus CO_2 range	308 to 768	270 to 709	406 to 892
	7%	427	383	531
	3% plus CO_2 range	478 to 938	419 to 857	627 to 1,113
	3%	597	532	752

* This table presents the annualized costs and benefits associated with analyzed CWH equipment shipped in 2019–2048. These results include benefits to commercial consumer that accrue after the last year of analyzed shipments (2048) from the equipment purchased during the 30-year analysis period. The incremental installed costs include incremental equipment cost as well as installation costs. The CO_2 reduction benefits are global benefits due to actions that occur nationally. The primary, low benefits, and high benefits estimates utilize projections of energy prices from the *AEO2015* reference case, low estimate, and high estimate, respectively. In addition, DOE used a constant equipment price assumption as the default price projection; the cost to manufacture a given unit of higher efficiency neither increases nor decreases over time. The equipment price projection is described in chapter 8 of the technical support document (TSD).

** The interagency group selected four sets of SCC values for use in regulatory analyses. Three sets of values are based on the average SCC from the integrated assessment models, at discount rates of 5, 3, and 2.5 percent. For example, for 2015 emissions, these values are $12.2/metric ton, $40.0/metric ton, and $62.3/metric ton, in 2014$, respectively. The fourth set ($117 per metric ton in 2014$ for 2015 emissions), which represents the 95th percentile of the SCC distribution calculated using SCC estimate across all three models at a 3-percent discount rate, is included to represent higher-than-expected impacts from temperature change further out in the tails of the SCC distribution. The SCC values are emission year specific. See chapter 14 for more details.
† The $/ton values used for NO_X are described in chapter 14 of the NOPR TSD. DOE estimated the monetized value of NO_X emissions reductions using benefit per ton estimates from the Regulatory Impact Analysis titled, "Proposed Carbon Pollution Guidelines for Existing Power Plants and Emission Standards for Modified and Reconstructed Power Plants," published in June 2014 by EPA's Office of Air Quality Planning and Standards. (Available at www3.epa.gov/ttnecas1/regdata/RIAs/111dproposalRIAfinal0602.pdf.) Note that the agency is presenting a national benefit-per-ton estimate for particulate matter emitted from the Electric Generating Unit sector based on an estimate of premature mortality derived from the ACS study (Krewski et al., 2009). If the benefit-per-ton estimates were based on the Six Cities study (Lepuele et al., 2011), the values would be nearly two-and-a-half times larger. Because of the sensitivity of the benefit-per-ton estimate to the geographical considerations of sources and receptors of emissions, DOE intends to investigate refinements to the agency's current approach of one national estimate by assessing the regional approach taken by EPA's Regulatory Impact Analysis for the Clean Power Plan Final Rule.
‡ Total benefits for both the 3-percent and 7-percent cases are presented using only the average SCC with a 3-percent discount rate. In the rows labeled "7% plus CO_2 range" and "3% plus CO_2 range," the operating cost and NO_X benefits are calculated using the labeled discount rate, and those values are added to the full range of CO_2 values.

1.3 OVERVIEW OF COMMERCIAL EQUIPMENT STANDARDS FOR COMMERCIAL WATER HEATING EQUIPMENT

Title III, Part C[k] of the Energy Policy and Conservation Act of 1975 (EPCA or the Act), Pub. L. 94-163 (42 U.S.C. 6311–6317, as codified), establishes the Energy Conservation Program for Certain Industrial Equipment.[l] These include CWH equipment, the subject of this TSD. (42 U.S.C. 6311(1)(K)) In general, this program addresses the energy efficiency of certain types of commercial and industrial equipment. Relevant provisions of EPCA specifically include definitions (42 U.S.C. 6311), energy conservation standards (42 U.S.C. 6313), test procedures (42 U.S.C. 6314), labeling provisions (42 U.S.C. 6315), and the authority to require information and reports from manufacturers (42 U.S.C. 6316).

The initial Federal energy conservation standards for CWH equipment were added to EPCA by the Energy Policy Act of 1992 (EPACT 1992), Public Law 102–486. (42 U.S.C. 6313(a)(5)) The energy conservation standards for CWH equipment established by EPACT 1992 correspond to the levels contained in American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) Standard 90.1-1989.

DOE adopted amended energy conservation standards in a final rule published on January 12, 2001 (January 2001 final rule). 66 FR 3336. Pursuant to EPCA's requirements in 42 U.S.C. 6313(a)(6)(A), the January 2001 final rule adopted applicable standard levels established in ASHRAE 90.1-1999 for CWH equipment.

DOE's latest amendments to its CWH equipment standards were adopted in a final rule published on July 17, 2015 adopting ASHRAE 90.1-2013 standard levels for commercial oil-

[k] For editorial reasons, upon codification in the U.S. Code, Part C was redesignated Part A–1.
[l] All references to EPCA refer to the statute as amended through the Energy Efficiency Improvement Act of 2015 (EEIA 2015), Pub. L. 114-11 (April 30, 2015).

fired storage water heaters. 80 FR 42614. DOE's current energy conservation standards for CWH equipment are summarized in Table 1.3.1.

Table 1.3.1 Current Federal Energy Conservation Standards for CWH Equipment

Product	Size	Energy conservation standards*	
		Minimum thermal efficiency (equipment manufactured on and after October 9, 2015) **, †	**Maximum standby loss (equipment manufactured on and after October 29, 2003)** **,‡
Electric storage water heaters	All	N/A	0.30 + 27/V_m (%/h)
Gas-fired storage water heaters	≤155,000 Btu/h	80%	Q/800 + 110$(V_r)^{1/2}$ (Btu/h)
	>155,000 Btu/h	80%	Q/800 + 110$(V_r)^{1/2}$ (Btu/h)
Oil-fired storage water heaters	≤155,000 Btu/h	80%†	Q/800 + 110$(V_r)^{1/2}$ (Btu/h)
	>155,000 Btu/h	80%†	Q/800 + 110$(V_r)^{1/2}$ (Btu/h)
Electric instantaneous water heaters‡‡	<10 gal	80%	N/A
	≥10 gal	77%	2.30 + 67/V_m (%/h)
Gas-fired instantaneous water heaters and hot water supply boilers	<10 gal	80%	N/A
	≥10 gal	80%	Q/800 + 110$(V_r)^{1/2}$ (Btu/h)
Oil-fired instantaneous water heater and hot water supply boilers	<10 gal	80%	N/A
	≥10 gal	78%	Q/800 + 110$(V_r)^{1/2}$ (Btu/h)
Product	**Size**	**Minimum thermal insulation**	
Unfired hot water storage tank	All	R-12.5	

* V_m is the measured storage volume and V_r is the rated volume, both in gallons. Q is the nameplate input rate in Btu/h.
** For hot water supply boilers with a capacity of less than 10 gallons: (1) the standards are mandatory for products manufactured on or after October 21, 2005 and (2) products manufactured prior to that date, and on or after October 23, 2003, must meet either the standards listed in this table or the applicable standards in subpart E of this part for a "commercial packaged boiler."
†For oil-fired storage water heaters: (1) the standards are mandatory for equipment manufactured on and after October 9, 2015 and (2) equipment manufactured prior to that date must meet a minimum thermal efficiency level of 78 percent.
‡ Water heaters and hot water supply boilers having more than 140 gallons of storage capacity need not meet the standby loss requirement if: (1) the tank surface area is thermally insulated to R-12.5 or more, (2) a standing pilot light is not used, and (3) for gas or oil-fired storage water heaters, they have a fire damper or fan assisted combustion.
‡‡ Standards for electric instantaneous water heaters are included in EPCA. (42 U.S.C. 6313(a)(5)(D)-(E)) In the NOPR, DOE proposes to codify these standards for electric instantaneous water heaters in its regulations at 10 CFR 431.110.

1.4 PROCESS FOR SETTING ENERGY CONSERVATION STANDARDS

This section presents an overview of the rulemaking process DOE follows in its energy conservation standards for covered equipment, including CWH equipment, the subject of this NOPR and associated TSD.

Under EPCA, DOE is obligated to review its energy conservation standards for certain commercial and industrial equipment[m] (*i.e.*, "ASHRAE equipment") whenever ASHRAE updates the efficiency levels in ASHRAE Standard 90.1. DOE must either adopt the levels contained in ASHRAE Standard 90.1 or adopt levels more stringent than the ASHRAE levels if there is clear and convincing evidence in support of doing so. (42 U.S.C. 6313(a)(6)(A)) DOE must conduct such review in accordance with the procedures established for ASHRAE equipment under 42 U.S.C. 6313(a)(6).

In addition, pursuant to amendments to EPCA made by the Energy Independence and Security Act of 2007 (EISA 2007), Pub. L. 110-140 (Dec. 19, 2007), under 42 U.S.C. 6313(a)(6)(C), the agency must periodically review its already established energy conservation standards for ASHRAE equipment, including CWH equipment. This provision was further amended by the American Energy Manufacturing Technical Corrections Act (AEMTCA), Pub. L. 112–210 (Dec. 18, 2012), to clarify that DOE's periodic review of ASHRAE equipment must occur "[e]very six years." (42 U.S.C. 6313(a)(6)(C)(i)) In order to meet the requirements added by AEMTCA, DOE has begun to review its existing energy conservation standards for those equipment types listed in 42 U.S.C. 6313(a) for which at least 6 years have elapsed since issuance of the most recent final rule, including CWH equipment, the subject of this rulemaking.

EPCA, as amended by AEMTCA, prescribes specific statutory criteria for DOE to consider when setting standards for CWH equipment. (42 U.S.C. 6313(a)(6)(A)–(C)) 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. 6313(a)(6)(A)) Furthermore, DOE may not adopt any standard that would not result in the significant additional conservation of energy. *Id*. DOE, in deciding whether a standard is economically justified, must determine, after receiving comments on the proposed standard, whether the benefits of the standard exceed its burdens by considering, to the maximum extent practicable, the following seven factors:

1) the economic impact of the standard on the manufacturers and commercial consumers of the products subject to the standard;

2) the savings in operating costs throughout the estimated average life of the products in the type (or class) compared to any increases in the price, initial charges, or maintenance expense for the products that are likely to result from the imposition of the standard;

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;

[m] These equipment types include small, large, and very large commercial package air-conditioning and heating equipment, packaged terminal air conditioners and heat pumps, warm air furnaces, packaged boilers, storage water heaters, instantaneous water heaters, or unfired hot water storage tanks.

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.

(42 U.S.C. 6313(a)(6)(B)(ii) and (C)(i))

DOE considers the participation of interested parties a very important part of the process for setting energy conservation standards. Through formal public notifications (*i.e.,* Federal Register notices), DOE encourages the participation of all interested parties during the comment period in each stage of the rulemaking. Throughout the entire duration of the rulemaking process, interactions among interested parties provide a balanced discussion of the information that is required for the standards rulemaking.

Before DOE determines whether to adopt a proposed energy conservation standard, it must first solicit comments on the proposed standard. (42 U.S.C 6313(a)(6)(A)(i) and (C)(i)) 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. 6313(a)(6)(B)(ii) and (C)(i))

On October 21, 2014, DOE published a request for information ("October 2014 RFI") in the *Federal Register* as a preliminary step pursuant to EPCA's requirements in 42 U.S.C. 6313(a)(6)(C)(i) for DOE to consider amended energy conservation standards for CWH equipment. 79 FR 62899. The October 2014 RFI sought information to assist DOE in determining whether national standards more stringent than those that are currently in place would result in a significant amount of additional energy savings, and whether such amended standards would be technologically feasible and economically justified. The RFI requested information on various issues related to each of the analyses to be performed for the rulemaking, including the market assessment, engineering analysis, energy use analysis, life-cycle cost (LCC) and payback period (PBP) analysis, and national impact analysis. Specifically, DOE requested comment on potential energy savings benefits, equipment classes, equipment applications, performance metrics, efficiency levels, repair/maintenance issues, market trends, technology options, analytical approaches, and data availability.

DOE conducted several analyses in preparation for publishing the NOPR and TSD, incorporating feedback, as appropriate, from comments received in response to October 2014 RFI. A list of the corresponding chapter numbers is presented in the next section. A summary of each conducted analysis can be found in Chapter 2 of this TSD.

DOE is publishing a NOPR and associated TSD as the second formal notice associated with the current CWH equipment rulemaking. The NOPR, as well as the relevant documents from previous rulemaking phases and a link to the docket for this rulemaking, are available at the DOE website for commercial water heating equipment:
https://www1.eere.energy.gov/buildings/appliance_standards/standards.aspx?productid=36.

1.5 STRUCTURE OF THE DOCUMENT

This TSD outlines the analytical approaches used in this rulemaking. The TSD consists of 17 chapters as well as appendices.

Chapter 1	Introduction: Provides an overview of the appliance standards program and how it applies to the CWH rulemaking, and outlines the structure of the document.
Chapter 2	Analytical Framework: Describes the rulemaking process step by step and summarizes the major components of DOE's analyses.
Chapter 3	Market and Technology Assessment: Characterizes the CWH equipment market and the technologies available for increasing equipment efficiency.
Chapter 4	Screening Analysis: Determines which technology options are viable for consideration in the engineering analysis.
Chapter 5	Engineering Analysis: Discusses the methods used for developing the relationship between increased manufacturer production cost/selling price and increased efficiency.
Chapter 6	Markups for Equipment Price Determination: Discusses the methods used for establishing markups for converting manufacturer prices to customer equipment prices.
Chapter 7	Energy Use Analysis: Discusses the process used for generating energy use estimates for each analyzed equipment class and efficiency level.
Chapter 8	Life-Cycle Cost and Payback Period Analysis: Discusses energy savings and economic impacts of evaluated standards on individual commercial consumers and compares the LCC and PBP of equipment at different efficiency levels evaluated in the NOPR.
Chapter 9	Shipments Analysis: Discusses the methods used for projecting shipments with and without evaluated higher efficiency standards.
Chapter 10	National Impact Analysis: Discusses the methods used for projecting national energy consumption and national economic impacts based on annual equipment shipments and estimates of future efficiency distributions in the absence and presence of evaluated higher efficiency standards.
Chapter 11	Consumer Subgroup Analysis: Discusses the effects of evaluated standards on identifiable commercial consumer subgroups and compares the LCC and PBP of equipment at different efficiency levels evaluated in the NOPR.

Chapter 12 Manufacturer Impact Analysis: Discusses the effects of proposed standards on the finances and profitability of CWH equipment manufacturers.

Chapter 13 Emissions Impact Analysis: Discusses the effects of evaluated standards on airborne emissions including the impact of emissions of six pollutants or greenhouse gases: sulfur dioxide (SO_2), nitrogen oxides (NO_x), Carbon dioxide (CO_2), mercury (Hg), methane (CH_4), and nitrous oxide (N_2O).

Chapter 14 Monetization of Emissions Reductions Benefits: Considers the estimated monetary benefits likely to result from reduced emissions of CO_2 and NOx expected to result from the evaluated standards.

Chapter 15 Utility Impact Analysis: Discusses the effects of proposed standards on the installed generation capacity of electric utilities.

Chapter 16 Employment Impact Analysis: Discusses the effects of proposed standards on National employment.

Chapter 17 Regulatory Impact Analysis: Discusses the present regulatory actions as well as the impact of non-regulatory alternatives to setting energy efficiency standards.

Appendix 6A Markups: Contains the data used to develop markups.

Appendix 7A Energy Use Analysis, Building Use Variables: Contains explanations of the CBECS and RECS building data used in the Energy Use Analysis.

Appendix 7B Energy Use Analysis, Energy Calculations and Data: Contains further detail of the energy use methodologies, calculations and data in the Energy Use Analysis.

Appendix 7C Energy Use Analysis, Weather Station Mapping: Contains the methodology to map weather station data to CBECS and RECS data.

Appendix 8A User Instructions for the Life-Cycle Cost Analysis Spreadsheet: Contains a description of the spreadsheet and instructions that allow the user to examine and reproduce the detailed results of the LCC and PBP analysis.

Appendix 8B Uncertainty and Variability in LCC Analysis: Explains how the LCC model accounts for the uncertainty and variability of the numerical values.

Appendix 8C Estimation of Potential Energy Price Trend for CWH Equipment: Presents experiential learning analysis in the LCC analysis

Appendix 8D	Installation Cost Determination: Presents a detailed explanation of the methodology DOE used to determine installation costs of the CWH equipment classes analyzed for the NOPR
Appendix 8E	Maintenance and Repairs: Presents a detailed explanation of the methodology DOE used to determine maintenance and repairs costs of the CWH equipment classes analyzed for the NOPR
Appendix 8F	Equipment Lifetime: Explains how DOE derived lifetime for the equipment classes analyzed for the NOPR.
Appendix 8G	Discount Rate: Explains how DOE estimates discount rates used in its LCC analyses.
Appendix 8H	No-New-Standards Case Efficiency Distribution: Explains how DOE derives base case efficiency distribution by efficiency levels and equipment classes.
Appendix 10A	User Instructions for Shipments and NIA Spreadsheets: Contains a description of the NIA spreadsheet and instructions on how to use it to examine and reproduce the NIA results.
Appendix 10B	National Net Present Value Using Alternative Sensitivity Analyses: Presents electricity and fuel price and associated economic growth sensitivity analysis results, and 9-year analysis results.
Appendix 10C	Trial Standard Levels and Standards Equations: Presents the criteria for trial standard levels (TSLs) selection and the proposed standards equation at each TSL.
Appendix 10D	Full Fuel Cycle Multipliers: Contains a summary of the methods used to calculate full-fuel-cycle (FFC) energy savings.
Appendix 10E	RICS & OIRA Consolidated Information System (ROCIS) Tables: Presents the net present values (NPVs) that would result if the U.S. Department of Energy (DOE) were to add the estimates of the potential economic benefits resulting from reduced carbon dioxide (CO_2) and nitrogen oxide (NO_x) emissions to the NPV of commercial consumer savings calculated for each TSL considered in the NOPR.
Appendix 12A	Manufacturer Impact Analysis Interview Guide: Reproduction of MIA interview guide.
Appendix 12B	Government Regulatory Impact Model Overview: Contains a description of the GRIM model.
Appendix 13A	Emissions Analysis Methodology

Appendix 14A	Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866: Reproduction of SCC analysis.
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Appendix 15A	Utility Impact Analysis Methodology

CHAPTER 2. ANALYTICAL FRAMEWORK

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CHAPTER 2. ANALYTICAL FRAMEWORK

2.1 INTRODUCTION

The Energy Policy and Conservation Act (EPCA) requires the U.S. Department of Energy (DOE) to set forth energy conservation standards that are technologically feasible and economically justified and would result in significant additional energy conservation for commercial water heating (CWH) equipment. (42 U.S.C. 6313(a)(6)(A)(ii)(II) and (C)(i)) This chapter provides a description of the general analytical framework that DOE uses in developing such standards, in particular, standards for CWH equipment. The analytical framework is a description of the methodology, the analytical tools, and relationships among the various analyses that are part of this rulemaking.

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

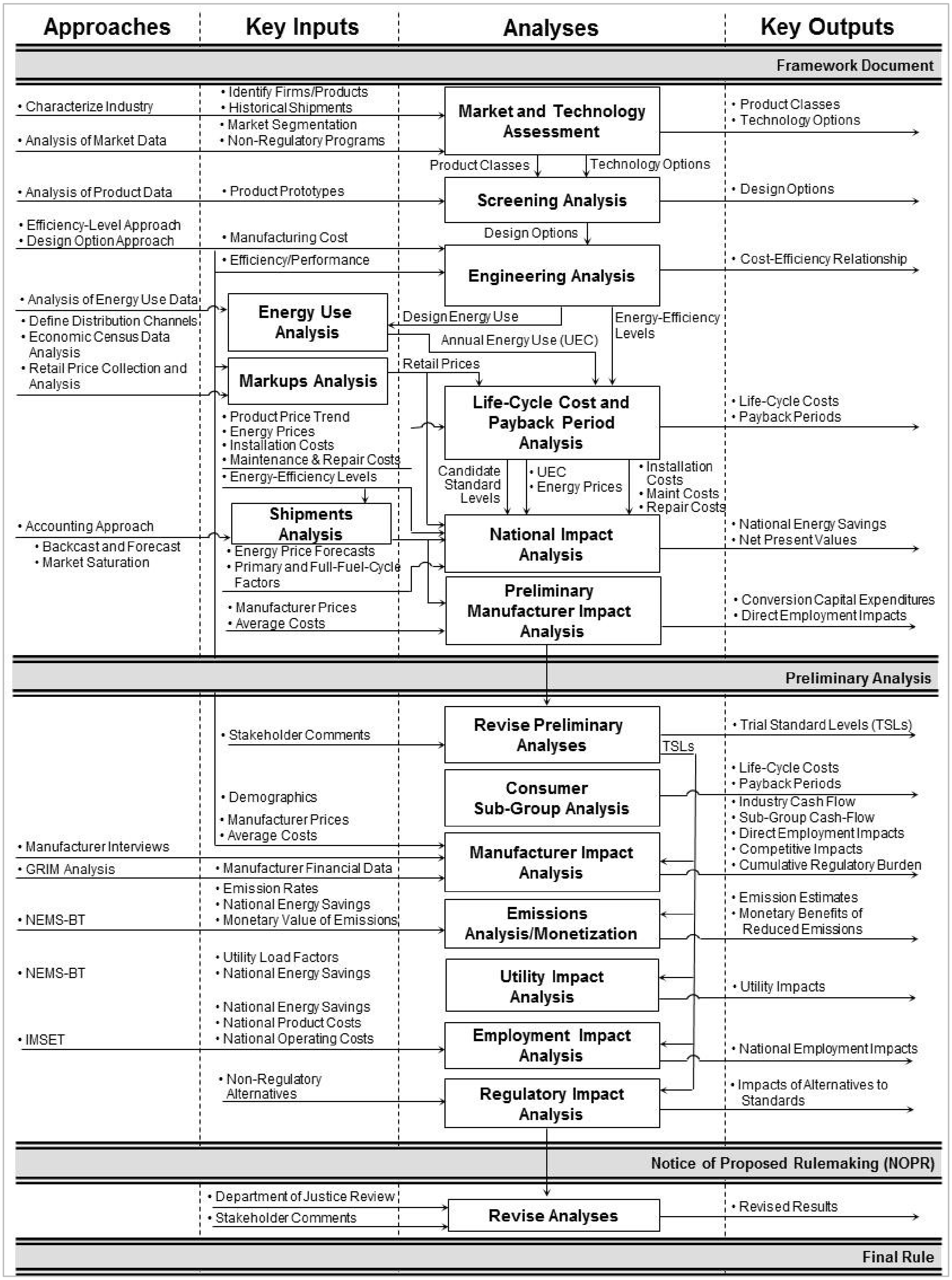

Figure 2.1.1 Flow Diagram of Analyses for the Rulemaking Process

This chapter provides a description of the analytical framework that DOE is using to evaluate potential amended energy conservation standards for CWH equipment evaluated for the notice of proposed rulemaking (NOPR). This chapter sets forth the methodology, analytical tools, and relationships among the various analyses that are part of this rulemaking. In conducting NOPR analyses, DOE considered comments and new information received in response to the request for information for energy conservation standards for CWH equipment published on October 21, 2014 ("October 2014 RFI"). 79 FR 62899. In this technical support document (TSD), DOE presents results of the following analyses that were performed for this NOPR.

- A market and technology assessment to characterize relevant equipment, their markets, and technology options for improving their energy efficiency, including prototype designs.
- A screening analysis to review each technology option and to determine if it is technologically feasible; is practicable to manufacture, install, and service; would adversely affect equipment utility or availability; or would have adverse impacts on health and safety.
- An engineering analysis to develop relationships that show the cost of achieving increased efficiency.
- A markups analysis to develop distribution channel markups that convert the manufacturer production cost (MPC) to the cost to the commercial consumer.
- An energy use analysis to determine the annual energy use of the considered equipment across efficiency levels in a representative set of applications.
- A life-cycle cost (LCC) and payback period (PBP) analysis to calculate the discounted savings in operating costs at the consumer level throughout the estimated average lifetime of covered equipment compared with any increase in installed cost for the equipment likely to result directly from imposition of a given standard.
- A shipments analysis to project equipment shipments, which are then used to calculate the national impacts of standards on energy, net present value (NPV), and future manufacturer cash flows.
- A national impact analysis (NIA) to assess the aggregate impacts at the national level of potential energy conservation standards for the considered equipment, as measured by the NPV of total commercial consumer economic impacts and the national energy savings (NES).
- A consumer subgroup analysis to evaluate variations in commercial consumer characteristics that may cause a standard to affect particular commercial consumer sub-populations (such as small businesses) differently than the overall population.
- A manufacturer impact analysis (MIA) to estimate the financial impact of potential standards on manufacturers and to calculate impacts on competition, employment, and manufacturing capacity.
- An emissions analysis to assess the effects of the considered standards on emissions of carbon dioxide (CO_2), nitrogen oxides (NO_X), mercury (Hg), methane (CH_4), sulfur dioxide (SO_2), and nitrous oxide (N_2O).
- An emissions monetization that estimates the economic value of reductions in CO_2 and NO_X emissions from the considered standards.
- A utility impact analysis to estimate effects of the considered standards on electric utilities' power generation capacity.

- An employment impact analysis to assess the aggregate impacts of the considered standards on national employment.
- A regulatory impact analysis (RIA) to evaluate non-regulatory alternatives to amended energy conservation standards in order to assess whether such alternatives could achieve substantially the same goal at a lower cost.

2.2 BACKGROUND

As noted in chapter 1 of this TSD, DOE initiated this rulemaking pursuant to 42 U.S.C. 6313(a)(6)(C), which requires that every 6 years, DOE must publish either a notice of determination that standards for the CWH equipment do not need to be amended or a NOPR including new proposed energy conservation standards.

DOE published the October 2014 RFI as a preliminary step pursuant to EPCA's requirements for DOE to evaluate energy conservation standards for CWH equipment. 79 FR 62899 (Oct. 21, 2014).

In preparing this NOPR, DOE considered the comments and new information in response to the October 2014 RFI. The following sections provide a general description of the different analytical components of the rulemaking analytical framework. DOE used the most reliable, current and accurate data available at the time of each analysis in this rulemaking. DOE welcomes and will consider any submissions of additional data during the rulemaking process.

2.3 MARKET AND TECHNOLOGY ASSESSMENT

The market and technology assessment characterizes the relevant equipment markets and existing technology options, including prototype designs, for the CWH equipment under consideration.

2.3.1 Market Assessment

As part of the market and technology assessment, DOE gathered information for an overall picture of the market for CWH equipment, including the nature of the equipment, market characteristics, and industry structure. DOE collected quantitative and qualitative information, primarily from publicly available sources. The market assessment examined manufacturers, trade associations, and the quantities and types of equipment sold and offered for sale. DOE reviewed relevant literature and interviewed manufacturers to develop an overall picture of the CWH equipment industry in the United States. Industry publications and trade journals, government agencies, and trade organizations provided much of the information, including: (1) manufacturers and their market shares; (2) shipments by equipment type; (3) equipment information; and (4) industry trends. Through surveying manufacturer literature and online equipment listings from manufacturer trade associations and government organizations, such as the Air-Conditioning, Heating, and Refrigeration Institute (AHRI) and California Energy Commission (CEC), as well as DOE's Compliance Certification Database, DOE compiled a database of CWH equipment models and their characteristics. This information, along with other sources, was used to carry out the market analysis and inform the downstream analyses. DOE also interviewed manufacturers to further understand market conditions. The analyses for the market assessment are described in chapter 3 of this TSD.

2.3.2 Equipment Classes

When evaluating and establishing energy conservation standards, DOE generally divides covered equipment into classes by the type of energy used, capacity, or other performance-related features that affect efficiency. Different energy conservation standards may apply to different equipment classes. DOE then conducts its analysis and considers establishing standards to provide separate standard levels for each equipment class.

In the NOPR, DOE proposes modifying the current equipment class structure to include the 12 equipment classes shown in Table 2.3.1. The reasoning and justification for the modified equipment class structure are discussed in the NOPR and in chapter 3 of this TSD.

Table 2.3.1 Proposed CWH Equipment Classes

Equipment		Specifications
Electric storage water heaters		All
Gas-fired storage water heaters	Commercial	Rated input >105 kBtu/h or rated storage volume >120 gal
	Residential-duty*	Rated input ≤105 kBtu/h and rated storage volume ≤120 gal
Oil-fired storage water heaters	Commercial	Rated input >140 kBtu/h or rated storage volume >120 gal
	Residential-duty*	Rated input ≤140 kBtu/h and rated storage volume ≤120 gal
Electric instantaneous water heaters†		<10 gal
		≥10 gal
Gas-fired instantaneous water heaters and hot water supply boilers	Instantaneous water heaters (other than storage-type) and hot water supply boilers	<10 gal
	Instantaneous water heaters (other than storage-type) and hot water supply boilers	≥10 gal
	Storage-type instantaneous water heaters	≥10 gal
Oil-fired instantaneous water heaters and hot water supply boilers	Instantaneous water heaters and hot water supply boilers	<10 gal
	Instantaneous water heaters and hot water supply boilers	≥10 gal
Unfired hot water storage tanks		All

* To be classified as a residential-duty commercial water heater, a water heater must, if requiring electricity, use single-phase external power supply, and not be designed to provide hot water at temperatures greater than 180 °F. 79 FR 40542, 40586 (July 11, 2014).

** DOE proposed a new equipment class for storage-type instantaneous water heaters, which are similar to storage water heaters with a ratio of input capacity to storage volume greater than or equal to 4,000 Btu/h per gallon of water stored. As discussed in the NOPR and chapter 3 of this TSD, DOE proposed a definition for storage-type instantaneous water heaters in a NOPR issued in April 2016 for test procedures for CWH equipment. (See Docket No. EERE-2014-BT-TP-0008.)

† Energy conservation standards for electric instantaneous water heaters are included in EPCA. (42 U.S.C. 6313(a)(5)(D)-(E)) In the NOPR, DOE proposes to codify these equipment classes and corresponding energy conservation standards for electric instantaneous water heaters in its regulations at 10 CFR 431.110.

For the NOPR analysis, DOE did not analyze all of the equipment classes listed above. The justification for not analyzing oil-fired CWH equipment and unfired hot water storage tanks is discussed in the NOPR. The analyzed equipment classes are shown in Table 2.3.2.

Table 2.3.2 Analyzed CWH Equipment Classes

Equipment Class		Specifications
Electric storage water heaters		All
Commercial gas-fired storage water heaters and gas-fired storage-type instantaneous water heaters		Rated input >105 kBtu/h or rated storage volume >120 gal
Residential-duty gas-fired storage water heaters*		Rated input ≤105 kBtu/h and rated storage volume ≤120 gal
Gas-fired instantaneous water heaters and hot water supply boilers	Tankless water heaters	<10 gal
	Hot water supply boilers	All

* To be classified as a residential-duty water heater, a water heater must, if requiring electricity, use single-phase external power supply, and not be designed to heat water at temperatures greater than 180 °F. 79 FR 40542, 40586 (July 11, 2014).

2.3.3 Technology Assessment

DOE typically uses information relating to existing and past technology options and prototype designs as inputs to determine what technologies manufacturers 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 DOE tentatively determined are technologically feasible.

Based on the information obtained through market analysis, DOE conducted a review of existing water heating technologies and upcoming technologies that can potentially improve water heater performance. DOE developed its list of technologically feasible design options for the considered equipment through consultation with manufacturers of components and systems, and from trade publications and technical papers. Since many options for improving efficiency are available in existing units, product literature examination provided additional information. The technologies examined in the technology assessment are described in detail in chapter 3 of this TSD.

2.4 SCREENING ANALYSIS

The purpose of the screening analysis is to evaluate the energy-saving technologies identified in the technology assessment to determine which ones to consider further and which ones to screen out. The screening analysis (chapter 4 of this TSD) examines various technologies as to whether they (1) are technologically feasible; (2) are practicable to manufacture, install, and service; (3) have an adverse impact on equipment utility or availability; and (4) have adverse impacts on health and safety. As described in section 2.3.3 of this chapter, DOE develops an initial list of efficiency-enhancement options from the technologies identified as technologically feasible. Then DOE, in consultation with interested parties, reviews the list to determine if these options are practicable to manufacture, install, and service; would adversely affect equipment utility or availability; or would have adverse impacts on health and safety. DOE includes any technology options that were not eliminated at this step in the engineering analysis.

2.5 ENGINEERING ANALYSIS

The engineering analysis (chapter 5 of the TSD) establishes the relationship between manufacturer selling price and increased efficiency for each CWH equipment class. This relationship serves as the basis for cost-benefit calculations in terms of modified equipment designs intended to improve energy efficiency for individual commercial consumers, manufacturers, and the Nation. Chapter 5 discusses the equipment classes analyzed, representative baseline units, incremental efficiency levels, the methodology used to develop price estimates at each efficiency level, price-efficiency curves, and the impact of efficiency improvements on the considered equipment. To determine the cost to commercial consumers of CWH equipment at potential higher efficiency levels, DOE estimated manufacturer selling prices at various efficiency levels, markups in the distribution chain, installation costs, and maintenance costs.

In the engineering analysis, DOE evaluated a range of CWH equipment efficiency levels and associated manufacturing costs. The purpose of the analysis is to estimate the incremental increase to selling prices that would result from increasing efficiency levels above the baseline model in each equipment class. The engineering analysis considers technologies not eliminated in the screening analysis, although certain technologies were not analyzed due to other reasons, such as lack of data quantifying improvement in efficiency or analysis of a less expensive technology option that achieves a similar efficiency improvement. DOE considers the remaining technologies, as appropriate, in developing the cost-efficiency curves, which are subsequently used for the LCC and PBP analyses.

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

DOE conducted this engineering analysis for CWH equipment using a combination of the efficiency-level and cost-assessment approaches. For the analysis of thermal efficiency levels for CWH equipment, DOE identified the efficiency levels for the analysis based on market data and then used the cost-assessment approach to determine the manufacturing production cost (MPC) at each level. For the analysis of standby loss levels for storage water heaters, DOE identified efficiency levels for analysis based on market data and commonly used technology options (*i.e.*, insulation type, thickness) and then used the cost-assessment approach to determine the MPC of equipment at each level. The cost-assessment approach involved physically disassembling commercially available equipment, consulting with outside experts, reviewing publicly available cost and performance information, and modeling product cost. Chapter 5 of the TSD describes the methodology and results of the engineering analysis used to derive the cost-efficiency relationships.

2.6 MARKUPS ANALYSIS

DOE uses distribution channel markups to convert the manufacturer selling price estimates from the engineering analysis to commercial consumer prices, which are then used in the LCC and PBP analysis, and in the MIA. Retail prices are necessary for the baseline efficiency level and all other efficiency levels under consideration.

Before developing markups, DOE must first define key market participants and identify distribution channels (*i.e.*, how the equipment is distributed from the manufacturer to the commercial consumer).

See chapter 6, Markup Analysis, of this TSD for additional details.

2.7 ENERGY USE ANALYSIS

The purpose of the energy use analysis is to determine the annual energy consumption of CWH equipment in representative U.S. building types that utilize the equipment, which includes assessing the energy-savings potential of increased equipment efficiencies. The annual energy consumption for CWH equipment includes use of natural gas, liquefied petroleum gas (LPG), or electricity for hot water production, as well as use of electricity for auxiliary components. DOE uses the annual energy consumption and energy-savings potential in the LCC and PBP analysis to establish the operating cost savings at various equipment efficiency levels.[a] The annual energy consumption of CWH equipment is used in subsequent analyses, including the LCC and PBP analysis and the NIA.

For commercial building types, DOE used Commercial Building Energy Consumption Survey (CBECS) 2003 data to estimate energy use of CWH equipment.[b] CBECS is a national survey of commercial buildings that contains statistical information on the energy consumption and expenditures in commercial building units along with data on energy-related characteristics of the commercial buildings and occupants (*e.g.*, principal building activity type, square footage, fuels used). For CWH equipment used in residential applications, DOE used the hot water loads model developed by Lawrence Berkeley National Laboratory (LBNL) for the 2010 “Energy Conservation Standards for Residential Water Heaters, Direct Heating Equipment, and Pool Heaters” rulemaking. 75 FR 20112 (April 16, 2010). DOE applied this model to the residential building records in the Energy Information Administration’s (EIA’s) 2009 Residential Energy Consumption Survey (RECS).[c] For RECS housing unit records in multi-family buildings, DOE modified the model for the analysis of whole building loads.

Chapter 7, Energy Use Analysis, of this TSD describes the details of the energy use analysis methodology.

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[a] Equipment efficiency levels are combinations of thermal efficiency levels and standby loss levels.
[b] U.S. Department of Energy—Energy Information Administration. *Commercial Buildings Energy Consumption Survey (CBECS), 2003 CBECS Survey Data*. www.eia.gov/consumption/commercial/data/2003/index.cfm?view=microdata. Last accessed November 2013.
[c] U.S. Department of Energy—Energy Information Administration. *Residential Energy Consumption Survey (RECS), 2009 RECS Survey Data*. www.eia.gov/consumption/residential/data/2009/. Last accessed March 2014.

2.8 LIFE-CYCLE COST AND PAYBACK PERIOD ANALYSIS

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

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

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

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

DOE is also required to perform a PBP analysis to determine whether the rebuttable presumption of economic justification applies (where the higher installed cost of more energy-efficient equipment is less than three times the value of the energy savings in the first year of the energy conservation standard). However, DOE routinely conducts a full economic analysis that considers the full range of impacts, including those to the consumer, manufacturer, nation, and environment. The results of this analysis serve as the basis for DOE to definitively evaluate the economic justification for a potential standard level (thereby supporting or rebutting the results of any preliminary determination of economic justification). The LCC results are also used for selecting different trial standard levels (TSLs)

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

2.9 SHIPMENTS ANALYSIS

DOE uses forecasts of equipment shipments to calculate the national impacts of standards on energy use, NPV, and future manufacturer cash flows. DOE develops shipment forecasts based on an analysis of key market drivers for each equipment class.

DOE estimated CWH equipment shipments by projecting water heater shipments in three market segments: (1) replacements, (2) new construction, and (3) new owners in buildings that did not previously have a commercial water heater.

To project CWH equipment replacement shipments, DOE developed retirement functions for water heaters from the lifetime estimates and applied them to the existing equipment in the building stock. The existing stock of equipment is tracked by vintage and developed from historical shipments data.

To project shipments to the new construction market, DOE used *AEO2015* for projections of new buildings. CWH equipment saturation rates in new buildings are based on the overall stock saturation rate in residential and commercial buildings. Net shipments to new owners are based on historical shipment data, and held constant over the analysis period.

TSD chapter 9 presents the mathematical formulation of the shipment analysis model and the methodology used to estimate historical and future shipments of CWH equipment.

2.10 NATIONAL IMPACT ANALYSIS

The NIA assesses the NES and the NPV from a national perspective of total commercial consumer costs and savings expected to result from new or amended energy conservation standards at specific efficiency levels. DOE determined the NPV and NES for the standard levels considered for the CWH equipment classes analyzed. To make the analysis more accessible and transparent to all interested parties, DOE prepared a computer spreadsheet that uses typical values (as opposed to probability distributions) as inputs. To assess the effect of input uncertainty on NES and NPV results, DOE has developed its spreadsheet model to conduct sensitivity analyses by running scenarios on specific input variables.

To estimate the impact that potential amended standards may have in the year of required compliance, DOE used a “roll-up” scenario in this rulemaking. Under the “roll-up” scenario, DOE assumes: (1) equipment efficiencies in the no-new-standards case that do not meet the standard level under consideration would “roll-up” to meet the new standard level and (2) equipment efficiencies above the standard level under consideration would not be affected.

Chapter 10 of the TSD provides additional details on the national impact analysis.

2.10.1 National Energy Savings Analysis

The inputs for determining the NES for each equipment class analyzed are (1) annual energy consumption per unit, (2) shipments, (3) equipment stock, (4) national energy consumption, and (5) site-to-primary energy conversion factors. DOE calculated the national energy consumption by multiplying the number of units (stock) of equipment (by vintage or age) by the unit energy consumption (also by vintage). DOE calculated annual NES based on the difference in national energy consumption for the no-new-standards case and for each potential standards case. DOE estimated energy consumption and savings based on site energy and converted the electricity consumption and savings to primary energy using annual conversion factors derived from the most recent version of the National Energy Modeling System (NEMS).[d] Cumulative energy savings are the sum of the NES for each year over the timeframe of the analysis.

DOE has historically presented NES in terms of primary energy savings. In response to the recommendations of a committee on "Point-of-Use and Full-Fuel-Cycle Measurement Approaches to Energy Efficiency Standards" appointed by the National Academy of Sciences, DOE published a final statement of policy in the *Federal Register* that announced its intention to use full-fuel-cycle (FFC) measures of energy use and greenhouse gas and other emissions in the NIA and emissions analyses included in future energy conservation standards rulemakings. 76 FR 51281 (August 18, 2011). After evaluating the approaches discussed in the August 18, 2011 notice, DOE published a statement of amended policy in the *Federal Register*, in which DOE explained its determination that NEMS is the most appropriate tool for its FFC analysis and its intention to use NEMS for that purpose. 77 FR 49701 (August 17, 2012). The approach used for the NOPR analysis is described in appendix 10D of this TSD.

Chapter 10 of this TSD presents both the primary NES and the FFC NES for the considered potential standards cases.

2.10.2 Net Present Value Analysis

The inputs for determining NPV 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 net savings each year as the difference between the no-new-standards case and each standards case in terms of total savings in operating costs versus total increases in installed costs. DOE calculated savings over the lifetime of equipment shipped in the projection period. DOE calculated NPV as the difference between the present value of operating cost savings and the present value of total installed costs. For future energy prices, DOE used the projected annual changes in average commercial and residential sector energy prices in *AEO2015*.

DOE estimates the NPV of commercial consumer benefits using both a 3-percent and a 7-percent real discount rate, 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").

[d] For more information on NEMS, please refer to the DOE, EIA documentation. A useful summary is National Energy Modeling System: An Overview 2009, DOE/EIA-0581 (October 2009) (Available at: http://www.eia.gov/oiaf/aeo/overview/).

2.11 COMMERCIAL CONSUMER SUBGROUP ANALYSIS

For the NOPR, DOE conducted a consumer subgroup analysis. A commercial consumer subgroup comprises a subset of the population that may be affected disproportionately by new or revised energy conservation standards (*e.g.*, small businesses and low income population subgroups). The purpose of a subgroup analysis is to determine the extent of any such disproportional impacts. Further detail of commercial consumer subgroup analysis is provided in chapter 11 of this TSD.

2.12 MANUFACTURER IMPACT ANALYSIS

The purpose of the MIA is to identify the likely impacts of more-stringent energy conservation standards on manufacturers of CWH equipment. In conducting this analysis, DOE sought input from manufacturers and other interested parties and consider financial impacts, as well as a wide range of quantitative and qualitative industry impacts that might occur after the adoption of amended standards. For example, a particular standard level could require changes to manufacturing practices of CWH equipment. DOE identified and discussed these potential impacts in interviews with manufacturers and other interested parties as part of its analysis.

DOE conducts the MIA in three phases and further tailors its analytical framework based on the comments it receives. In phase I, DOE creates an industry profile to characterize the industry and to identify important issues that require consideration. In phase II, DOE prepares an industry cash-flow model and determines what information it will discuss with manufacturers during manufacturer interviews. In phase III, DOE interviews manufacturers and assesses the impacts of potential standards both quantitatively and qualitatively. DOE calculates industry and subgroup cash flow and industry net present value (INPV) using the Government Regulatory Impact Model (GRIM). DOE then assesses impacts on competition, manufacturing capacity, employment, and regulatory burden based on manufacturer interview feedback.

DOE gathers the information for the analysis during manufacturer interviews. See chapter 12 of the TSD for more detailed information on the MIA.

2.13 EMISSIONS ANALYSIS

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

The analysis of power sector emissions uses marginal emissions factors that were derived from data in *AEO2015*. The methodology is described in chapters 13 and 15 of this TSD.

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

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

Because the on-site operation of CWH equipment may involve the combustion of fossil fuels and results in emissions of CO_2, NO_X, and SO_2 at the sites where these appliances are used, DOE also accounted for the reduction in these site emissions and the associated upstream emissions due to potential standards. Site emissions of CO_2, NO_X, and SO_2 were estimated using emissions intensity factors from an EPA publication.[f]

The *AEO* incorporates the projected impacts of existing air quality regulations on emissions. *AEO2015* generally represents current legislation and environmental regulations, including recent government actions, for which implementing regulations were available as of October 31, 2014.

Further detail is provided in chapter 13 and appendix 13A of this TSD.

2.14 MONETIZATION OF EMISSIONS REDUCTIONS BENEFITS

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

To estimate the monetary value of benefits resulting from reduced emissions of CO_2, DOE plans to use the most current Social Cost of Carbon (SCC) values developed and/or agreed to by an interagency process. The SCC is intended to be a monetary measure of the incremental damage resulting from GHG emissions, including, but not limited to, net agricultural productivity loss, human health effects, property damage from sea level rise, and changes in ecosystem services. Any effort to quantify and to monetize the harms associated with climate change will raise serious questions of science, economics, and ethics. However, with full regard for the limits of both quantification and monetization, the SCC can be used to provide estimates of the social benefits of reductions in GHG emissions.

The Interagency Working Group on Social Cost of Carbon released an update of its previous report in 2013.[1] The most recent estimates of the SCC in 2015, expressed in 2014$, are $12.2, $40.0, $62.3, and $117 per metric ton of CO_2 avoided. For emissions reductions that occur

[e] Available at www.epa.gov/sites/production/files/2015-07/documents/emission-factors_2014.pdf.
[f] U.S. Environmental Protection Agency. Compilation of Air Pollutant Emission Factors, AP-42, Fifth Edition, Volume I: Stationary Point and Area Sources (Chapter 1) (Available at www.epa.gov/ttn/chief/ap42/index.html.)

in later years, these values grow in real terms over time. Additionally, the interagency group determined that a range of values from 7 percent to 23 percent should be used to adjust the global SCC to calculate domestic effects, although DOE will give preference to consideration of the global benefits of reducing CO_2 emissions. To calculate a present value of the stream of monetary values, DOE discounts the values in each of the four cases using the discount rates that had been used to obtain the SCC values in each case.

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

DOE also considers the potential monetary benefits of reduced NO_X emissions attributable to the standard levels it considers. DOE estimated the monetized value of NO_X emissions reductions using benefit per ton estimates from the *Regulatory Impact Analysis for the Proposed Carbon Pollution Guidelines for Existing Power Plants and Emission Standards for Modified and Reconstructed Power Plants,* published in June 2014 by EPA's Office of Air Quality Planning and Standards.[g] The report includes high and low values for NO_X (as $PM_{2.5}$) for 2020, 2025, and 2030 discounted at 3 percent and 7 percent.

Further detail is provided in chapter 14, appendix 14A, and appendix 14B of this TSD.

2.15 UTILITY IMPACT ANALYSIS

To estimate the impacts of potential energy conservation standards on the electric utility industry, DOE used published output from the NEMS associated with *AEO2015*. NEMS is a large, multi-sectoral, partial-equilibrium model of the U.S. energy sector that EIA has developed over several years, primarily for preparing the *AEO*. NEMS produces a widely recognized forecast for the United States through 2040 and is available to the public.

As of 2014, DOE is using a new methodology based on results published for the *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 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.

[g] http://www3.epa.gov/ttnecas1/regdata/RIAs/111dproposalRIAfinal0602.pdf. See Tables 4-7, 4-8, and 4-9 in the report.

Further detail is provided in chapter 15 and appendix 15A of this TSD.

2.16 EMPLOYMENT IMPACT ANALYSIS

The adoption of energy conservation standards can affect employment both directly and indirectly. Direct employment impacts are changes in the number of plant employees up to the line-supervisor level who are directly involved in producing and assembling the covered equipment. Workers performing services that are closely associated with production operations, such as material handling with a forklift, are also included as production labor. DOE evaluated 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 modified spending driven by increased equipment prices and reduced spending on energy.

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

Further detail is provided in chapter 16 of this TSD.

2.17 REGULATORY IMPACT ANALYSIS

In the NOPR stage, DOE prepared a RIA pursuant to Executive Order 12866, regulatory Planning and Review, 58 FR 51735, October 4, 1993, which is subject to review by the Office of Information and Regulatory Affairs at the Office of Management and Budget. The RIA address the potential for non-regulatory approaches to supplant energy conservation standards in order to improve the energy efficiency or reduce the energy consumption of the equipment covered under this rulemaking.

DOE recognized that voluntary or other non-regulatory efforts by manufacturers, utilities, and other interested parties can substantially affect energy efficiency or reduce energy consumption. DOE bases its assessment on the actual impacts of any such initiatives to date, but also considers information presented by interested parties regarding the impacts existing initiatives might have in the future. Further detail is provided in chapter 17 of this TSD.

[h] Scott M.J., O.V. Livingston, P.J. Balducci, J.M. Roop, and R.W. Schultz. *ImSET: Impact of Sector Energy Technologies Model Description and User's Guide*. 2009. Pacific Northwest National Laboratory. PNNL-18412.

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1. United States Government–Interagency Working Group on Social Cost of Carbon. *Technical Support Document: Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866*. May 2013. Revised July 2015. https://www.whitehouse.gov/sites/default/files/omb/inforeg/scc-tsd-final-july-2015.pdf.

CHAPTER 3. MARKET AND TECHNOLOGY ASSESSMENT

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CHAPTER 3. MARKET AND TECHNOLOGY ASSESSMENT

3.1 INTRODUCTION

This chapter details the market and technology assessment that the U.S. Department of Energy (DOE) has conducted in support of the ongoing energy conservation standards rulemaking for commercial water heating (CWH) equipment.

This chapter consists of the market assessment and the technology assessment. The goal of the market assessment is to develop a qualitative and quantitative characterization of the CWH equipment industry and market structure based on publicly available information and data and other information that DOE received directly from manufacturers and other interested parties. DOE examined publicly available information from the Air-Conditioning, Heating, and Refrigeration Institute (AHRI) *Directory of Certified Product Performance*,[1] the appliance database from the California Energy Commission (CEC),[2] and DOE's *Compliance Certification Database*. The market and technology assessment addresses manufacturer characteristics and market shares, existing regulatory and non-regulatory efficiency improvement initiatives, equipment classes, and trends in equipment markets and characteristics. DOE performs the technology assessment to develop a preliminary list of technologies (referred to as technology options) that could be used to improve the efficiency of CWH equipment.

3.2 EQUIPMENT DEFINITIONS

Title III, Part C[a] of the Energy Policy and Conservation Act of 1975 (EPCA), Pub. L. 94-163 (42 U.S.C. 6311-6317, as codified), added by Pub. L. 95-619, Title IV, section 441(a), established the Energy Conservation Program for Certain Industrial Equipment,[b] which includes provisions covering the CWH equipment that are the subject of this rulemaking. EPCA includes the following categories of CWH equipment as covered industrial equipment: storage water heaters, instantaneous water heaters, and unfired hot water storage tanks. EPCA defines "industrial equipment" as any equipment:

(i) Which in operation consumes, or is designed to consume, energy;

(ii) Which, to a significant extent, is distributed in commerce for industrial or commercial use; and

(iii) Which is not a "covered product" as defined in 42 U.S.C. 6291(a)(2), other than a component of a covered product with respect to which there is in effect a determination under 42 U.S.C. 6312(c); without regard to whether such article is in fact distributed in commerce for industrial or commercial use. (42 U.S.C. 6311(2))

[a] For editorial reasons, upon codification in the U.S. Code, Part C was redesignated Part A-1.
[b] All references to EPCA in this document refer to the statute as amended through the Energy Efficiency Improvement Act of 2015 (EEIA 2015), Pub. L. 114-11 (April 30, 2015).

EPCA defines a storage water heater as a water heater that heats and stores water internally at a thermostatically controlled temperature for use on demand. This term does not include units that heat with an input rating of 4,000 Btu per hour or more per gallon of stored water. EPCA defines an instantaneous water heater as a water heater that heats with an input rating of at least 4,000 Btu per hour per gallon of stored water. Lastly, EPCA defines an unfired hot water storage tank as a tank that is used to store water that is heated external to the tank. (42 U.S.C. 6311(12)(a)-(c))

DOE codified the following more specific definitions for CWH equipment in 10 CFR 431.102 in a final rule published October 21, 2004 ("October 2004 final rule"). 69 FR 61974, 61983.[c]

Specifically, DOE defined hot water supply boiler as a packaged boiler that is industrial equipment and that: (1) has an input rating from 300,000 Btu/h to 12,500,000 Btu/h and of at least 4,000 Btu/h per gallon of stored water, (2) is suitable for heating potable water, and (3) has the temperature and pressure controls necessary for heating potable water for purposes other than space heating, and/or the manufacturer's product literature, product markings, product marketing, or product installation and operation instructions indicate that the boiler's intended uses include heating potable water for purposes other than space heating.[d]

DOE also defined an instantaneous water heater as a water heater that has an input rating not less than 4,000 Btu/h per gallon of stored water, and that is industrial equipment, including products meeting this description that are designed to heat water to temperatures of 180 °F or higher.[e]

DOE defined a storage water heater as a water heater that heats and stores water within the appliance at a thermostatically controlled temperature for delivery on demand and that is industrial equipment, and does not include units with an input rating of 4,000 Btu/h or more per gallon of stored water.[f]

Lastly, DOE defined an unfired hot water storage tank as a tank used to store water that is heated externally, and that is industrial equipment.

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[c] In a NOPR for test procedures for certain CWH equipment issued in April 2016 ("2016 CWH TP NOPR"), DOE proposed to amend its definitions for commercial water heating equipment by changing the phrase "input rating" to "fuel input rate" for gas-fired and oil-fired equipment, in order to match DOE's proposed regulations regarding fuel input rate. (See EERE-2014-BT-TP-0008)

[d] In the 2016 CWH TP NOPR, DOE proposed to amend its definition for "hot water supply boiler" by citing the definition for "packaged boiler" included in §431.82 instead of a duplicated definition for "packaged boiler" in §431.102, which DOE proposed to remove. (See EERE-2014-BT-TP-0008)

[e] In the 2016 CWH TP NOPR, DOE proposed to amend its definition for "instantaneous water heater" by making the following changes: (1) removing the clause stating that products designed to heat water to temperatures of 180 °F or higher are included; (2) removing the clause "that is industrial equipment"; and (3) adding the input criteria that separate consumer and commercial instantaneous water heaters for each energy source (*i.e.*, gas, oil, and electricity). (See EERE-2014-BT-TP-0008)

[f] In the 2016 CWH TP NOPR, DOE proposed to amend its definition for "storage water heater" by adding the input criteria that separate consumer and commercial storage water heaters for each energy source (*i.e.*, gas, oil, and electricity). (See EERE-2014-BT-TP-0008)

In a final rule for test procedures for residential water heaters and certain commercial water heaters published July 11, 2014 ("July 2014 final rule"), DOE established a definition for "residential-duty commercial water heater," which is defined as any gas-fired, electric, or oil-fired storage or instantaneous commercial water heater that meets the following conditions:

1) For models requiring electricity, uses single-phase external power supply;

2) Is not designed to provide outlet hot water at temperatures greater than 180 °F; and

3) Is not excluded by any of the specified limitations regarding rated input and storage volume established in Table 3.2.1 (below). 79 FR 40542, 40586.

Table 3.2.1 Classification of Residential-Duty Commercial Water Heaters

Water Heater Type	Indicator of Non-Residential Application
Gas-fired storage	Rated input >105 kBtu/h; rated storage volume >120 gallons
Oil-fired storage	Rated input >140 kBtu/h; rated storage volume >120 gallons
Electric storage	Rated input >12 kW; rated storage volume >120 gallons
Heat pump with storage	Rated input >12 kW; rated current >24 A at a rated voltage of not greater than 250 V; rated storage volume >120 gallons
Gas-fired instantaneous	Rated input >200 kBtu/h; rated storage volume >2 gallons
Electric instantaneous	Rated input >58.6 kW; rated storage volume >2 gallons
Oil-fired instantaneous	Rated input >210 kBtu/h; rated storage volume >2 gallons

For four classes of residential-duty commercial water heaters – electric storage water heaters, heat pump water heaters, gas-fired instantaneous water heaters, and oil-fired instantaneous water heaters – the input criteria established to separate residential-duty commercial water heaters and commercial water heaters are identical to those codified at 10 CFR 430.2 that separate consumer water heaters and commercial water heaters. Because these input criteria are identical, by definition, no models can be classified under these four residential-duty equipment classes. Therefore, in a NOPR for test procedures for certain CWH equipment issued in April 2016 ("2016 CWH TP NOPR"), DOE proposed to remove these classes from the definition for "residential-duty commercial water heater" codified at 10 CFR 431.102. (See EERE-2014-BT-TP-0008)

CWH equipment primarily provides hot water to commercial buildings, such as office buildings, retail buildings, and hotels. The basic design of a gas-fired storage water heater comprises a pilot or electronic ignition system, a gas valve, a burner assembly, flue tube(s), flue baffle(s), an insulated water tank, sacrificial anode rod(s), a thermostat, and an outer case. The basic design of an electric storage water heater comprises electric resistance heating elements, an insulated water tank, sacrificial anode rod(s), a thermostat, and an outer case. A basic gas-fired tankless water heater consists of an electronic ignition system, a gas valve, a burner assembly, a blower assembly, a heat exchanger, a thermostat, and an outer case. A basic gas-fired hot water supply boiler consists of an electronic ignition system, a gas valve, a burner assembly, a heat exchanger, a thermostat, and an outer case.

The energy conservation standards for CWH equipment are represented in terms of the thermal efficiency (E_t) and/or standby loss (SL) in 10 CFR 431.110. In the October 2004 final rule, DOE codified definitions for thermal efficiency and standby loss at 10 CFR 431.102, which read as follows:

Thermal efficiency for an instantaneous water heater, a storage water heater or a hot water supply boiler means the ratio of the heat transferred to the water flowing through the water heater to the amount of energy consumed by the water heater as measured during the thermal efficiency test procedure prescribed in this subpart.

Standby loss means the average hourly energy required to maintain the stored water temperature, expressed as applicable either (1) as a percentage (per hour) of the heat content of the stored water and determined by the formula for S given in section 2.10 of American National Standards Institute (ANSI) Z21.10.3-1998, denoted by the term "S," or (2) in Btu per hour based on a 70 °F temperature differential between stored water and the ambient temperature, denoted by the term "SL."

69 FR 61974, 61983 (Oct. 21, 2004)

In the 2016 CWH TP NOPR, DOE proposed a new definition for standby loss, which reads as follows:

Standby loss means –

1) For electric commercial water heating equipment (not including commercial heat pump water heaters), the average hourly energy required to maintain the stored water temperature expressed as a percent per hour (%/h) of the heat content of the stored water above room temperature and determined in accordance with appendix B, D, or E to subpart G of 10 CFR part 431 (as applicable), denoted by the term "S."

2) For gas-fired and oil-fired commercial water heating equipment, the average hourly energy required to maintain the stored water temperature expressed in British thermal units per hour (Btu/h) based on a 70 °F temperature differential between stored water and ambient temperature and determined in accordance with appendix A, C, or E to subpart G of part 431 (as applicable), denoted by the term "SL"; or

3) For unfired hot water storage tanks, the average hourly energy lost from the storage tank when in standby mode expressed in British thermal units per hour (Btu/h) and determined in accordance with appendix G to subpart G of 10 CFR part 431, denoted by term "SL".

(See Docket No. EERE-2014-BT-TP-0008)

Additionally, in the 2016 CWH TP NOPR, DOE proposed to define storage-type gas-fired instantaneous water heaters and to include these units in a separate equipment class because of significant design differences from other instantaneous water heaters. Storage-type instantaneous water heaters are instantaneous water heaters (*i.e.,* greater than 4,000 Btu/h per gallon of water stored and greater than 10 gallons of water stored) that include a storage tank. The following definition was proposed in 2016 CWH TP NOPR:

Storage-type instantaneous water heater means an instantaneous water heater comprising a storage tank with a submerged heat exchanger(s) or heating element(s).

(See EERE-2014-BT-TP-0008)

Another class of commercial CWH equipment is commercial heat pump water heaters (CHPWHs). As discussed in the NOPR, energy conservation standards for CHPWHs were not analyzed. Electric CHPWHs use a refrigeration circuit, similar to that found in an air conditioner or heat pump, to heat water. This is essentially a water-to-air heat pump operating in reverse. For electric water heaters, this is an alternative to resistive heating, as heat is only being moved, not generated. CHPWHs use existing heat pump technology to transfer heat from air, typically at room temperature, to water at a higher temperature. Because heat does not naturally transfer from a low temperature to a higher temperature, a mechanical system consisting primarily of a closed refrigeration loop containing a refrigerant vapor compressor, an evaporator (a type of heat exchanger), a condenser (another heat exchanger), and an expansion device is used to transfer the heat. Typically, the evaporator captures heat from the ambient air and the condenser delivers this heat to the water inside of a storage tank. The compressor and expansion devices facilitate refrigerant pressure changes to allow for these heat transfer processes.

CHPWHs are configured as add-on units, heating water without any storage capacity. Typically these units are combined with a storage tank or an electric resistance water heater if higher demand or an outlet water temperature higher than about 140 °F is desired (this is typically the maximum operating temperature of a CHPWH). A small pump circulates cold water from the tank through the heat pump and pumps the resulting hot water back to the tank.

Several manufacturers produce commercial heat pump water heaters, and significant research is being conducted to improve their performance.

Gas-fired absorption heat pump water heaters use the same principle as electric CHPWHs (*i.e.*, extracting heat from air to heat water), except that they use a gas-fired absorption process to increase the pressure of the refrigerant instead of electric mechanical compression. Instead of a compressor increasing the pressure of the refrigerant, the refrigerant is absorbed into water, pumped to higher pressure, and then boiled out in a generator, after which it moves on to the heat exchanger. The absorption working fluid is then recycled back to the absorber, and heat is exchanged between the two fluids.

3.3 EQUIPMENT CLASSES

When evaluating and establishing energy conservation standards, DOE divides covered equipment into equipment classes by the type of energy used or by capacity or other performance-related features that justify a different standard. In making a determination whether a performance-related feature justifies a different standard, DOE considers the feature's utility to the consumer and other factors DOE determines are appropriate.

DOE's current equipment classes are characterized by energy source (*i.e.*, gas, oil, or electricity), equipment type (*i.e.*, storage vs. instantaneous and hot water supply boilers), and size (*i.e.*, input capacity rating and rated storage volume). Unfired hot water storage tanks are included in a separate equipment class.

Table 3.3.1 shows DOE's current CWH equipment classes, which may be found in DOE's regulations at 10 CFR 431.110.

Table 3.3.1 Existing CWH Equipment Classes

Equipment	Size
Electric storage water heaters	All
Gas-fired storage water heaters	≤155,000 Btu/h
	>155,000 Btu/h
Oil-fired storage water heaters	≤155,000 Btu/h
	>155,000 Btu/h
Electric instantaneous water heaters*	<10 gal
	≥10 gal
Gas-fired instantaneous water heaters and hot water supply boilers	<10 gal
	≥10 gal
Oil-fired instantaneous water heater and hot water supply boilers	<10 gal
	≥10 gal
Unfired hot water storage tank	All

* Energy conservation standards for electric instantaneous water heaters are included in EPCA. (42 U.S.C. 6313(a)(5)(D)-(E)) In the NOPR, DOE proposes to codify these equipment classes and corresponding energy conservation standards for electric instantaneous water heaters in its regulations at 10 CFR 431.110.

DOE established new equipment classes for residential-duty commercial water heaters and a new uniform energy factor to replace the current thermal efficiency and standby loss metrics for these new equipment classes in the July 2014 final rule. 79 FR 40542, 40586 (July 11, 2014). The uniform efficiency descriptor only applies to commercial water heaters that meet the definition of "residential-duty commercial water heater," as defined above in section 3.2.

Within the "gas-fired instantaneous water heaters and hot water supply boilers" equipment class, DOE has identified two different kinds of equipment: tankless water heaters and hot water supply boilers. From examination of equipment literature and discussion with manufacturers, DOE understands that tankless water heaters are typically used without a storage tank, flow-activated, wall-mounted, and capable of higher temperature rises. Hot water supply boilers, conversely, are typically used with a storage tank and recirculation loop, thermostatically-activated, and not wall-mounted. However, despite these differences, tankless water heaters and hot water supply boilers share basic similarities: both kinds of equipment supply hot water in commercial applications with at least 4,000 Btu/h per gallon of stored water, and both include heat exchangers through which incoming water flows and is heated by combustion flue gases that flow around the heat exchanger tubes. Because of these basic similarities, DOE continued to group these types of equipment into a single equipment class and analyzed tankless water heaters and hot water supply boilers as two separate kinds of representative equipment for the instantaneous water heaters and hot water supply boilers equipment class for this NOPR.

Because storage-type instantaneous water heaters are similar to commercial storage water heaters in design and performance, gas-fired storage-type instantaneous water heaters were analyzed in the commercial gas-fired storage water heater equipment class in this NOPR.

The equipment classes proposed in this rulemaking for CWH equipment are shown in Table 3.3.2.

Table 3.3.2 Proposed CWH Equipment Classes

Equipment		Specifications
Electric storage water heaters		All
Gas-fired storage water heaters	Commercial	Rated input >105 kBtu/h or rated storage volume >120 gal
	Residential-duty*	Rated input ≤105 kBtu/h and rated storage volume ≤120 gal
Oil-fired storage water heaters	Commercial	Rated input >140 kBtu/h or rated storage volume >120 gal
	Residential-duty*	Rated input ≤140 kBtu/h and rated storage volume ≤120 gal
Electric instantaneous water heaters**		<10 gal
		≥10 gal
Gas-fired instantaneous water heaters and hot water supply boilers	Instantaneous water heaters (other than storage-type) and hot water supply boilers	<10 gal
	Instantaneous water heaters (other than storage-type) and hot water supply boilers	≥10 gal
	Storage-type instantaneous water heaters	≥10 gal
Oil-fired instantaneous water heaters and hot water supply boilers	Instantaneous water heaters and hot water supply boilers	<10 gal
	Instantaneous water heaters and hot water supply boilers	≥10 gal
Unfired hot water storage tanks		All

* In addition to the listed specifications, to be classified as a residential-duty water heater, a water heater must, if requiring electricity, use single-phase external power supply, and not be designed to heat water at temperatures greater than 180 °F. 79 FR 40542, 40586. (July 11, 2014).
** Energy conservation standards for electric instantaneous water heaters are included in EPCA. (42 U.S.C. 6313(a)(5)(D)-(E)) In the NOPR, DOE proposes to codify these equipment classes and corresponding energy conservation standards for electric instantaneous water heaters in its regulations at 10 CFR 431.110.

American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE) Standard 90.1-2013, "*Energy Standard for Buildings Except Low-Rise Residential Buildings*," increased its thermal efficiency level for commercial oil-fired storage water heaters from 78 percent to 80 percent.[3] DOE reviewed the updated ASHRAE Standard 90.1-2013 efficiency level as well as more-stringent levels as potential Federal standards and published a final rule on July 17, 2015 ("July 2015 ASHRAE equipment final rule") that, among other things, adopted this increased ASHRAE efficiency level as a Federal standard. 80 FR 42614, 42667. Because DOE determined in the July 2015 ASHRAE equipment final rule that there were not enough potential energy savings for proposing thermal efficiency standards higher than the ASHRAE 90.1 levels for oil-fired storage water heaters, DOE did not analyze amended thermal efficiency standards for oil-fired storage water heaters in the NOPR.

In the 2016 CWH TP NOPR, DOE proposed, among other things, a new test procedure for unfired hot water storage tanks. (See EERE-2014-BT-TP-0008) This test procedure uses a new standby loss metric, compared to the current insulation R-value metric. DOE plans to analyze unfired hot water storage tanks in a separate rulemaking. Therefore, amended energy conservation standards for unfired hot water storage tanks were not analyzed in the NOPR.

3.4 EQUIPMENT TEST PROCEDURES

The statutory criteria for Federal test procedures require that a test procedure be reasonably designed to produce test results that reflect energy efficiency, energy use, and estimated operating costs of a type of industrial equipment (or class thereof) during a representative average use cycle (as determined by the Secretary), and shall not be unduly burdensome to conduct. (42 U.S.C. 6314 (a)(2))

The DOE test procedure for most CWH equipment is currently specified in 10 CFR 431.106. This section prescribes the methods of measuring the thermal efficiency and standby loss of CWH equipment. The DOE test procedure currently incorporates by reference ANSI Z21.10.3-2011: *Gas Water Heaters, Volume III, Storage Water Heaters with Input Ratings Above 75,000 Btu Per Hour, Circulating and Instantaneous*. The DOE test procedure for residential-duty commercial water heaters was established in the July 2014 final rule, and is specified in Appendix E to Subpart B of 10 CFR 430. 79 FR 40542, 40567 (July 11, 2014). In the 2016 CWH TP NOPR, DOE proposes to update its reference to the updated industry test method – Annex E.1 of ANSI Z21.10.3-2015. Additionally, DOE proposes new test procedures for commercial heat pump water heaters and unfired hot water storage tanks that incorporate by reference the following industry test methods, respectively: (1) ANSI/ASHRAE Standard 118.1-2012, "Method of Testing for Rating Commercial Gas, Electric, and Oil Service Water-Heating Equipment"; and (2) sections 4, 5, 6.0, and 6.1 of GAMA IWH-TS-1, "Method to Determine Performance of Indirect-Fired Water Heaters," March 2003 edition.

3.5 MANUFACTURER TRADE GROUPS

DOE identified AHRI as the trade group that represents manufacturers of CWH equipment. Formed in 1953, AHRI is a national trade association with more than 300 member companies that account for more than 90 percent of the residential and commercial air conditioning, space heating, water heating, and commercial refrigeration equipment manufactured and sold in North America.[4] The Air-conditioning and Refrigeration Institute (ARI) and the Gas Appliance Manufacturers Association (GAMA) merged to become AHRI on Jan. 1, 2008. AHRI's scope includes gas-fired, oil-fired, and electric products and equipment. AHRI serves many functions, including advocating for the heating, ventilation, air-conditioning and refrigeration (HVACR) industry; certifying product performance; compiling statistical reports of industry data; and sponsoring HVACR research programs.

AHRI develops and publishes technical standards for residential and commercial air-conditioning, heating, and refrigeration equipment using rating criteria and procedures for measuring and certifying equipment performance. Manufacturers certify their own equipment by providing AHRI with test data. AHRI maintains the *Directory of Certified Product Performance* ("AHRI Directory"), which is a database of equipment ratings for all manufacturers who elect to participate in the program. DOE used the data for CWH equipment in the AHRI Directory, along with other data sources, in this market assessment.

3.6 MANUFACTURER INFORMATION

The following section details information regarding manufacturers of CWH equipment, including estimated market shares (section 3.6.1) and small businesses (section 0). DOE identified manufacturers from the AHRI Directory, the CEC Appliance Database, DOE's Compliance Certification Database, and other publicly-available information.

3.6.1 Manufacturers and Market Shares

DOE identified three major manufacturers of commercial and residential-duty gas-fired and electric storage water heaters that represent more than 90 percent of the market in terms of shipments. Current industry characteristics, DOE research, and discussions with manufacturers were used to identify these major manufacturers. These three manufacturers also manufacture units under many other subsidiary names.

Table 3.6.1 shows these manufacturers and their subsidiary brands and six other manufacturers.

Table 3.6.1 Manufacturers of Commercial and Residential-Duty Gas-Fired and Electric Storage Water Heaters

Major Manufacturers and Brands	Other Manufacturers
• A.O. Smith Corporation (brands include American, GSW, John Wood, Kenmore*, Lochinvar, Reliance, State) • Rheem Manufacturing Company** (brands include Richmond, Ruud) • Bradford-White Corporation (brands include Laars)	• HTP, Inc. • Bock Water Heaters • Giant† • American Standard • PVI Industries • Hubbell Electric Heater Company

* Kenmore is not a subsidiary of A.O. Smith Corporation, but A.O. Smith manufactures water heaters sold by Kenmore.
** Rheem Manufacturing Company is a subsidiary of the Paloma Group.
† Giant is a subsidiary of Usines Giant, Inc.

DOE identified six manufacturers of gas-fired tankless water heaters. Table 3.6.2 shows these manufacturers and their subsidiaries.

Table 3.6.2 Manufacturers of Gas-Fired Tankless Water Heaters

Rinnai Corporation
Noritz Corporation
Bosch*
Takagi
Intellihot Green Technologies, Inc.
Hubbell Electric Heater Company

* Bosch is a subsidiary of Robert Bosch GmbH

DOE identified manufacturers of gas-fired hot water supply boilers. Table 3.6.3 shows these manufacturers and their subsidiaries.

Table 3.6.3 Manufacturers of Gas-Fired Hot Water Supply Boilers

Ace Boiler, Inc.
Aerco International*
A. O. Smith Corporation (Brands include Lochinvar)
Bradford-White Corporation (Brands include Laars)
Burnham Holdings (Brands include Bryan Boilers and Thermal Solutions)
Camus Hydronics
Gasmaster Industries
Hamilton Engineering
HTP, Inc.
Parker Boiler Co.
RBI Water Heaters
Rheem Manufacturing Company
Sellers Manufacturing Company
Triangle Tube

* Aerco International is a subsidiary of Watts Water Technologies

3.6.2 Small Businesses

DOE considered the possibility that energy conservation standards for CWH equipment could adversely affect small businesses. The Small Business Administration (SBA) has set a size threshold to define those entities as small businesses. DOE used the SBA small business size standards to determine whether any small entities would be subject to the requirements of the rule. 65 FR 30836, 30848 (May 15, 2000), as amended at 77 FR 49991, 50000, 50011 (August 20, 2012) and codified at 13 CFR part 121. The size standards are listed by North American Industry Classification System (NAICS) code and industry description and are published by the SBA. Manufacturing of CWH equipment is classified under NAICS 333318, "*Other Commercial and Service Industry Machinery Manufacturing*." The SBA sets a threshold of 1,000 employees or fewer for an entity to be considered as a small business for this category.

Chapter 12 of this technical support document (TSD) contains additional details regarding DOE's analysis of impacts of amended energy conservation standards for CWH equipment on manufacturers and in particular, small businesses.

3.7 REGULATORY PROGRAMS

The following section details current regulatory programs mandating energy conservation standards for CWH equipment. Section 3.7.1 discusses current Federal energy conservation standards; section 3.7.2 discusses efficiency levels in ASHRAE Standards 90.1; and section 3.7.3 provides an overview of existing state standards. Sections 3.7.4 and 0 review standards in Canada and Mexico, respectively, which may affect the companies serving the North American market.

3.7.1 Current Federal Energy Conservation Standards

DOE most recently amended energy conservation standards for CWH equipment in the July 2015 ASHRAE equipment final rule. 80 FR 42614 (July 17, 2015). The current standards, as prescribed at 10 CFR 431.110, are listed in Table 3.7.1.

Table 3.7.1 Current Federal Energy Conservation Standards for CWH Equipment

Equipment class	Size	Energy conservation standards[*]	
		Minimum thermal efficiency (equipment manufactured on and after October 9, 2015) [**, †]	**Maximum standby loss (equipment manufactured on and after October 29, 2003)**[**,‡]
Electric storage water heaters	All	N/A	$0.30 + 27/V_m$ (%/h)
Gas-fired storage water heaters	≤155,000 Btu/h	80%	$Q/800 + 110(V_r)^{1/2}$ (Btu/h)
	>155,000 Btu/h	80%	$Q/800 + 110(V_r)^{1/2}$ (Btu/h)
Oil-fired storage water heaters	≤155,000 Btu/h	80%[†]	$Q/800 + 110(V_r)^{1/2}$ (Btu/h)
	>155,000 Btu/h	80%[†]	$Q/800 + 110(V_r)^{1/2}$ (Btu/h)
Electric instantaneous water heaters[‡‡]	<10 gal	80%	N/A
	≥10 gal	77%	$2.30 + 67/V_m$ (%/h)
Gas-fired instantaneous water heaters and hot water supply boilers	<10 gal	80%	N/A
	≥10 gal	80%	$Q/800 + 110(V_r)^{1/2}$ (Btu/h)
Oil-fired instantaneous water heater and hot water supply boilers	<10 gal	80%	N/A
	≥10 gal	78%	$Q/800 + 110(V_r)^{1/2}$ (Btu/h)
Product	**Size**	**Minimum thermal insulation**	
Unfired hot water storage tank	All	R-12.5	

* V_m is the measured storage volume and V_r is the rated volume, both in gallons. Q is the nameplate input rate in Btu/h.
** For hot water supply boilers with a capacity of less than 10 gallons: (1) the standards are mandatory for products manufactured on an after October 21, 2005 and (2) products manufactured prior to that date, and on or after October 23, 2003, must meet either the standards listed in this table or the applicable standards in Subpart E of this Part for a "commercial packaged boiler."
† For oil-fired storage water heaters: (1) the standards are mandatory for equipment manufactured on and after October 9, 2015 and (2) equipment manufactured prior to that date must meet a minimum thermal efficiency level of 78 percent.
‡ Water heaters and hot water supply boilers having more than 140 gallons of storage capacity need not meet the standby loss requirement if (1) the tank surface area is thermally insulated to R-12.5 or more, (2) a standing pilot light is not used and (3) for gas-fired or oil-fired storage water heaters, they have a fire damper or fan assisted combustion.
‡‡ Energy conservation standards for electric instantaneous water heaters are included in EPCA. (42 U.S.C. 6313(a)(5)(D)-(E)) The compliance date for these energy conservation standards is January 1, 1994. In the NOPR, DOE proposes to codify these standards for electric instantaneous water heaters in its regulations at 10 CFR 431.110.

3.7.2 ASHRAE Standard 90.1

ASHRAE Standard 90.1, "Energy Standard for Buildings Except Low-rise Residential Buildings," contains voluntary energy efficiency levels for certain types of commercial equipment. Standard 90.1 is sometimes adopted as part of state building codes, making certain parts or all of Standard 90.1 mandatory for compliance with the building codes in that State. As a result, although Standard 90.1 contains voluntary efficiency levels, CWH equipment manufacturers usually design their equipment to meet its requirements so they sell equipment in certain states. Further, when ASHRAE increases the efficiency level for CWH equipment in Standard 90.1, then EPCA requires that DOE review the amended efficiency levels. DOE is mandated to either adopt those levels as the Federal energy conservation standard or adopt a more stringent standard if that would result in significant energy savings, be technologically feasible, and economically justified. (42 U.S.C. 6313(a)(6)(ii)) ASHRAE Standard 90.1-2013 raised the minimum thermal efficiency level for commercial oil-fired storage water heaters from 78 to 80 percent. DOE adopted this amended efficiency level as the energy conservation standard for commercial oil-fired storage water heaters in the July 2015 ASHRAE equipment final rule. 80 FR 42614, 42667 (July 17, 2015).

3.7.3 State Energy Conservation Standards

Pursuant to EPCA, states may petition to have more stringent energy conservation standards than those codified into law by DOE (see 42 U.S.C. 6297(d)). DOE has not granted a petition to any state to establish more stringent energy conservation standards than the levels established by EPCA for CWH equipment.

3.7.4 Canadian Energy Conservation Standards

The Natural Resources Canada (NRCan) Office of Energy Efficiency does not currently mandate energy conservation standards for commercial water heaters.[5] However, in November 2011, NRCan released a bulletin proposing, among other things, new energy conservation standards for several classes of commercial water heaters.[6] The proposed standards would likely take effect in 2018 or later, and are shown in Table 3.7.2 The proposed Canadian energy conservation standards for gas-fired tankless water heaters, oil-fired storage water heaters, and electric storage water heaters match the current US energy conservation standards for those equipment classes. However, Canada's proposed thermal efficiency standard for commercial gas-fired storage water heaters, at 92 percent, is higher than the current US standard. The thermal efficiency standard proposed in the NOPR for commercial gas-fired storage water heaters, 95 percent, would more closely align with the proposed Canadian standard.

Table 3.7.2 Canadian Energy Conservation Standards for Commercial Water Heaters

Water Heater Class	Size	Thermal Efficiency	Standby Loss
Gas-fired tankless	>250,000 Btu/h	80%	N/A
Gas-fired storage	>75,000 Btu/h	92%	$Q/800 + 110(V)^{1/2}$ (Btu/h)
Oil-fired storage	>105,000 Btu/h	78%	$Q/800 + 110(V)^{1/2}$ (Btu/h)
Electric storage	>12 kW and >454 L	N/A	0.3 + 27/V (%/h)

3.7.5 Mexican Energy Conservation Standards

Mexico's Secretaría de Energía (SENER), through the Comisíon Nacional para el Uso Eficiente de la Energía, mandates energy conservation standards for residential and commercial water heaters.[7] The thermal efficiency standards, which apply to both residential and commercial water heaters, are shown in Table 3.7.3.

Table 3.7.3 Mexican Energy Conservation Standards for Residential and Commercial Water Heaters

Water Heater Type	Thermal Efficiency
Storage, >28 gal	82%
Rapid recovery	82%
Instantaneous	84%

3.8 VOLUNTARY PROGRAMS

3.8.1 ENERGY STAR

ENERGY STAR®,[g] is a voluntary labeling program backed by the U.S. Environmental Protection Agency (EPA) and DOE that identifies energy-efficient products through a qualification process. To qualify, a product must exceed Federal standards by a specified amount, or if no Federal standard exists, exhibit particular energy saving features. The ENERGY STAR program recognizes the top quartile of products on the market, meaning that approximately 25 percent of selected equipment on the market meets or exceeds the ENERGY STAR levels.

The current ENERGY STAR criteria for commercial water heaters took effect on March 20, 2013. Criteria were established only for commercial gas-fired storage and instantaneous water heaters, and are shown in Table 3.8.1. To qualify for ENERGY STAR classification, the program's guidelines require commercial water heaters be tested using DOE's test procedure codified at 10 CFR 431.106.

Table 3.8.1 ENERGY STAR Qualifying Criteria for Commercial Water Heaters

Water Heater Type	Specifications*	Thermal Efficiency	Standby Loss	Minimum Manufacturer Warranty
Gas-fired storage	>75,000 Btu/h, ≤140 gallons	94%	$0.84*[Q/800 + 110(V)^{1/2}]$ (Btu/h)	3 years on tank and/or heat exchanger and 1 year on parts
Gas-fired tankless	≥4,000 Btu/h per gallon of stored water	94%	N/A	

Prior to the establishment of ENERGY STAR criteria for commercial water heaters, criteria were established for "light duty EPACT-covered gas water heaters" as part of the ENERGY STAR program for residential water heaters. The definition ENERGY STAR uses for this class is as follows: "Light Duty EPACT-covered gas water heaters heat and store water at a thermostatically controlled temperature, with an input rate >75,000 Btu per hour and ≤100,000 Btu per hour, and storage volume between 20 and 100 gallons." Table 3.8.2 shows the current ENERGY STAR criteria for light duty EPACT-covered water heaters.

Table 3.8.2 ENERGY STAR Qualifying Criteria for Light Duty EPACT-Covered Water Heaters

Criteria	ENERGY STAR Specifications
Thermal Efficiency	$E_t \geq 0.90$
Standby Loss	Standby loss ≤1889 Btu/h × (E_t – 0.73)
Warranty	Warranty ≥ 6 years on system
Safety	ANSI Z21.10.3/CSA 4.3

[g] For more information, please visit www.energystar.gov.

3.8.2 Consortium for Energy Efficiency

The Consortium for Energy Efficiency (CEE)[h] 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 commercial gas-fired storage and tankless water heaters. Table 3.8.3 presents the two-tiered commercial water heater efficiency specifications, effective January 20, 2012, under its Commercial Water Heating Initiative.

Table 3.8.3 CEE Criteria for Commercial Gas-Fired Storage and Tankless Water Heaters

Tier	Minimum Thermal Efficiency
Tier 1	90%
Tier 2	94%

3.9 SHIPMENTS

Information about annual equipment shipment trends allows DOE to estimate the impacts of energy conservation standards on the CWH equipment industry. Using data from AHRI estimates, DOE examined unit shipments for commercial gas-fired and electric storage water heaters. More information about shipments for CWH equipment can be found in the shipments analysis section (chapter 9) of the TSD.

3.9.1 Unit Shipments

Figure 3.9.1 presents the total shipments estimated by AHRI for commercial gas-fired and electric storage water heaters from 1994 to 2014.[8]

[h] For more information, please visit www.cee1.org.

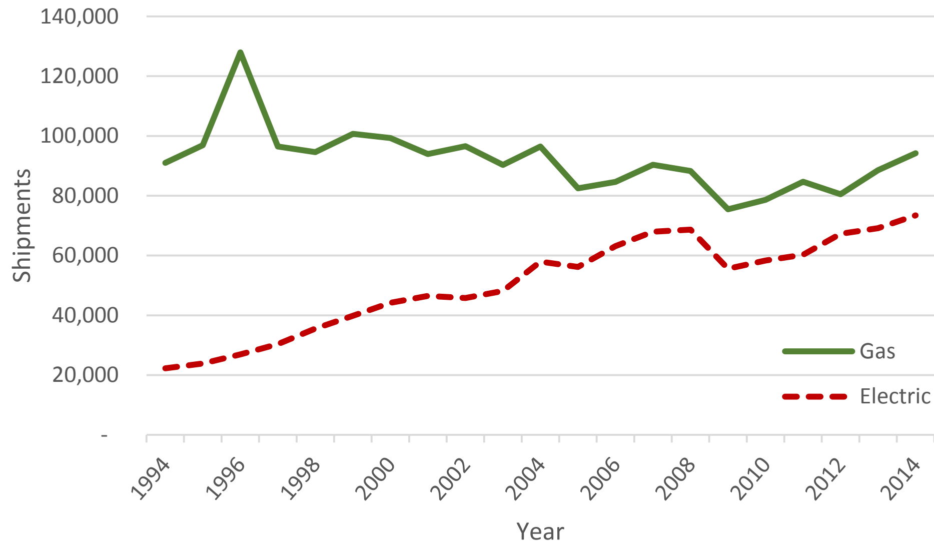

Figure 3.9.1 Historical Shipments of Commercial Gas-Fired and Electric Storage Water Heaters

The AHRI data show a steady increase in shipments for commercial electric storage water heaters in the entire 1994-2014 period, except for 2008-2009, when there was a significant decrease. Commercial gas-fired storage water heater shipments showed a sharp increase from 1995 to 1996, but a gradual decline in shipment after 1996. Commercial gas-fired water heater shipments also showed a decrease for 2008-2009, but this did not significantly deviate from the longer decreasing trend. Commercial electric storage water heater shipments have grown from 20 to 44 percent of the total share of shipments for commercial gas-fired and electric storage water heaters from 1994 to 2014.

3.9.2 Equipment Lifetime

DOE reviewed available literature and consulted with manufacturers to establish typical equipment lifetimes. These sources offered a wide range of typical equipment lifetimes. For this NOPR, DOE assumed the lifetimes for CWH equipment shown below in

Table 3.9.1 based on available literature and manufacturer information. More information about CWH equipment lifetimes is available in the life-cycle cost and payback period analyses section (Chapter 8) of this TSD.

Table 3.9.1 CWH Equipment Lifetimes

CWH Equipment Class		Average Lifetime *years*
Commercial gas-fired storage water heaters and gas-fired storage-type instantaneous water heaters		10
Residential-duty gas-fired storage water heaters		12
Gas-fired instantaneous water heaters and hot water supply boilers	Tankless water heaters	17
	Hot water supply boilers	25
Electric storage water heaters		12

3.10 MARKET CHARACTERIZATION

DOE combined information from the 2015 AHRI Directory, the CEC Appliance Database, DOE's *Compliance Certification Database*, and other publicly available data from manufacturer catalogs of CWH equipment to develop a database of CWH equipment models currently on the market in each of the equipment classes analyzed in the NOPR. The database contains information such as manufacturer name, model number, input capacity, storage volume, thermal efficiency, standby loss, venting type, and energy source. Because many manufacturers sell units under multiple different model numbers and brands, DOE identified models in the database that are basic, and those that are duplicates of basic models "non-basic", based upon data from the AHRI Directory, DOE's *Compliance Certification Database*, and equipment specification sheets. For this section and the remainder of the analysis in this rulemaking, only units selected as "basic" models were analyzed. Because the following market characterization was conducted using rated information in public databases, the market distributions do not include custom-built or built-to-order units, which may be sold at storage volumes and input capacities beyond the ranges shown in this market characterization.

Several models listed in the AHRI Directory were removed from the market distributions: a unit classified as a boiler to be used for space heating, not potable water heating; an electric storage model with greater than 140 gallons storage volume and insulation of R-12.5 or higher that is not subject to DOE's standby loss requirements; and very small (*i.e.,* less than ten gallons) electric storage water heaters that are designed as booster heaters or point-of-use models. While these low-volume electric storage water heaters are covered under DOE's current standard, DOE's standard equation includes measured volume in a denominator, so the standard approaches the equation intercept, 0.3, at very low volumes. This behavior of the standby loss equation leads to rated standby loss values for low-volume units that are significantly below the current standard (*i.e.*, less than 10% of the current standard). DOE therefore removed these units from its analyzed base case market distribution to prevent the inclusion of units on the market at less than 10% of the current standard across all storage volumes.

For characterizing market distributions, DOE used the measured storage volume of models as reported in the AHRI Directory as opposed to the rated volume, because of the proposed changes to DOE's certification, compliance, and enforcement regulations that would require the measured volume be based off the mean of measured volumes in a sample. These proposed changes are described in detail in the NOPR.

Figure 3.10.1 through Figure 3.10.21 show the distribution of efficiencies (thermal efficiency and standby loss) and capacities (storage volume and input) for commercial and residential-duty gas-fired storage water heaters, electric storage water heaters, gas-fired tankless water heaters, and gas-fired hot water supply boilers.

3.10.1 Commercial Gas-Fired Storage Water Heaters

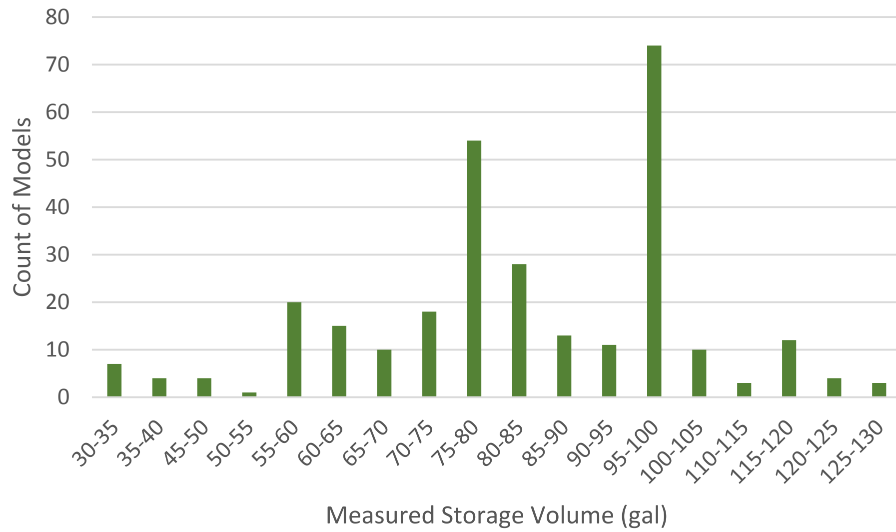

Figure 3.10.1 Distribution of Commercial Gas-Fired Storage Water Heater Models by Measured Storage Volume

Figure 3.10.1 shows the number of commercial gas-fired storage water heaters at each measured storage volume. The lowest volume on the market is 33 gallons, and the highest volume on the market is 129 gallons. There are clusters of models around 55 gallons, 80 gallons, and 100 gallons, with 26 percent of all models with a storage volume around 100 gallons.

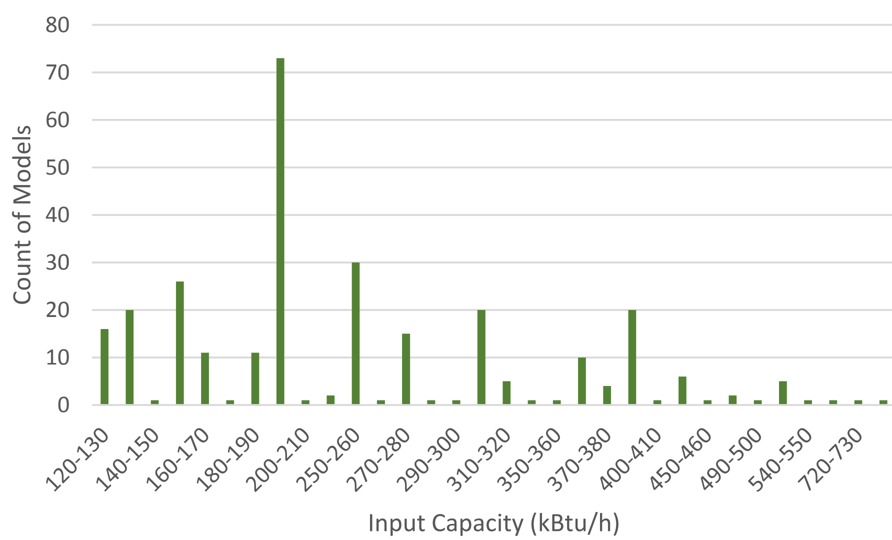

Figure 3.10.2 Distribution of Commercial Gas-Fired Storage Water Heater Models by Rated Input Capacity

Figure 3.10.2 shows the number of commercial gas-fired storage water heaters at each rated input capacity. The minimum input capacity is 120,000 Btu/h and the maximum input capacity is 740,000 Btu/h. The most common input capacities are 150,000 Btu/h, 199,000 Btu/h, 250,000 Btu/h, 300,000 Btu/h, and 400,000 Btu/h. Significantly more models are rated at 199,000 Btu/h than at any other input capacity. Seventy-seven percent of models are rated at input capacities less than or equal to 300,000 Btu/h, and 92 percent of models are rated at input capacities less than or equal to 400,000 Btu/h.

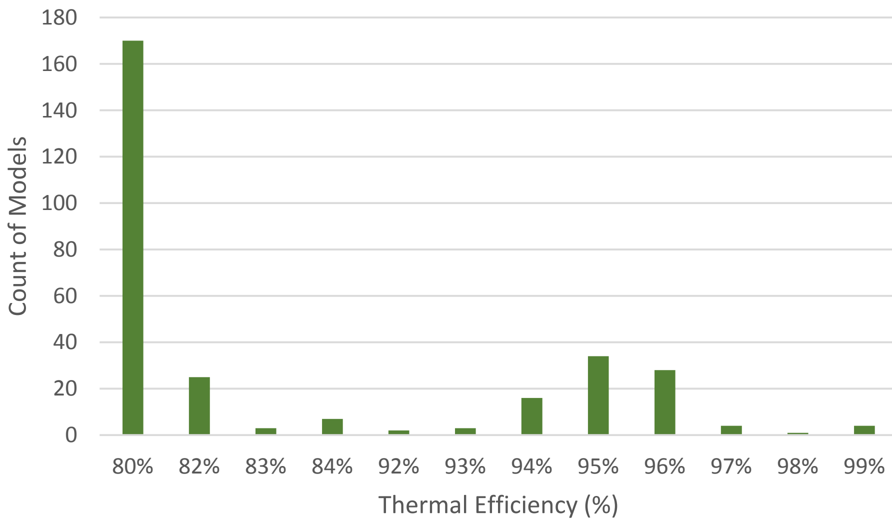

Figure 3.10.3 Distribution of Commercial Gas-Fired Storage Water Heater Models by Thermal Efficiency

Figure 3.10.3 shows the number of commercial gas-fired storage water heaters at each thermal efficiency level. The minimum efficiency is 80 percent and the maximum efficiency is 99 percent. Levels with the highest number of models are 80 percent, 95 percent, and 96 percent. Fifty-seven percent of models have a thermal efficiency of 80 percent – more than at any other level. Thirty-one percent of models are condensing equipment (with thermal efficiencies of 92 percent or higher).

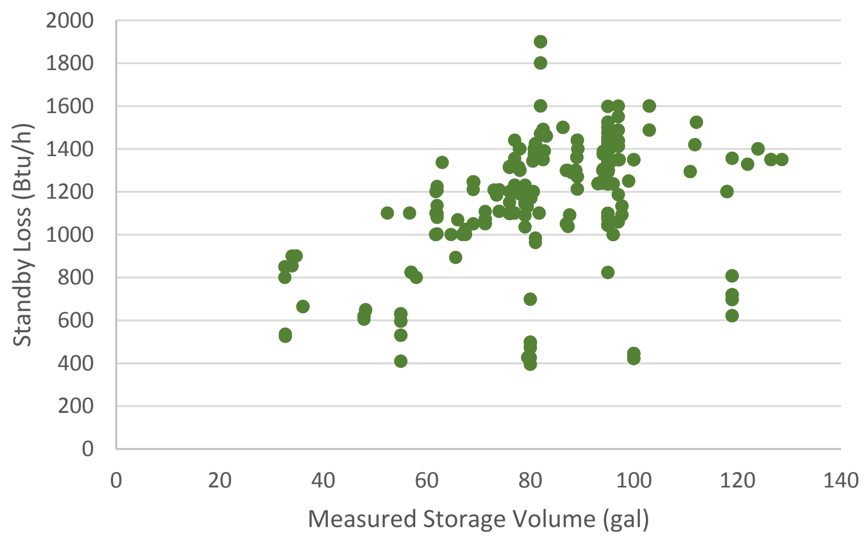

Figure 3.10.4 Distribution of Commercial Gas-Fired Storage Water Heater Models by Measured Storage Volume and Standby Loss for All Input Capacities

Figure 3.10.4 shows the standby loss of commercial gas-fired storage water heaters at each measured storage volume. The minimum standby loss is 395 Btu/h and the maximum standby loss is 1900 Btu/h. Standby loss generally increases with increasing storage volume but is also influenced by the input capacity.

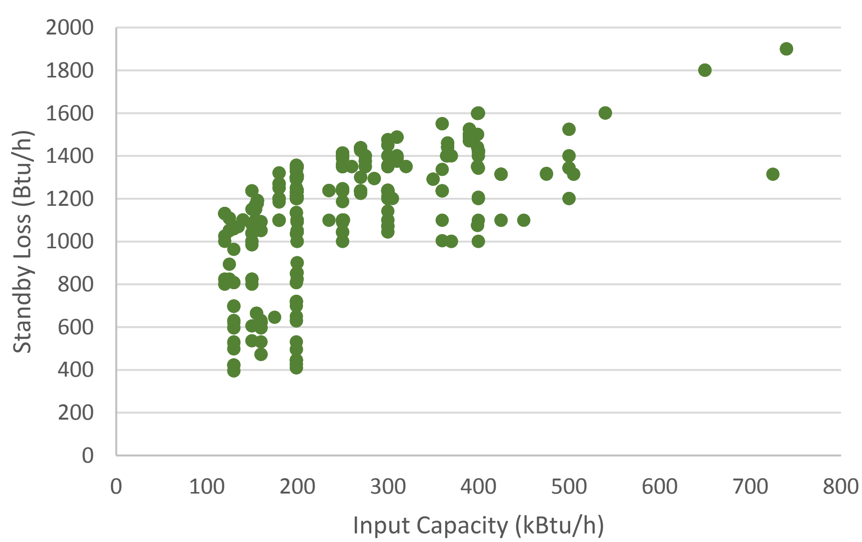

Figure 3.10.5 Distribution of Commercial Gas-Fired Storage Water Heater Models by Rated Input Capacity and Standby Loss for All Storage Volumes

Figure 3.10.5 shows the standby loss of commercial gas-fired storage water heaters at each rated input capacity. The minimum standby loss is 395 Btu/h and the maximum standby loss is 1900 Btu/h. Standby loss generally increases with increasing input capacity but is also influenced by the storage volume.

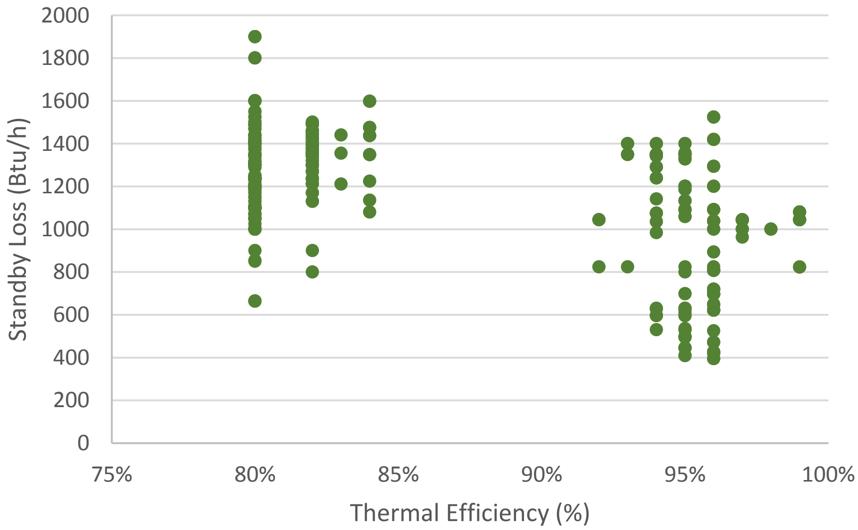

Figure 3.10.6 Distribution of Commercial Gas-Fired Storage Water Heater Models by Thermal Efficiency and Standby Loss

Figure 3.10.6 shows the standby loss of commercial gas-fired storage water heaters at each thermal efficiency level. Condensing models (those with thermal efficiency higher than 86 percent) generally have lower standby loss values than non-condensing models. However, this includes variation in rated storage volume and input capacity. Figure 3.10.7 shows the ratio of the standby loss to the minimum standby loss standard for each model.

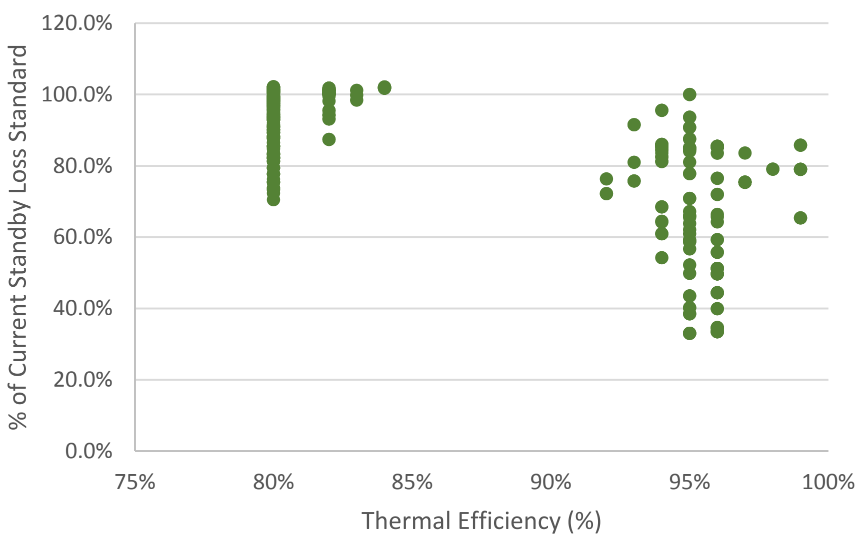

Figure 3.10.7 Distribution of Commercial Gas-Fired Storage Water Heater Models by Thermal Efficiency and Percentage of Current Federal Standby Loss Standard

Once the standby loss is normalized for volume and input, the difference between standby loss of non-condensing and condensing units is clearer. Some condensing gas-fired storage models have standby loss values less than 40 percent of the current minimum standard, while the lowest fraction for a non-condensing model is 70 percent. One reason standby loss values are lower for condensing models than for non-condensing models is that standby loss is dependent upon the thermal efficiency because standby loss is calculated using fuel flow to the burner during the test period. Condensing models also tend to have fewer flue pipes that vent because the flue gas must follow a longer path within the heat exchanger to begin condensation. Because there are fewer pipes that vent outside the water heater in most condensing models than in non-condensing models, less heat is lost out of these pipes in standby mode. All commercial gas-fired storage water heaters currently on the market have a mechanism to restrict flue losses: condensing and power-vent models have blowers that sit atop the heat exchanger and restrict losses, and atmospherically-vented non-condensing water heaters have electromechanical flue dampers that restrict losses.

There is a large range of standby loss values within the market for condensing commercial gas-fired storage water heaters. The values span from 33 percent to 100 percent of the current minimum standard. Standby loss values tend to be lower for models with a helical heat exchanger configuration than for models with a "multi-pass" configuration. This is because models with multi-pass heat exchangers have return plenums at the top and bottom of tanks, where flue gases are directed from one set of flue pipes to another. Because these plenums are located outside the tank volume, they present an opportunity for heat loss not present in models with helical heat exchangers. Also, helical heat exchangers present a more tortuous path for heat transfer to the outside of the tank, and there are significantly fewer intersections of the heat exchanger with the outside wall of the tank. Chapter 5 of this TSD (engineering analysis) includes further detail on heat exchanger design differences between condensing commercial gas-fired storage water heaters.

3.10.2 Residential-Duty Gas-Fired Storage Water Heaters

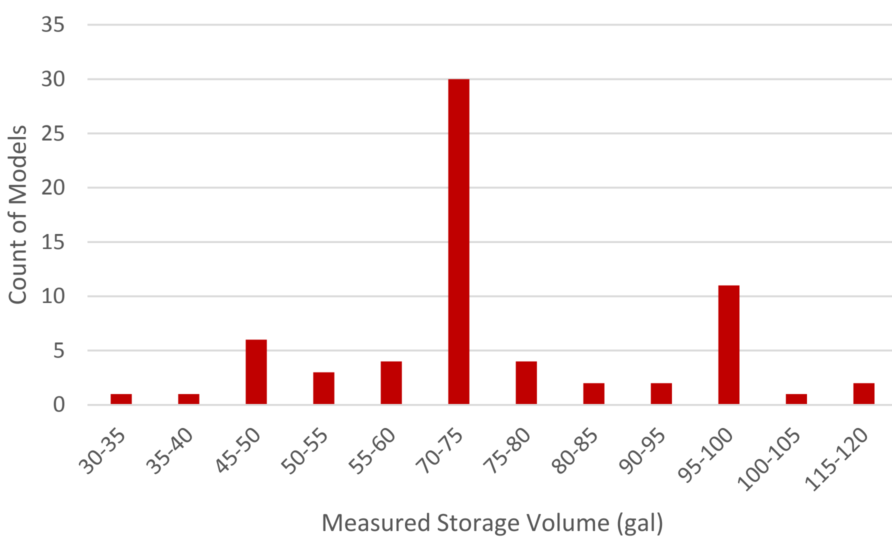

Figure 3.10.8 Distribution of Residential-Duty Gas-Fired Storage Water Heater Models by Measured Storage Volume

Figure 3.10.8 shows the number of residential-duty gas-fired storage water heaters at each measured storage volume. The minimum volume is 33 gallons and the maximum volume is 119 gallons. The most common volumes are around 75 gallons and 100 gallons. Forty-six percent of units have a measured volume of 75 gallons – more than any other volume.

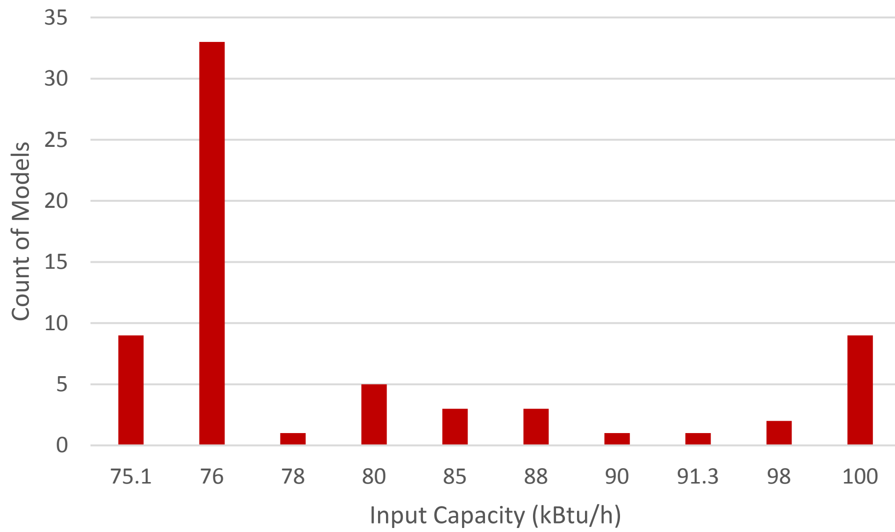

Figure 3.10.9 Distribution of Residential-Duty Gas-Fired Storage Water Heater Models by Rated Input Capacity

Figure 3.10.9 shows the number of residential-duty gas-fired storage water heaters at each rated input capacity. The minimum input capacity is 75,100 Btu/h and the maximum input capacity is 100,000 Btu/h. Most models have input capacities of either 75,100-76,000 Btu/h or 100,000 Btu/h, with 63 percent of models rated in this range.

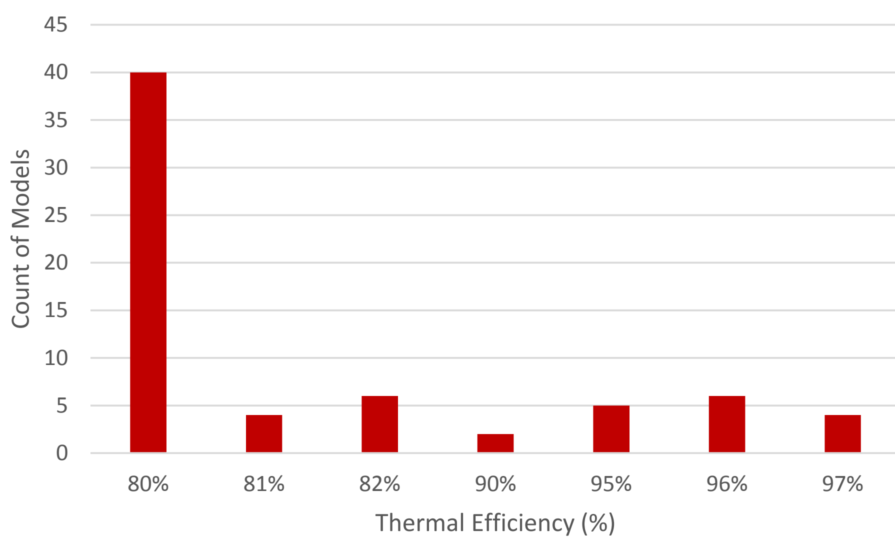

Figure 3.10.10 Distribution of Residential-Duty Gas-Fired Storage Water Heater Models by Thermal Efficiency

Figure 3.10.10 shows the number of residential-duty gas-fired storage water heaters at each thermal efficiency level. The minimum efficiency is 80 percent and the maximum efficiency is 97 percent. Levels with the highest number of models are 80 percent, 82 percent, and 96 percent. More than 60 percent of models have a thermal efficiency of 80 percent. Twenty-five percent of models are condensing (with thermal efficiencies of 90 percent or higher).

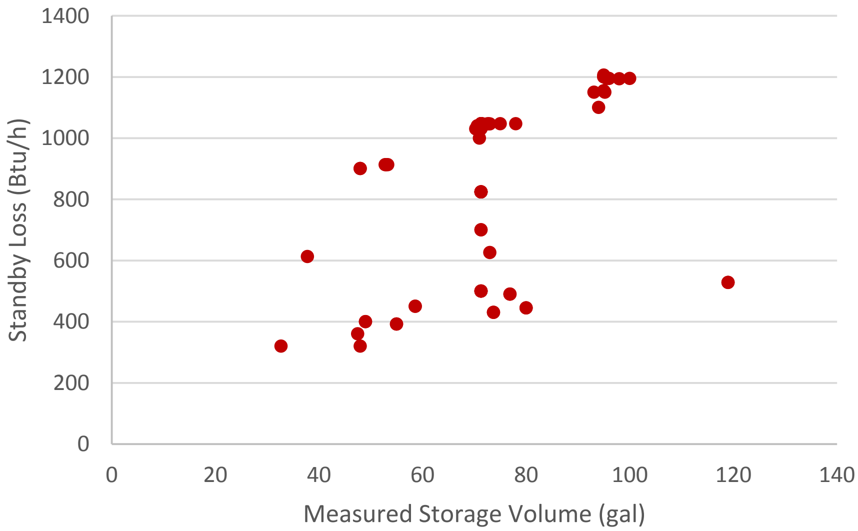

Figure 3.10.11 Distribution of Residential-Duty Gas-Fired Storage Water Heater Models by Measured Storage Volume and Standby Loss for All Input Capacities

Figure 3.10.11 shows the standby loss of residential-duty gas-fired storage water heaters at each measured storage volume. The minimum standby loss is 320 Btu/h and the maximum standby loss is 1206 Btu/h. Standby loss generally increases with increasing storage volume but is also influenced by the input capacity.

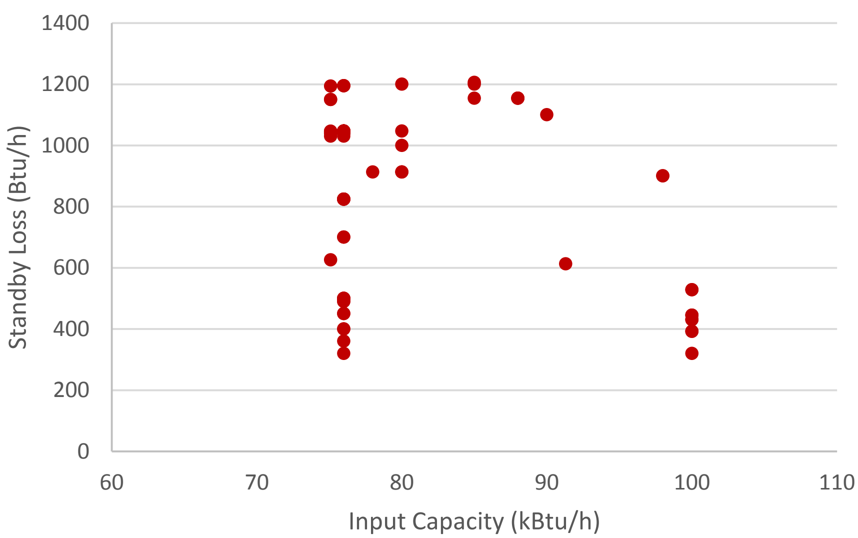

Figure 3.10.12 Distribution of Residential-Duty Gas-Fired Storage Water Heater Models by Rated Input Capacity and Standby Loss for All Storage Volumes

Figure 3.10.12 shows the standby loss of residential-duty gas-fired storage water heaters at each rated input capacity. The minimum standby loss is 320 Btu/h and the maximum standby loss is 1206 Btu/h. While standby loss increases with increasing input capacity, it is also influenced by the storage volume.

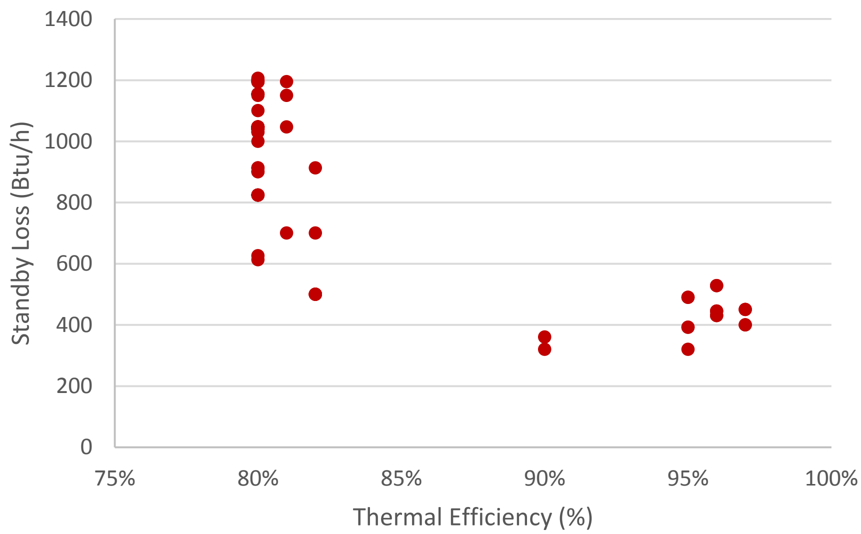

Figure 3.10.13 Distribution of Residential-Duty Gas-Fired Storage Water Heater Models by Thermal Efficiency and Standby Loss

Figure 3.10.13 shows the standby loss of residential-duty gas-fired storage water heaters at each thermal efficiency level. Condensing models (those with thermal efficiency higher than 86 percent) have lower standby loss values than non-condensing models. However, this includes variation in rated storage volume and input capacity. Figure 3.10.14 shows the ratio of the standby loss to the minimum standby loss standard for each model of residential-duty gas-fired storage water heaters.

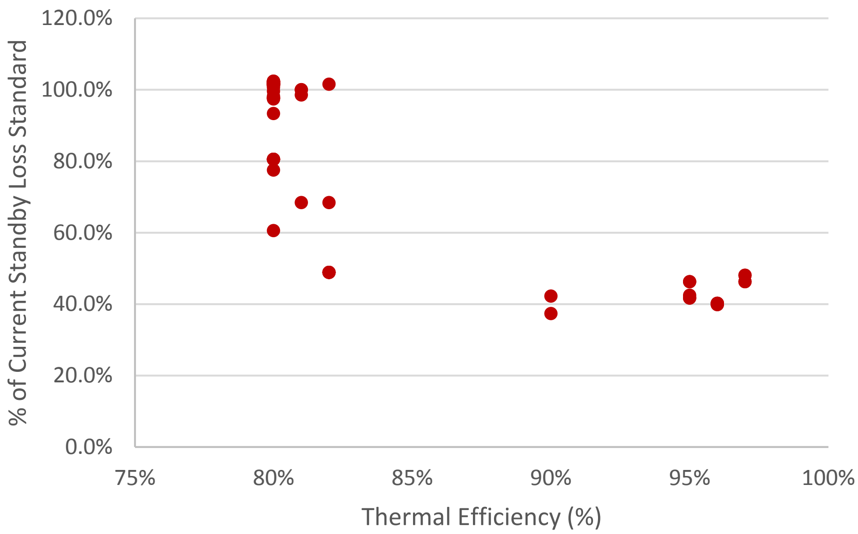

Figure 3.10.14 Distribution of Residential-Duty Gas-Fired Storage Water Heater Models by Thermal Efficiency and Percentage of Current Federal Standby Loss Standard

Normalizing for the effects of input capacity and volume doesn't have a large effect on the data for residential-duty gas-fired storage water heaters because of the relatively narrow ranges of storage volume and input capacity on the market. All condensing gas-fired storage models have standby loss values less than all non-condensing models. Standby loss ranges from 49 percent to 100 percent of the current standards for non-condensing models, and from 37 percent to 48 percent of the current standard for condensing models. One reason standby loss values are lower for condensing models than non-condensing models is that standby loss is dependent upon the thermal efficiency, because standby loss is calculated using fuel flow to the burner during the test period. There is a larger difference between standby loss of condensing and non-condensing residential-duty gas-fired storage water heaters than between condensing and non-condensing commercial gas-fired storage water heaters. As mentioned above in discussion of Figure 3.10.7, condensing gas-fired storage water heaters with helical heat exchangers tend to have lower standby loss values than those with "multi-pass" heat exchangers. One reason that all standby loss values for condensing residential-duty gas-fired storage water heaters are lower than those for non-condensing models might be that all condensing residential-duty models currently on the market include helical heat exchangers.

3.10.3 Electric Storage Water Heaters

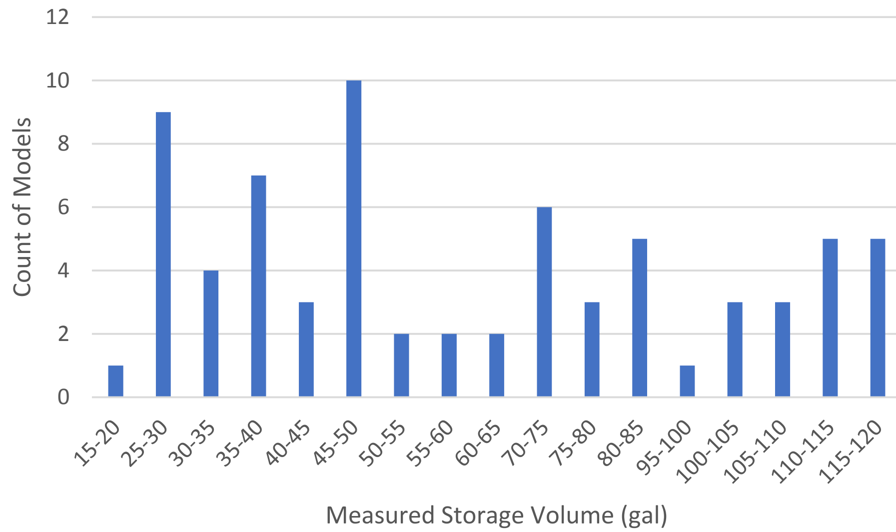

Figure 3.10.15 Distribution of Electric Storage Water Heater Models by Measured Storage Volume

Figure 3.10.15 shows the number of electric storage water heaters at each measured storage volume. The minimum measured volume is 19.5 gallons, and the maximum volume is 116 gallons. There are clusters of models around 50 gallons, 75 gallons, and 115 gallons, with more units with a measured volume around 50 gallons than any other volume.

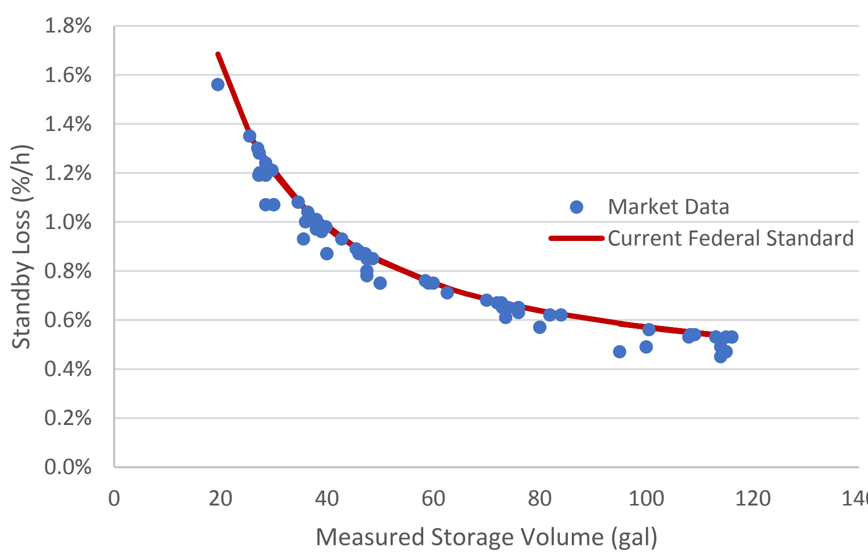

Figure 3.10.16 Distribution of Electric Storage Water Heater Models by Measured Storage Volume and Standby Loss

Figure 3.10.16 shows the standby loss of electric storage water heaters at each measured storage volume. The minimum standby loss is 0.45 %/h and the maximum standby loss is 1.56 %/h. Relative to gas-fired storage water heaters, there is not much deviation in standby loss in electric storage water heaters from the current federal standard, as all rated values are within 20 percent of the current standard. While standby loss in Btu/h increases with increasing volume, standby loss in %/h decreases with increasing volume. This is because some of the volume increase is in the radial direction. When the radius of a tank increases, the surface area increases linearly in proportion to the radius while the volume increases quadratically in proportion to the radius. Therefore any increase in radius has a larger effect on the volume than the surface area, meaning that heat loss through the tank shell would increase less than would the heat stored in the water in the tank. An increase in volume due to increased tank height would have a smaller effect on the standby loss in %/h, because both the heat loss and stored heat would scale linearly with the tank height.

3.10.4 Gas-Fired Tankless Water Heaters

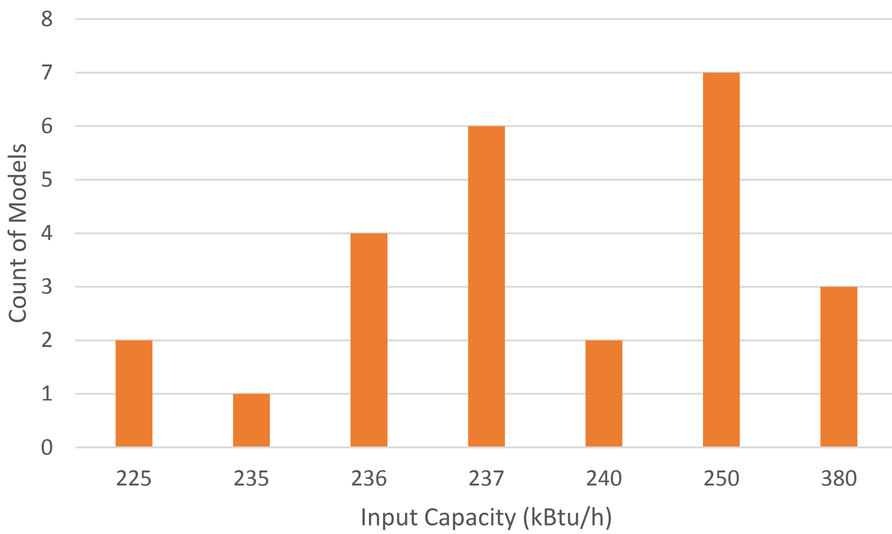

Figure 3.10.17 Distribution of Gas-Fired Tankless Water Heater Models by Rated Input Capacity

Figure 3.10.17 shows the number of gas-fired tankless water heaters at each rated input capacity. The minimum input capacity is 225,000 Btu/h and the maximum input capacity is 380,000 Btu/h. Some models rated less than or equal to 200,000 Btu/h were included in the AHRI Directory and CEC Database for commercial water heaters. However, DOE did not include these models in its analysis because EPCA includes gas-fired instantaneous water heaters with an input capacity less than or equal to 200,000 Btu/h in its definitions of consumer water heaters. (42 U.S.C. 6291(27)(b)) The most common input capacities are 250,000 Btu/h, and 235,000-240,000 Btu/h. The largest number of models are rated at 250,000 Btu/h. Eighty-eight percent of models are rated at input capacities less than or equal to 250,000 Btu/h.

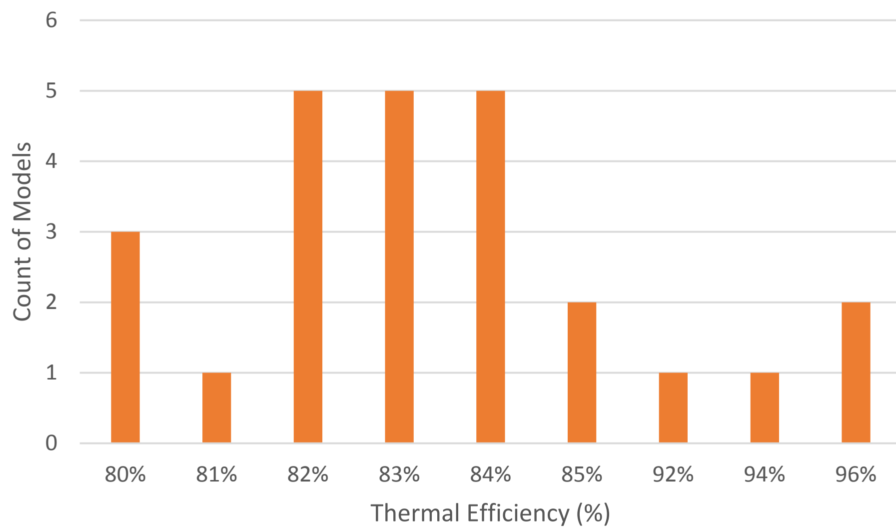

Figure 3.10.18 Distribution of Gas-Fired Tankless Water Heater Models by Thermal Efficiency

Figure 3.10.18 shows the number of gas-fired tankless water heaters at each thermal efficiency level. The minimum efficiency is 80 percent and the maximum efficiency is 96 percent. Sixty percent of models are rated between 82 percent and 84 percent thermal efficiency. Sixteen percent of models are condensing (with thermal efficiency levels greater than 85 percent).

3.10.5 Gas-Fired Hot Water Supply Boilers

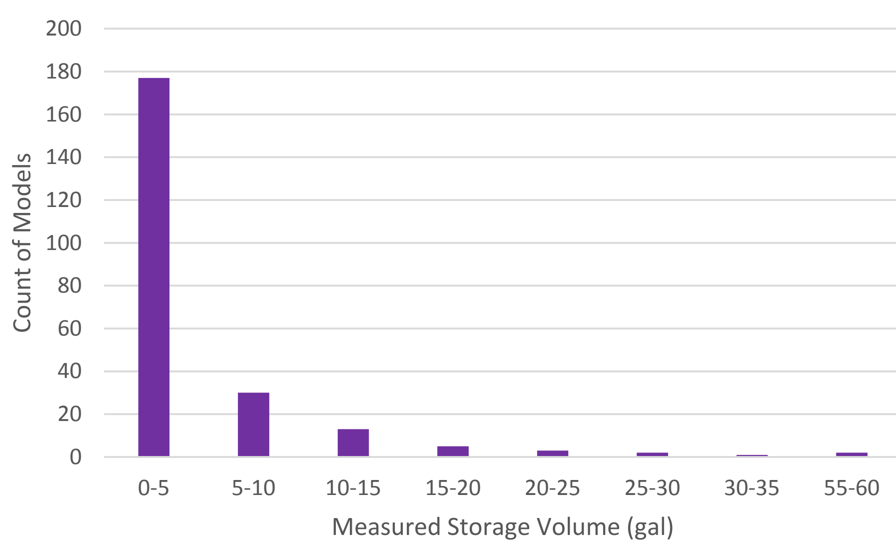

Figure 3.10.19 Distribution of Gas-Fired Hot Water Supply Boilers by Measured Storage Volume

Figure 3.10.19 shows the number of hot water supply boilers at each measured volume. DOE's current regulations include separate equipment classes, and therefore separate thermal efficiency and standby loss standards, for instantaneous water heaters and hot water supply boilers with a storage volume less than ten gallons and for units with a volume greater than or equal to ten gallons. Eleven percent of hot water supply boiler models have a measured volume greater than or equal to ten gallons, and only 5.5 percent of models have a volume greater than 15 gallons.

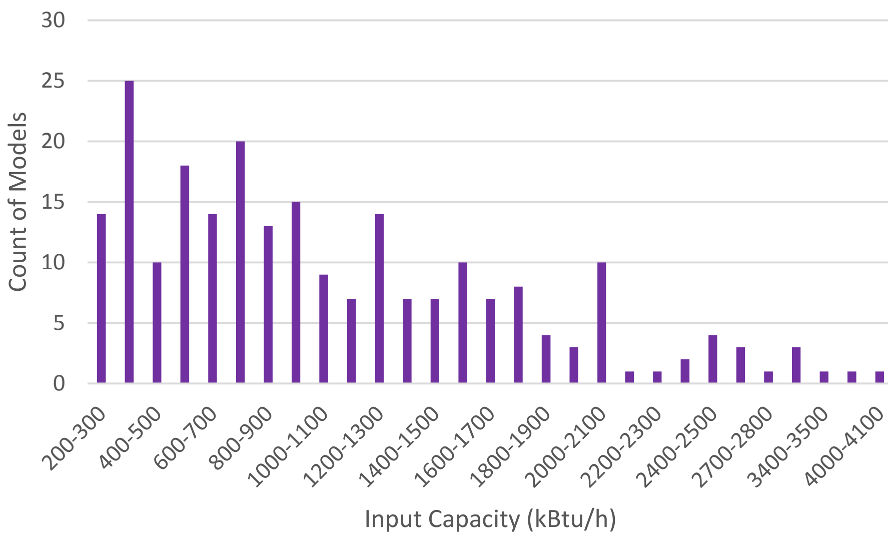

Figure 3.10.20 Distribution of Gas-Fired Hot Water Supply Boiler Models by Rated Input Capacity

Figure 3.10.20 shows the number of gas-fired hot water supply boilers at each rated input capacity. Many of the hot water supply boiler models were identified from the CEC Database. The minimum input capacity is 225,000 Btu/h and the maximum input capacity is 4 million Btu/h. More models are rated between 300,000-400,000 Btu/h than are rated in any other input capacity range. Fifty-eight percent of models are rated at input capacities less than or equal to 1 million Btu/h.

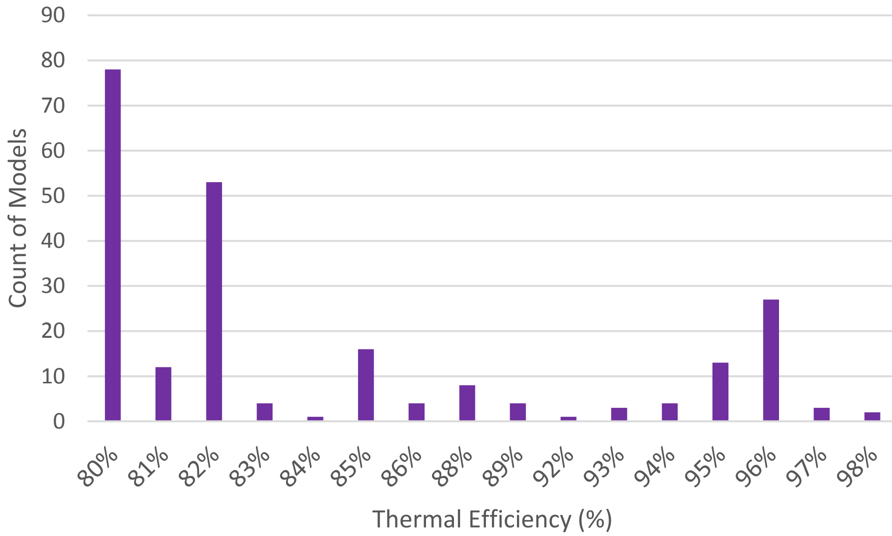

Figure 3.10.21 Distribution of Gas-Fired Hot Water Supply Boiler Models by Thermal Efficiency

Figure 3.10.21 shows the number of gas-fired hot water supply boilers at each thermal efficiency level. The minimum efficiency is 80 percent and the maximum efficiency is 98 percent. The levels with the highest number of models are 80 percent and 82 percent. More models are rated at 80 percent than any other level. Thirty-three percent of models have a thermal efficiency of 80 percent. Twenty-four percent of models are condensing (with thermal efficiency levels greater than 88 percent). The thermal efficiency level at which a water heater becomes condensing is not a universal determination, and varies based upon ambient and water temperatures of the water heater. DOE therefore relied on manufacturer classification of units to determine whether units are condensing.

3.11 TECHNOLOGY ASSESSMENT

This section provides a technology assessment for CWH equipment. The purpose of the technology assessment is to develop a preliminary list of technologies that could potentially be used to improve the efficiency of CWH equipment. Not all technology options contained in this assessment apply to all CWH equipment classes – the applicable equipment classes are noted for each option.

Contained in this technology assessment are details about equipment characteristics and operation (section 3.11.1); an examination of possible technology options that increase efficiency as measured by DOE's test procedures for thermal efficiency, standby loss, or uniform energy factor (UEF; section 3.11.2); and an examination of possible technology options that do not increase efficiency as measured (section 3.11.3).

3.11.1 Equipment Characteristics and Operation

Commercial storage water heaters can be gas-fired, oil-fired, or electric. All storage water heaters contain an insulated water tank, a thermostat, and an outer case. Storage water heaters with a tank and heat exchanger made of a corrodible material (*e.g.*, hot-rolled steel) include enameling on the surface of the tank and heat exchanger as well as sacrificial anode rod(s). Gas-fired storage water heaters also include a gas valve, a burner assembly, and a heat exchanger. The gas valve regulates the fuel flow to the burner, the burner ignites the fuel, and the hot combustion gases are then drawn through the heat exchanger – flue tubes in which the heat of the flue gases is transferred to the stored water. Electric storage water heaters also include electric resistance heating elements, through which electrical energy is used to heat the stored water.

Condensing gas-fired storage water heaters can be configured as bottom-fired, top-fired, or side-fired. In bottom-fired designs, the atmospheric burner is located below the tank, and the flue gases rise from the burner through the tank. An induced-draft blower is typically used in bottom-fired designs, in which the blower is located at the top of the water heater upstream of the pipe venting flue gases outdoors. This induced draft results in a negative pressure in the heat exchanger. In top-fired designs, the powered pre-mix burner assembly is located above the tank. A forced-draft blower supplies excess air to the burner, creating positive pressure in the heat exchanger. The pre-mix burner tube is typically submerged in the tank volume, and the flue gases are forced down through the heat exchanger. Side-fired designs typically use a powered pre-mix burner assembly similar to that used in top-fired models, except that the burner fires into the heat exchanger from the side of the tank.

Gas-fired instantaneous water heaters and hot water supply boilers include an electronic ignition system, a gas valve, a burner assembly, a heat exchanger, a thermostat, and an outer case. Tankless water heaters are smaller than hot water supply boilers and typically do not contain pumps. Hot water supply boilers are larger and often contain recirculation pumps. Tankless water heaters can be top-fired or bottom-fired. In the top-fired design, the burner is located at the top of the water heater and the forced draft blower pushes the flue gases through the heat exchanger(s). In the bottom-fired design, the burner is located near the bottom of the water heater, and the flue gases rise through the heat exchanger(s).

3.11.2 Technology Options that Improve Efficiency as Measured

To gain a deeper understanding of the technological improvements used to increase the efficiency of CWH equipment, DOE examined the most common improvements currently used in the market as well as researched technical journals, patent filings, and other sources for prototype designs that have not yet been commercialized. DOE identified technologies to improve efficiency through examining equipment currently on the market, reviewing industry publications, and discussing technology options with manufacturers.

The purpose of the technology assessment is to develop a list of all technologies that could be used to improve the energy efficiency of CWH equipment. However, some technologies that may improve efficiency of CWH equipment when operating in the field do not affect the thermal efficiency or standby loss as measured by the DOE test procedure. These technologies are listed separately in this assessment for informational purposes. This assessment provides the technical background and structure on which DOE bases its screening analysis (chapter 4 of this TSD) and engineering analyses (chapter 5).

3.11.2.1 Improved Insulation

Improving insulation of storage water heaters can decrease the measured standby loss. Manufacturers insulate storage water heaters by filling the cavity between the jacket and the tank (top and sides) with insulation. Increasing the thermal resistance of the water heater jacket reduces the amount of heat loss during standby periods, and thereby decreases the water heater's energy consumption. Insulation can be improved by modifying the baseline design of a commercial storage water heaters using improved insulation type, increased insulation thickness, and insulation of tank bottom.

Most commercial storage water heaters are insulated with one of two types of insulation: fiberglass, or sprayed polyurethane (PU) foam. PU foam is a more effective insulating material than fiberglass, with an R-value of approximately 6.25 vs 3.5 $°F \cdot ft^2 \cdot h/Btu$. Most water heaters on the market already use PU foam insulation, but some commercial gas-fired storage water heaters are sold with fiberglass insulation and are still able to meet the current standby loss standard. PU foam cannot be used to cover the entire surface of the tank, as it cannot be exposed to as high temperatures as can fiberglass. Therefore, even in high-efficiency water heaters, fiberglass insulation is often used around hot water ports or near the combustion chamber.

Most storage water heaters on the market today have at least 1-inch thick insulation; some models have 2- or 3-inch thick insulation. Increasing the thickness of the jacket insulation reduces standby losses by increasing the thermal resistance of the water heater jacket. After-market insulating blankets are also commercially available to increase water heater insulation thickness.

Insulation of the tank bottom reduces standby loss through the bottom of the tank. Typically this design has only been incorporated in electric storage water heaters. Gas-fired storage waters have commonly been bottom-fired, and a combustion chamber at the bottom of the tank prevents insulation of the tank bottom. In contrast, many condensing gas-fired storage water heaters are top-fired, allowing the tank bottom to be insulated. However, because condensing water heaters are designed to maximize temperature stratification of the tank to allow for further condensation near the bottom of the tank, heat losses from the tank bottom would likely be significantly lower than those from hotter areas of the tank.

3.11.2.2 Advanced Insulation Types

Alternate ways of reducing the jacket losses without increasing the diameter of gas-fired and electric storage water heaters include using advanced insulation materials or evacuated panels. The advanced materials or methods of insulation considered below involve using vacuum insulation, inert gases, aerogel insulation, or partial vacuums.

Vacuum Insulation. A "hard" vacuum (approximately 5 psi) between internal reflective surfaces is a very good insulator. These "hard" vacuums have been used for years in Thermos® bottles and dewar tanks for cryogenic applications. Manufacturing cost, durability, and difficulty of maintaining the seal over the life of the storage water heater are some of the manufacturing problems that need to be resolved.

Gas-Filled Panels. Gas-filled panels are thermal insulating devices that retain a high concentration of a low-conductivity gas at atmospheric pressure within a multilayer infrared reflective baffle. The thermal performance of the panels depends on the type of gas fill and the baffle configuration. Gas-filled panels are flexible and self-supporting, and can be made in a variety of shapes and sizes to thoroughly fill most types of cavities. This technology has not been demonstrated for water heating applications.

Aerogel Insulation. Another advanced insulation material is silica aerogel, which is composed of 96 percent air and 4 percent silicon dioxide. Aerogels are more efficient and weigh less than the polyurethane foam currently used in most water heaters. The thermal resistance R-value of the aerogel at atmospheric pressure is comparable to that of polyurethane foam, but when 90 percent of the air is evacuated from a plastic-sealed aerogel packet, its thermal resistance nearly triples. New manufacturing processes have been developed that can produce flexible blankets or clamshell forms of this material. However, the aerogel material is vulnerable to shock and vibration, and material handling is an issue. Because the aerogel is hygroscopic, it requires a thorough sealing of the cavity between the water heater tank and the outer shell. The material has not been demonstrated for use with any commercially available water heaters.

Evacuated Panels. Other materials with a lightweight open structure can provide effective insulation combined with "soft" or low vacuums. The materials can be enclosed with metals or plastic. A vacuum is drawn in this panel before sealing, and a lightweight, rigid foam keeps the vacuum from compressing the panel. This technology has not been demonstrated for storage water heater applications.

3.11.2.3 Mechanical Draft

For gas-fired CWH equipment, vents are required to move combustion flue gases from the water heater to outside of the building. Some gas-fired CWH equipment models have atmospheric vents systems through which flue gases are exhausted with a natural draft. Mechanically-vented gas-fired CWH equipment models use a blower to create a draft for exhausting flue gases. Mechanical draft systems can be designed as either induced draft (*i.e.*, power vent) or forced draft (*i.e.*, power burner or power combustion) systems. An induced draft blower is located downstream of the heat exchanger in the venting system and pulls flue gases through the heat exchanger, creating negative pressure in the heat exchanger. A forced draft blower is located upstream of the heat exchanger and creates positive pressure in the heat exchanger that pushes products of combustion through the vent system.

Mechanical draft systems can theoretically improve efficiency over natural draft systems by providing the correct fuel-to-air ratio to optimize combustion efficiency and by regulating draft to optimize heat transfer in the heat exchanger. Specifically, mechanical draft systems can allow for increased heat exchanger surface area and/or tighter flue paths by overcoming the drop in pressure associated with restrictive flow passages in more efficient heat exchangers and by supplementing the loss of buoyancy in cooler flue gases to provide sufficient airflow. However, DOE did not find evidence that power vent systems (without a premix burner) increased thermal efficiency of commercial or residential-duty non-condensing gas-fired storage water heaters, and therefore it was not considered as an option for increasing thermal efficiency. Mechanical draft systems are required for condensing gas-fired storage water heaters, and were therefore considered as part of the technology path needed to reach condensing thermal efficiency levels. Power venting typically decreases the standby loss of a storage water heater, by creating a restriction in the flue path. Therefore, power vent was considered as a technology option for decreasing standby loss of gas-fired storage water heaters. Mechanical draft systems are typically used in baseline tankless waters as well as condensing hot water supply boilers. Power venting was considered as a technology option for increasing thermal efficiency of non-condensing hot water supply boilers, based upon DOE's survey of the market and manufacturer feedback.

3.11.2.4 Condensing Heat Exchanger

Condensing heat exchangers extract additional heat from gas-fired CWH equipment, therefore increasing thermal efficiency. A condensing heat exchanger increases thermal efficiency through both increased sensible and latent heat transfer. Latent heat is extracted through the condensation of water vapor in the flue gas. Condensation begins once the flue gas temperature drops to the dew point temperature. The condensate formed is acidic and corrosive due to the presence of sulfuric acid, which is formed from reaction of sulfur in the gas and water. Sulfuric acid is present in flue gases in all gas-fired CWH equipment, but condensation of the acid is avoided by maintaining sufficiently high flue gas temperatures. Therefore, special corrosion-resistant heat exchangers (typically made with corrosion-resistant stainless steel or aluminum alloys) or heat exchanger linings (typically glass enamel) are required for safe and reliable operation of condensing CWH equipment. Avoidance of this corrosion due to condensation of combustion gases by not allowing the exiting flue gas temperature to near the dew point temperature typically limits the thermal efficiency of a gas-fired water heater with a standard flue and vent system. For condensing CWH equipment, this acidic condensate is typically collected in a corrosion-resistant pan and drained away from the equipment through a neutralizing material (*e.g.*, limestone rocks), and then is commonly passed to the local sewer system. If local code permits, the condensate may be passed directly to the sewer system, bypassing the neutralization step; however, this is a less common method of condensate disposal.

In gas-fired storage heaters, condensing heat exchangers are designed to have a longer heat exchanger path than would be found in a non-condensing heat exchanger. In gas-fired tankless water heaters, condensing heat exchangers are typically secondary exchangers – flue gasses pass through the primary heat exchanger (typically copper) before reaching the secondary heat exchanger. In gas-fired hot water supply boilers, one stainless steel heat exchanger is typically used through which all heat is transferred, including latent heat form condensation. Chapter 5 of this TSD includes more detail on heat exchanger designs.

3.11.2.5 Pulse Combustion

Pulse combustion burners operate on self-sustaining resonating pressure waves that alternately rarefy the combustion chamber (drawing a fresh fuel/air mixture into the chamber) and pressurize it (causing ignition by compression heating of the mixture to its flash point). The primary advantage of pulse combustion is the pulses of exhaust create a high level of turbulence in the heat exchanger. This improves heat transfer which thus raises thermal efficiency. Pulse combustion systems are also capable of venting without the assistance of mechanical draft. Because the pulse combustion process is very efficient, pulse combustion is generally used in conjunction with a condensing secondary heat exchanger.

Pulse combustion gas furnaces were available in the United States for more than two decades, but they were withdrawn from the market because the manufacturers found that competing technologies cost significantly less to manufacture and operate. DOE is not aware of any pulse combustion CWH equipment currently available on the market.

3.11.2.6 Improved Heat Exchanger Design

Heat transfer from flue gasses to water can be increased by improving the design of the heat exchanger. The two options considered for improving heat exchanger design are increasing the surface area of the heat exchanger and improving flue baffling.

Increasing the heat exchanger surface area increases heat transfer to the water and therefore the thermal efficiency. This applies to both non-condensing and condensing gas-fired CWH equipment. In non-condensing CWH equipment, the heat exchanger area can only be increased to a certain point because once enough heat has been extracted from the flue gases, the gasses will begin to condense, causing acidic condensate to collect in the heat exchanger that can corrode through the heat exchanger material. The thermal efficiency corresponding to this maximum heat exchanger area for non-condensing CWH equipment varies with ambient temperature. An increase in the heat exchanger area also increases the pressure drop through the heat exchanger, which may require a higher blower speed in mechanically-drafted CWH equipment. For condensing CWH equipment with separate non-condensing and condensing heat exchangers, the surface area of the condensing heat exchanger is typically increased to avoid condensation in the primary heat exchanger (which is typically not corrosion-resistant).

The standard flue baffle of a gas-fired storage water heater is a twisted or finned strip of metal inserted into the flue tubes that increases the turbulence of flue gases and improves heat transfer to the walls of the flue. The geometry of the flue baffle can be modified to increase its effectiveness. Improving the flue baffle so that air flow becomes more restricted and more turbulent can increase heat transfer and thermal efficiency. This can be accomplished by including fins or other forms of extrusions from the flue wall, or by increasing the number of flow-altering features in the baffle. The air flow restrictions resulting from enhanced flue baffle designs can also decrease convective heat loss during standby periods and therefore reduce standby losses.

3.11.2.7 Sidearm Heating and Two-Phase Thermosiphon Technology

A side arm heater heats water from the bottom of a storage tank through a small heat exchanger located on the side of the tank using a small circulation pump. Heated water is returned to the top of the tank. This technology option for gas-fired storage water heaters avoids large flue standby losses by removing the flue from the center of the storage tank. The burner could have electronic ignition, which would reduce pilot light losses. DOE has found no evidence of gas-fired storage water heaters on the market that use this technology, though side-arm heat exchangers can be added to boiler/storage tank systems.

Two-phase thermosiphon (TPTS) technology removes the flue from the center of gas-fired storage water heaters and places a heat exchanger outside the storage tank, reducing standby losses. This is similar to the side-arm heater technology option. TPTSs are heat-pipe mechanisms that transfer heat from the external burner to the storage tank. The TPTS is a closed loop device consisting of an evaporator, in which the working fluid is heated by the burner, percolating liquid and vapor into the condenser where heat is transferred into the water storage tank. At the condenser, which is inside the storage tank, the vaporized working fluid is condensed and drains back through a separate restricted tube to the evaporator, where it is reheated. The restriction prevents the heated vapor and liquid from flowing to the condenser through the return path. During off-cycle, there is very little heat transfer through the TPTS system, therefore reducing standby losses.

3.11.2.8 Electronic Ignition Systems

Gas-fired CWH equipment is equipped with either a standing pilot light or an electronic ignition system, which lights the burner with an electrical component upon a call for heat. Standing pilot ignition systems consume fuel continuously, and not all of the generated heat is transferred to the stored water during off-cycle. Unlike standing pilot systems, electronic ignition systems operate only during active mode. The different types of electronic ignition systems are discussed in detail below.

Hot Surface Ignition. Hot surface ignition (HSI) uses an ignitor that is an electrically heated resistance element that thermally ignites the main burner directly, without use of a pilot light. In HSI operation, a voltage is applied to the igniter until its surface is sufficiently hot to light the system's main burner directly.

Direct Spark Ignition. A direct spark ignition (DSI) system provides the same functionality as a hot surface igniter – it serves to ignite the main burner and acts as a flame sensor. As its name implies, the DSI lights the main burner directly by generating a spark, removing the need for a pilot light. Flame rectification is used to detect flame presence – if a flame is present, the control module will hold the gas valve open and cut off power to the igniter.

Intermittent Pilot Ignition. This is a device that lights a pilot by generating a spark. The pilot light in turn lights the main burner.

Hydroelectric ignition is another form of electronic ignition used in some gas-fired instantaneous water heaters. However, it is not as common as the three forms of ignitions above. In hydroelectric systems, a small turbine is spun by flowing water to produce electricity, which ignites a pilot. This is similar to intermittent pilot ignition. Unlike standing pilot ignition systems that consume gas continuously, hydroelectric devices operate only at the beginning of each on-period. The benefit of hydroelectric ignition systems relative to electronic ignition systems is that no power supply is required.

Although there is no increase in thermal efficiency with the use of electronic ignition systems, these systems reduce standby losses relative to a standing pilot because no fuel is being consumed when the water heater is not firing.

3.11.2.9 Improved Heat Pump Water Heaters

As discussed in section III.C.6 of the NOPR, electric CHPWHs were not analyzed in this rulemaking. DOE has found no evidence of any integrated CHPWHs on the market. All

CHPWHs that DOE identified on the market are "add-on" units, which are designed to be paired with either an electric storage water heater or a storage tank in the field.

Gas-fired absorption heat pump water heaters (HPWHs) use the same principle as electric HPWHs of extracting heat from air to heat water, except that they use a gas-fired absorption process to increase the pressure of the refrigerant instead of electric mechanical compression. A refrigerant well suited for absorption and with no global warming potential is typically used, such as ammonia. However, less corrosive options are being investigated, including ionic liquids (particularly lithium bromide). Instead of a compressor simply increasing the pressure of the refrigerant, the refrigerant is absorbed into water, pumped to higher pressure, and then boiled out in a generator, after which it moves on to the heat exchanger. The absorption working fluid is then recycled back to the absorber, and heat is exchanged between the two fluids. Gas absorption HPWHs have the potential to reach coefficient of performance (COP) values of one to two, possibly doubling the efficiency of even condensing gas-fired water heaters.[9] However, high manufacturing costs and insufficient research make this not yet a marketable technology. DOE has funded several projects through various companies and national labs to develop more efficient and cost-effective absorption HPWHs. While research has focused mostly on models for residential use, the technology could also be used for CWH equipment.

3.11.2.10 Thermophotovoltaic and Thermoelectric Generators

Heat and light energy can be extracted from the combustion process of gas-fired CWH equipment and converted into useful electrical energy. Thermophotovoltaic generator technology uses a special light-emitting burner coupled with silicon photovoltaic cells that generate auxiliary power that can run a fan, operate the electronic ignition and controls, and charge a battery. This avoids the requirement of an auxiliary electrical supply, while offering the efficiency advantages of electronic ignition and forced-draft combustion.

Another method of generating electricity at the water heater is based on thermoelectric technology. Thermoelectric generators use semiconductors to convert a temperature differential into a voltage source. Thermocouples, a type of thermoelectric generators, are used to power on and off the gas valve in gas-fired storage water heaters without an external power supply.

3.11.2.11 Premix Burner

Premix burners are used in most condensing gas-fired CWH equipment. Some residential-duty condensing gas-fired storage water heaters and condensing tankless water heaters do not use premix burners. A powered premix burner assembly consists of a forced draft blower and premix burner. Gas flows from the gas valve into the blower through a venturi. In the blower, the desired air-gas fuel ratio is achieved by mixing air and gas prior to combustion. The air-fuel mixture then enters the premix burner and is ignited. Premix burners in gas-fired storage water heaters and hot water supply boilers are typically stainless steel tubes. Premix burners in tankless water heaters have a number of different designs. The combustion chamber containing a premix burner in a gas-fired storage water heater is typically submerged in the tank volume to reduce heat losses. By allowing for tight control of the fuel-air ratio, premix burner assemblies allow for increased thermal efficiency and lower nitrogen oxides (NO_X) emissions.

Premix burners reduce emissions in two ways: by reducing peak flame temperature and by reducing levels of excess air. They achieve this by completely mixing the primary air and fuel prior to combustion, thereby eliminating the need for secondary air. The greater level of primary air in the lean, premixed air-fuel mixture creates a uniform flame shape that ensures oxygen availability to all regions of the flame. This eliminates the interior region of an inshot burner flame, where sub-stoichiometric, fuel-rich "hot spots" form "thermal NO_X" at a rate that increases exponentially with flame temperatures above 2,800 °F. In addition, the absence of secondary air reduces the amount of free oxygen and nitrogen available to the flame exterior, thereby reducing "prompt NO_X" formation. Aside from NO_x reduction, the leaner, premixed flames also have a higher overall flame temperature than flames with secondary air. The hotter, leaner, premixed flame improves heat transfer and thermal efficiency. It also raises the water vapor dew point temperature, which facilitates more condensation and further improves thermal efficiency.

3.11.2.12 Electromechanical Flue Damper

Non-condensing gas-fired storage water heaters are typically equipped with a draft hood connecting the flue pipes to a vent pipe or chimney. During off-cycle, the water heater loses heat by natural convection and conduction through the vent pipe or chimney. Installing a damper at the flue exit or in the vent pipe can minimize the off-cycle heat losses. A flue damper is installed upstream of the draft diverter, while a vent damper is installed downstream of the draft diverter.

Electromechanical (or electric) flue dampers are activated by an external source of electricity. These dampers open when combustion starts and close immediately after combustion stops. When the damper reaches the open position, an interlock switch energizes the solenoid and enables the gas ignition circuit. Therefore, as a safety measure, the burner cannot be ignited when the damper is in the closed position. Because the dampers open and close immediately, no bypass is needed. The electromechanical flue damper needs an electrical connection and consumes a nominal amount of power even when the gas supply is off. Electric flue dampers are used in conjunction with electric ignition systems as opposed to standing pilot lights.

Flue dampers have no effect on the steady-state performance and thus thermal efficiency of water heaters. However, these dampers reduce standby losses of gas-fired storage water heaters, yielding improved energy efficiency. Electromechanical flue dampers are commonly used in baseline commercial gas-fired storage water heaters; however, DOE has not found evidence of their use in residential-duty gas-fired storage water heaters. Flue dampers were not considered as a technology option for condensing water heaters, as flue dampers are not used in water heaters with mechanical draft systems. Flue dampers were also not used as an option for instantaneous water heaters because there is very little stored water for heat to escape from during off-cycle.

3.11.3 Technology Options that do not Improve Efficiency as Measured

Because thermal efficiency, standby loss, and UEF are the relevant performance metrics in this rulemaking, DOE did not consider technologies that have no effect on those metrics. However, DOE does not discourage manufacturers from using these technologies because they might reduce annual energy consumption. DOE determined that the following technologies do not improve thermal efficiency, standby loss, or UEF based upon DOE's current test procedures.

3.11.3.1 Plastic Tank

Some electric storage water heaters use a tank made of plastic (polybutylene) instead of a tank made of steel. This design difference results in a significantly lower equipment weight. The plastic tank is also resistant to corrosion, and therefore equipment with this design may have a longer lifetime than water heaters with a steel tank (not stainless steel). While plastic has a higher thermal resistivity than steel and is therefore a better insulator, DOE is not aware of any evidence showing that water heaters with plastic tanks have lower standby losses than those with steel tanks.

3.11.3.2 Direct Vent

Direct vent is a venting configuration in which intake air for combustion is drawn directly from outdoors. Direct venting can be achieved either through a two-pipe system, which includes one pipe for bringing combustion air to the burner and one for exhausting the products of combustion, or through a single, concentric vent. Direct vent prevents problems associated with inadequate air for combustion in the area surrounding CWH equipment. However, because direct vent only changes the source of the intake air, it does not affect efficiency as measured by a DOE test procedure. In a concentric direct vent design, the flue gases are exhausted through a central vent pipe and the intake combustion air passes through a concentric duct surrounding it. This arrangement creates a counter-flow heat exchanger that recovers some heat from the flue gases to preheat the combustion air. However, DOE is not aware of any evidence showing that this preheating has a significant effect on thermal efficiency of CWH equipment.

3.11.3.3 Timer Controls

Timer controls limit the time of day when the elements of an electric storage water heater may be energized. This is most often used as part of an electric utility demand-side management program for load shifting. Energy savings are possible because the water in the tank remains at a reduced temperature for part of the day. Water heaters are considered ideal appliances for use in demand response programs due to their high thermal storage and relatively consistent load pattern. However, the actual energy savings will depend on the end-use profile, lifestyle of the consumer, and a basic desire to save energy. Savings will be greater for water heaters where standby loss levels are high because the electric consumption, in response to the standby losses, shifts from on-peak to off-peak times when electricity costs less.

Timer controls do not affect the standby loss as measured by the DOE test procedure, and therefore were not considered in this analysis.

3.11.3.4 Intelligent and Wireless Controls

Intelligent controls, self-diagnostics, and electronic controls for storage and instantaneous water heaters minimize energy consumption and maximize hot water output. Monitoring functions typically operate to minimize operating cost while still meeting household demand. This works by tracking usage patterns and adjusting water heater operations to maximize efficiency. Also, water heaters may employ economizer modes to limit the maximum temperature to reduce energy consumption. Smart vacation settings operate to minimize energy usage while maintaining temperatures above freezing. Diagnostic software may also maintain the optimal burner conditions, valve positions, and air-to-fuel ratios to maximize efficiency, for example. However, these controls do not affect the efficiency as measured by DOE test procedures.

3.11.3.5 Modulating Combustion

Modulating combustion within gas-fired CWH equipment can reduce energy consumption and improve overall performance by changing the operating conditions in response to hot water demand. Basic combustion systems (*i.e.*, those without modulation or multiple stages) only operate at the maximum output level, based on simple inputs from either the user or the water heater. Alternatively, modulation can reduce output so that excess energy is not wasted when only small temperature differentials or low flow rates need to be satisfied. By modulating the burner firing rate, the demand can be met more precisely by the appropriate outputs. While modulation can decrease overall energy consumption, it does not affect thermal efficiency as measured by the DOE test procedure, because the test procedure requires firing at the maximum input capacity.

Modulating controls are considered to be a baseline feature in gas-fired tankless water heaters, and are included in some gas-fired storage water heaters and hot water supply boilers.

3.11.3.6 Self-Cleaning

This technology option for storage water heaters is a modification of the conventional cold water inlet associated with a typical storage water heater. Water exits a conventional dip tube or inlet pipe with a weak diffusing action. Self-cleaning technology incorporates a method to introduce the inlet water at high turbulence. This is accomplished by modifying the exit orifice at the end of the water inlet to increase the inlet velocity of the water and create a spray pattern. These introduce inlet water at various points within the tank to increase mixing and overall tank turbulence. Further designs may turn the flow path of the inlet water to a horizontal angle to increase the amount of swirling, or rotational turbulence. By introducing the inlet water at higher velocities and with turbulence, naturally occurring sediment in the water is forced to remain in suspension. Therefore, the sediment can be drawn out of the tank when there is a call for hot water, instead of settling to the bottom. Sediment deposits can decrease heat transfer, cause leaks, and reduce tank volume. This technology has the benefit of reducing sedimentation, but this does not contribute to an increase in efficiency as measured by the DOE test procedure.

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CHAPTER 4. SCREENING ANALYSIS

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CHAPTER 4. SCREENING ANALYSIS

4.1 INTRODUCTION

This chapter details the screening analysis that the U.S. Department of Energy (DOE) conducted of the technology options identified in the market and technology assessment (Chapter 3 of this technical support document (TSD)) for commercial water heating (CWH) equipment. In the market and technology assessment, DOE presented an initial list of technologies that can be used to increase the efficiency of the considered equipment. The goal of the screening analysis is to identify any technology options that will be eliminated from further consideration in the rulemaking analyses.

The candidate technology options are assessed based on DOE's analysis as well as inputs from stakeholders including manufacturers, trade organizations, and energy efficiency advocates. Technology options that are judged to be viable approaches for improving efficiency are retained as inputs to the subsequent engineering analysis. Technology options that are not incorporated in commercial equipment or in working prototypes, or that fail to meet certain criteria, as to practicability to manufacture, install and service, as to impacts on equipment utility or availability, or as to health or safety will be eliminated from consideration in accordance with 10 CFR 430, subpart C, appendix A, section 4(a)(4)(i-iv). The rationale for either screening out or retaining each technology option is detailed in the following sections of this chapter.

The Energy Policy and Conservation Act (EPCA) establishes criteria for prescribing new or amended standards designed to achieve the maximum improvement in energy efficiency. Further, EPCA directs the Secretary of Energy to determine whether a standard is technologically feasible and economically justified. (42 U.S.C. 6313(a)(6)(A)(ii)(II)) EPCA also establishes guidelines for determining whether a standard is economically justified. (42 U.S.C. 6313(a)(6)(B)(ii)) 10 CFR 430, "Procedures, Interpretations and Policies for Consideration of New or Revised Energy Conservation Standards for Consumer Products" sets forth procedures to guide DOE in its consideration and promulgation of new or revised equipment energy conservation standards. These procedures elaborate on the statutory criteria provided in EPCA and, in part, eliminate problematic technologies early in the process of prescribing or amending an energy conservation standard. In particular, 10 CFR 430, subpart C, appendix A, section 4(a)(4)(i-iv) guide DOE in determining whether to eliminate from consideration any technologies that present unacceptable problems with respect to the following criteria:

1) *Technological feasibility*. DOE will consider technologies incorporated in commercial products or in working prototypes to be technologically feasible.

2) *Practicability to manufacture, install, and service*. If mass production and reliable installation and servicing of a technology in commercial products could be achieved on the scale necessary to serve the relevant market at the time the standard comes into effect, then DOE will consider that technology practicable to manufacture, install, and service.

3) *Adverse impacts on product utility or equipment availability*. If DOE determines a technology would have a significant adverse impact on the utility of the equipment to

significant subgroups of customers, or would result in the unavailability of any covered equipment type with performance characteristics (including reliability), features, sizes, capacities, and volumes that are substantially the same as equipment generally available in the United States at the time, it will not consider this technology further.

4) *Adverse impacts on health or safety*. If DOE determines that a technology will have significant adverse impacts on health or safety, it will not consider this technology further.

In sum, if DOE determines that a technology, or a combination of technologies, has unacceptable impacts based on the factors identified in 10 CFR 430, subpart C, appendix A, section 4(a)(4)(i-iv), it will be eliminated from consideration. If a particular technology fails to meet one or more of the four criteria, it will be screened out.

4.2 SCREENED-OUT TECHNOLOGY OPTIONS

This section describes the technologies that DOE eliminated for failure to meet one of the following four factors: (1) technological feasibility; (2) practicability to manufacture, install, and service; (3) impacts on equipment utility or equipment availability; and (4) adverse impacts on health or safety. DOE eliminated the following technology options from further consideration: advanced insulation types, pulse combustion, sidearm heating, two-phase thermosiphon technology, gas absorption heat pump water heaters (HPWHs), and thermophotovoltaic and thermoelectric generators.

4.2.1 Advanced Insulation Types

Insulating storage water heaters with vacuum, inert gases, aerogel, or evacuated panels is an alternative to increasing the thickness of the insulation to decrease heat transfer and standby losses. Manufacturers could elect to use alternative types of insulation because increasing the thickness of insulation may create shipping and installation problems if diameters exceed standard building clearance widths. However, several factors limit the inclusion of advanced forms of insulation into CWH equipment today.

To the best of DOE's knowledge, vacuum insulation technology has not been demonstrated for water heating applications in the United States for either production or prototyping. German manufacturer Hummelsberger developed a prototype vacuum-insulated storage tank, but this unit was designed at a small scale, and there are many challenges that must be met before this technology can be manufactured on a larger scale, including the weld precision required, leak detection, and time required to produce each unit.[1] Durability and maintaining the seal over the life of the storage water heater are some additional problems of vacuum insulation. Although vacuum insulation shows promising potential for decreasing standby loss, no manufacturer has incorporated this technology into a commercially-available product. Therefore, at this time this technology has not been demonstrated as practicable to manufacture, install, and service on the scale necessary to serve the relevant market at the time of the effective date of the standard.

Gas-filled panel technology has not been demonstrated for water heating applications for either production or prototyping, to the best of DOE's knowledge. Prototypes have been developed for other applications and insulation improvements have been achieved. However, gas-filled panel technology has not yet penetrated the market for storage water heaters. Therefore, it is not technologically feasible and not practicable to manufacture, install, and service gas-filled panel technology for storage water heaters on the scale necessary to serve the relevant market at the time of the effective date of the standard.

Aerogel insulation technology has not been demonstrated in any commercially-available water heating applications to the best of DOE's knowledge. Although aerogel insulation shows promising potential for decreasing standby loss, it has not yet penetrated the storage water heater market because manufacturers must first address potential problems. Aerogel insulation is vulnerable to shock and vibration, which may create shipping and installation problems if specific handling techniques are required. In addition, it is hygroscopic and requires thorough sealing within the cavity to prevent exposure to water sources. Therefore, this technology has not been demonstrated to be technologically feasible and practicable to manufacture, install, and service on the scale necessary to serve the relevant market at the time of the effective date of the standard.

Evacuated-panel technology has not been demonstrated for water heating applications for either production or prototyping, to the best of DOE's knowledge. Prototypes have been developed for other applications and insulation improvements have been achieved. However, evacuated-panel technology has not yet penetrated the gas-fired and electric storage water heater markets. Therefore, at this time it is not technologically feasible and not practicable to manufacture, install, and service evacuated-panel technology for gas-fired and electric storage water heaters on the scale necessary to serve the relevant market at the time of the effective date of the standard.

4.2.2 Pulse Combustion

Pulse combustion burners operate on self-sustaining resonating pressure waves that alternately rarefy the combustion chamber (drawing a fresh fuel–air mixture into the chamber) and pressurize it (causing ignition by compression heating of the mixture to its flash point). Pulse combustion systems are capable of direct venting without the assistance of mechanical draft. Because the pulse combustion process is very efficient, pulse combustion is generally used in condensing appliances.

Prototype gas-fired and oil-fired storage and instantaneous water heaters incorporating pulse combustion technologies have been developed in the past. However, this technology is not present among commercially-available CWH equipment, or even among CWH research efforts of which DOE is aware. Therefore, it is not practicable to manufacture, install, and service pulse combustion technology on the scale necessary to serve the relevant market at the time of the effective date of the standard.

4.2.3 Sidearm Heating

Sidearm heaters circulate potable water between the tank and an external heat exchanger, typically a shell-in-tube exchanger. The sidearm heater design avoids large flue losses by removing the flue from the center of the gas-fired storage tank.

DOE has not found evidence of commercially-available sidearm storage water heaters, although products incorporating sidearm heaters have been commercially available in small quantities. However, DOE was not able to identify a current working prototype for gas-fired storage water heaters, and believes manufacturers no longer use this technology. Therefore, it is not practical to manufacture, install, and service sidearm storage water heaters on the scale necessary to serve the relevant market at the time of the effective date of the standard.

4.2.4 Two-Phase Thermosiphon Technology

A two-phase thermosiphon (TPTS) removes the flue from the center of a gas-fired storage water heater and places a heat exchanger outside of the storage tank reducing standby losses. This is similar to the sidearm heater technology option.

Manufacturers have developed working prototype water heaters using TPTS. Several units are commercially available for solar water heating applications, but not for gas-fired storage water heating. TPTSs used for solar applications rely on large designs with large surface areas to maximize sun exposure. Large TPTSs are typically not practical for indoor installations using gas. Also, incorporating the TPTS system would cause a drastic redesign of all gas-fired storage water heaters with little increase in energy efficiency. The redesign would involve removing the center flue and relocating it outside the tank. As a result, only the standby losses would decrease with no increase in thermal efficiency.

TPTS for gas-fired storage water heaters is currently being researched and has not yet been demonstrated as practicable to manufacture, install, and service on the scale necessary to serve the relevant market at the time of the effective date of the standard.

4.2.5 Gas Absorption Heat Pump Water Heaters

Gas-fired absorption heat pump water heaters (HPWHs) use the same principle as electric heat pump water heaters of extracting heat from air to heat water, except that they use a gas-fired absorption process to increase the pressure of the refrigerant instead of electric mechanical compression. Gas absorption HPWHs have the potential to reach coefficient of performance (COP) values of 1-2, possibly doubling the efficiency of even condensing gas-fired CWH equipment.[2] DOE has funded several projects through various companies and national labs to develop more efficient and cost-effective absorption HPWHs. While research has focused mostly on models for residential use, the technology could also be used for CWH equipment. DOE recognizes that working prototypes of residential gas absorption storage HPWHs have been developed and may become commercially available. DOE also recognizes that gas absorption heat pumps for space heating are commercially available. While manufacturers may develop gas absorption HPWHs with an input capacity high enough to qualify as CWH equipment, DOE is not aware of any such units developed as prototypes or currently available on the market. Currently, this technology has not been demonstrated as being practicable to manufacture, install, and service on the scale necessary to serve the CWH equipment market at the time of the effective date of the standard.

4.2.6 Thermophotovoltaic and Thermoelectric Generators

Both thermophotovoltaic and thermoelectric generators convert a portion of the energy produced by a burner into electricity to supply auxiliary components. This conversion avoids the requirement of a conventional auxiliary power supply. Industry has conducted research on developing thermophotovoltaic and thermoelectric technologies to supply electricity to water heaters. For example, thermoelectric generators are used for pilot light safety valves. However, this technology option has not been developed to supply auxiliary power for larger applications, such as fans or electromechanical dampers, for use with water heater products. Currently, it is not practical to manufacture, install, or service thermophotovoltaic and thermoelectric generator technology for water heaters on a scale necessary to serve the relevant market. In addition, DOE is not aware of a prototype design that provides enough auxiliary power to operate all of the necessary electrical components on most CWH equipment, and therefore, these technology options are not currently considered technologically feasible.

4.3 REMAINING TECHNOLOGIES

After eliminating those technologies that have no effect on or do not increase energy efficiency and screening out those technologies that do not meet the four screening criteria described in section 4.1, DOE considered the following technology options in the engineering analysis (see chapter 5 of this TSD):

- Improved insulation (thickness, type, insulation of tank bottom)
- Mechanical draft
- Condensing heat exchanger
- Increased heat exchanger area, baffling
- Electronic ignition
- Premix burner
- Electromechanical flue damper

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CHAPTER 5. ENGINEERING ANALYSIS

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CHAPTER 5. ENGINEERING ANALYSIS

5.1 INTRODUCTION

The engineering analysis establishes the relationship between manufacturer selling price (MSP) and energy efficiency (thermal efficiency and standby loss) for the commercial water heating (CWH) equipment covered in this rulemaking. The cost-efficiency relationship serves as the basis for subsequent cost/benefit calculations for individual consumers, manufacturers, and the Nation. In determining this relationship, the U.S. Department of Energy (DOE) estimates the increase in the MSP associated with technological changes that reduce the energy consumption of the baseline models. This chapter provides an overview of the engineering analysis (section 5.2), discusses proposed equipment classes (section 5.3), discusses the analyzed representative equipment (section 5.4), establishes baseline, intermediate, and max-tech efficiency levels (section 5.5), discusses details and findings from the teardown analysis (section 5.6), explains the methodology used to develop cost estimates (section 5.7), discusses the engineering analysis results (sections 5.8 and 5.10), discusses the manufacturer markup and shipping costs (section 5.9), discusses the modification of standby loss equations (section 5.11), and discusses the conversion of standards for residential-duty water heaters to uniform energy factor (section 5.12)

The primary inputs to the engineering analysis are baseline information and market characteristics (*e.g.*, efficiency distributions) from the market and technology assessment (chapter 3 of this technical support document (TSD)) and technology options that passed the screening analysis (chapter 4 of this TSD). Additional inputs include laboratory testing and reverse-engineering of representative equipment, as well as feedback from manufacturer interviews. The primary output of the engineering analysis is a set of cost-efficiency curves relationships that represent the average incremental cost of increasing equipment efficiency above the baseline levels. In the subsequent markups analysis (chapter 6 of this TSD), DOE determined commercial consumer (*i.e.*, equipment purchaser) prices by applying distribution chain markups, sales tax, and contractor markups to the manufacturer selling prices (MSPs) developed in the engineering analysis. After applying these markups and an estimated installation cost, these prices serve as an input to the life-cycle cost (LCC) and payback period (PBP) analyses (chapter 8 of this TSD).

5.2 METHODOLOGY OVERVIEW

DOE typically structures its engineering analysis using one of three approaches: (1) design-option; (2) efficiency-level; or (3) reverse engineering (or cost-assessment). A design-option approach identifies individual technology options (from the market and technology assessment) that can be used alone or in combination with other technology options to increase the energy efficiency of a unit of equipment. Under this approach, cost estimates of the baseline equipment and more-efficient equipment that incorporates design options are based on manufacturer or component supplier data or engineering computer simulation models. Individual design options, or combinations of design options, are added to the baseline model in descending order of cost-effectiveness. An efficiency-level approach establishes the relationship between manufacturing production cost and increased efficiency at predetermined efficiency levels above the baseline. Under this approach, DOE typically assesses increases in manufacturer cost for incremental increases in efficiency, rather than the technology or design options that would be used to achieve such increases. A reverse-engineering, or cost-assessment, approach involves testing and disassembling representative units of CWH equipment, and estimating the manufacturing costs based on a "bottom-up" manufacturing cost assessment; such assessments use detailed data to estimate the costs for parts and materials, labor, shipping/packaging, and investment for models that operate at particular efficiency levels.

DOE conducted this engineering analysis for CWH equipment using a combination of the efficiency-level and cost-assessment approaches. For the analysis of thermal efficiency levels for CWH equipment, DOE identified the efficiency levels for the analysis based on market data and then used the cost-assessment approach to determine the manufacturing production cost (MPC) at each level. For the analysis of standby loss levels for storage water heaters, DOE identified standby loss levels for analysis based on market data and commonly used technology options (*i.e.*, insulation type, thickness), and then used the cost-assessment approach to determine the MPC of equipment at each efficiency level.

The cost-assessment is based on teardown data (see section 5.6). To derive it, DOE used public information to identify baseline units and representative equipment and selected a set of units at the baseline and higher efficiencies for teardown analysis. The baseline unit serves as a starting point for comparison with higher efficiency equipment, and the units selected for teardown analysis span a range of manufacturers, functionality, and efficiencies for commercially available equipment. DOE gathered data from physical teardowns and developed a bill of materials (BOM) for each of the units selected for teardown by disassembling each unit.

DOE supplemented its data set by using the BOMs while scaling the physical characteristics or making part substitutions, as applicable. For example, DOE can parametrically scale units by physical characteristics (*i.e.*, height, width, depth, insulation thickness, steel thickness, etc.) as well as substitute purchased part components such as gas valves, inducer fan units, etc. As a result, a limited number of physical teardowns can yield cost estimates for a far wider group of units, as long as the overall construction and design of the unit remains similar.

DOE converted the information recorded in the BOMs to dollar values to calculate the manufacturing production cost (MPC) for equipment spanning the full range of efficiencies from the baseline to the maximum technologically feasible ("max-tech") level. DOE also identified the technology or combination of technologies mainly responsible for improving the energy efficiency of CWH equipment across this range.

As part of the development of the cost-efficiency curves, DOE interviewed manufacturers to gain insight into the CWH industry and requested comments on the engineering approach DOE used for the analysis. DOE used the information gathered from these interviews to refine both the technology options implemented at each efficiency level and DOE's MPC estimates.

To determine the MSP of CWH equipment at each efficiency level, DOE applied derived manufacturer markups (see section 5.9) to the MPC and added the estimated shipping cost. To derive the manufacturer markup, DOE added a typical profit to the fully absorbed cost of production by using publicly available industry financial data and manufacturer feedback. DOE developed shipping costs based on published CWH equipment shipping dimensions and the size and cost of a typical tractor trailer truck used for shipping this equipment. DOE added the shipping cost to the marked-up MPC to calculate the total MSP. The results of the engineering analysis are a set of cost-efficiency relationships, in the form of MSP versus energy-efficiency (thermal efficiency and standby loss, as applicable), for each equipment class.

The methodology for the engineering analysis is a logical, concise, and reproducible process, as illustrated in Figure 5.2.1.

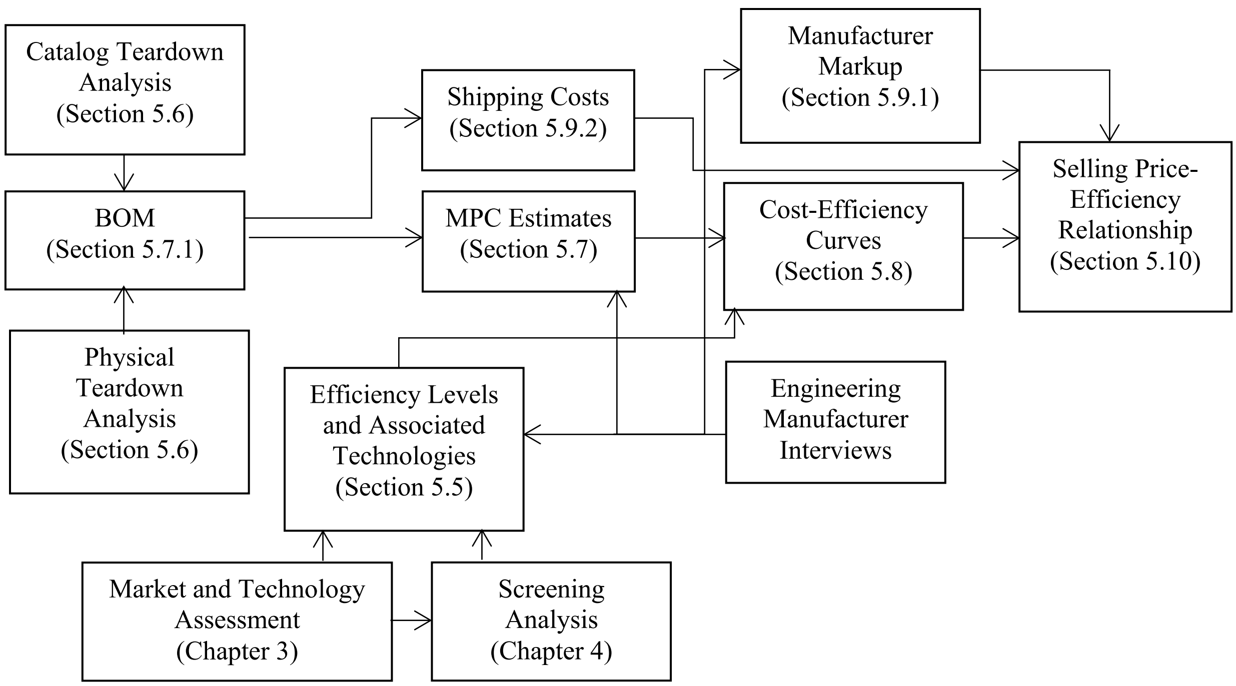

Figure 5.2.1 Flow Diagram of Engineering Analysis Methodology

5.3 EQUIPMENT CLASSES ANALYZED

According to the Energy Policy and Conservation Act (EPCA), equipment may be separated into different equipment classes by energy source (*e.g.*, natural gas, electricity), capacity, other performance-related features (such as those that provide utility to the consumer), or any other features deemed appropriate by the Secretary that would justify the establishment of a separate energy conservation standard. (42 U.S.C. 6295 (q) and 6316(a))

Table 5.3.1 shows the equipment classes for CWH equipment that were analyzed in the NOPR. As discussed in the NOPR, several proposed equipment classes were not analyzed, including oil-fired CWH equipment and unfired hot water storage tanks. Due to significant differences in design and application, DOE analyzed tankless water heaters and hot water supply boilers as separate kinds of representative equipment for the gas-fired instantaneous water heaters and hot water supply boilers equipment class.

Table 5.3.1 Equipment Classes Analyzed for CWH Equipment

Equipment Class		Specifications
Commercial Gas-fired storage water heaters and commercial gas-fired storage-type instantaneous water heaters*		>105 kBtu/h or >120 gal
Residential-duty gas-fired storage water heaters**		≤105 kBtu/h and ≤120 gal
Gas-fired instantaneous water heaters and hot water supply boilers	Tankless water heaters	<10 gal
	Hot water supply boilers	All[†]
Electric storage water heaters		N/A

* In a NOPR issued in April 2016 to amend test procedures for certain CWH equipment ("2016 CWH TP NOPR"), DOE proposed, among other things, a new definition for storage-type instantaneous water heaters. (See Docket No. EERE-2014-BT-TP-0008) This class of equipment is similar to storage water heaters in design, cost and application. However, these units have a ratio of input capacity to storage volume greater than or equal to 4,000 Btu/h per gallon of water stored, and are therefore classified as instantaneous water heaters by EPCA's definition at 42 U.S.C. 6311(12)(B). Because of their similarities with storage water heaters, DOE grouped these two equipment classes together in its analyses for the NOPR.
** To be classified as a residential-duty water heater, a water heater must, if requiring electricity, use single-phase external power supply, and not be designed to heat water at temperatures greater than 180 °F. 79 FR 40542, 40586 (July 11, 2014).
[†] For the engineering analysis, hot water supply boilers <10 gallons and ≥10 gallons were analyzed in the same equipment class. Amended standby loss standards for hot water supply boilers ≥10 gallons were not analyzed in the NOPR.

5.4 REPRESENTATIVE EQUIPMENT

For the engineering analysis, DOE reviewed all CWH equipment classes covered in this rulemaking. Because the storage volume, input capacity, and design can affect the energy efficiency of CWH equipment, DOE examined each equipment class separately. Within each equipment class, CWH equipment span a wide range of capacities. This variation in capacity also can cause wide variations in equipment prices and energy use. Thus, DOE selected a representative equipment capacity for each equipment class at which an analysis was conducted.

Using a representative capacity allowed DOE to analyze specific equipment in detail that can provide information representative of the entire equipment class. DOE analyzed the database it compiled during the market and technology assessment (see chapter 3 of this TSD) and discussions with manufacturers to determine appropriate representative equipment for each equipment class. DOE's database includes data from the Air Conditioning, Heating, and Refrigeration Institute *Directory of Certified Product Performance* ("AHRI Directory")[1], the California Energy Commission (CEC) Appliance Database,[2] and DOE's *Compliance Certification Database*. DOE used representative equipment sizes as the basis for the rest of the engineering analysis and the cost-efficiency relationships. In the engineering analysis, DOE analyzed equipment with characteristics as close to those of the representative equipment as possible.

For storage water heaters, the volume of the tank is a significant factor for costs and efficiency. Water heaters with larger volumes have higher costs for materials, labor, and shipping. A larger tank volume is likely to lead to a larger tank surface area, increasing the standby loss of the tank (assuming other factors are held constant, *e.g.*, same insulation thickness and materials). The current standby loss standards for storage water heaters are, in part, a function of tank volume. The incremental cost of increasing insulation thickness varies as the tank volume increases. Increases in height, diameter, or changes in spud locations can increase installation costs significantly. DOE examined specific storage volumes for commercial and residential-duty gas-fired storage water heaters and electric storage water heaters (referred to as representative storage volumes). Because DOE lacked specific information on shipments, DOE examined the number of models at each storage volume in its database to determine the representative storage volume, and also solicited feedback from manufacturers during manufacturer interviews as to which storage volumes corresponded to the most shipments. Table 5.4.1 shows the representative storage volumes that DOE determined best represent each equipment class.

The current standby loss standards for commercial storage water heaters differ in the type of storage volume used in calculation of the standby loss standard (*i.e.,* rated storage volume is used for certain classes, while measured storage volume is used for others). The standby loss standard for gas-fired and oil-fired storage water heaters depends on the rated storage volume of the water heater. However, the current standby loss standard for electric storage water heaters depends on the measured storage volume of the water heater. There is often a difference between the rated and measured volumes of water heaters, as reported in data in the AHRI Directory. In the NOPR, DOE proposes changes to its certification, compliance, and enforcement regulations that would add a requirement for manufacturers that the rated volume of storage water heaters must equal the mean of the measured storage volumes of units in the sample. Additionally, DOE proposes changing the standby loss equation for electric storage water heaters to depend on rated volume instead of measured volume. For electric storage water heaters, DOE used a representative measured volume to calculate standby loss levels because the rated volume would need to be equal to the mean of the measured values in the test sample if the proposed changes to certification of rated volume are adopted. DOE selected a representative measured storage volume based upon data for measured volumes for electric storage water heaters at the selected representative rated storage volume in the AHRI Directory. Table 5.4.1 shows both rated and measured representative storage volumes for electric storage water heaters. For gas-fired storage water heaters, DOE used rated volume to calculate standby loss levels instead of measured volume (which was used for electric storage water heaters) because of significant variation in the difference between rated and measured volume for units currently on the market, as reported in the AHRI Directory. Due to this variation, DOE could not determine a trend in how rated and measured storage volume might correlate for CWH equipment and, thus, did not have a basis for assuming an average measured storage volume for the calculation of standby loss.

For all CWH equipment classes, the input capacity is a significant factor for cost and efficiency. Water heaters with higher input capacities typically require larger heat exchangers, which add materials and which may require enlargement of the tank to maintain a rated capacity. High input systems commonly require different burners than low-input units and more complex control systems. All factors combined will lead to higher material, labor, and shipping costs for high-input storage water heaters. Similarly, tankless water heaters also increase in size, complexity, and cost as input rating increases.

DOE examined input capacities for all CWH equipment classes to determine representative input capacities. Because DOE did not receive any shipments data for specific input capacities, DOE considered the number of models at each input capacity in the database of models it compiled (based on the AHRI Directory, CEC Appliance Database, and manufacturer literature) as well as feedback from manufacturer interviews. DOE used this information to select representative input capacities for each equipment class, which are shown in Table 5.4.1.

Table 5.4.1 Representative CWH Equipment for Analysis

Equipment Class		Specifications	Representative Storage Volume (gal)	Representative Input Capacity (kBtu/h or kW)
Commercial gas-fired storage water heaters and commercial gas-fired storage-type instantaneous water heaters		>105 kBtu/h or >120 gal**	100	199 kBtu/h
Residential-duty gas-fired storage water heaters[†]		≤105 kBtu/h and ≤120 gal	75	76 kBtu/h
Gas-fired instantaneous water heaters and hot water supply boilers	Tankless water heaters	<10 gal	-	250 kBtu/h
	Hot water supply boilers	All[†]	-	399 kBtu/h
Electric storage water heaters		N/A	119 (rated), 114 (measured)	18 kW

* For all equipment classes where not specified, the representative volume is a rated storage volume, not a measured storage volume.
** To be classified as a residential-duty water heater, a water heater must, if requiring electricity, use single-phase external power supply, and not be designed to heat water at temperatures greater than 180 °F. 79 FR 40542, 40586 (July 11, 2014).
† For the engineering analysis, hot water supply boilers <10 gallons and ≥10 gallons were analyzed in the same equipment class. Amended standby loss standards for hot water supply boilers ≥10 gallons were not analyzed in the NOPR. Therefore, no representative storage volume was chosen for tankless water heaters or hot water supply boilers.

5.5 EFFICIENCY LEVELS

For each equipment class, DOE analyzed multiple efficiency levels and estimated manufacturer production costs at each efficiency level. The following subsections provide a description of the full efficiency level range that DOE analyzed from the baseline efficiency level to the maximum technologically feasible ("max-tech") efficiency level for each equipment class. The highest efficiency level was identified through review of available market data and product literature, as well as consideration of technology options that DOE believes to be feasible and that are currently used in CWH equipment on the market. Thermal efficiency levels were analyzed for all CWH equipment considered in this rulemaking except for electric storage water heaters. Standby loss levels were analyzed for all commercial and residential-duty storage water heaters.

5.5.1 Baseline Units

DOE selected baseline units as reference points for each equipment class, against which changes resulting from potential amended energy conservation standards could be measured. The baseline unit in each equipment class displays the basic characteristics of equipment in that class. A baseline unit is a unit that just meets and does not exceed current Federal energy conservation standards and provides basic consumer utility.

DOE uses the baseline unit for comparison in several phases of the analyses, including the engineering analysis, lifecycle cost (LCC) analysis, payback period (PBP) analysis and national impacts analysis (NIA).

The identification of baseline units requires establishing the baseline efficiency level. For all equipment classes, DOE defined the baseline efficiency level as the efficiency level equal to the current Federal energy conservation standards. The baseline efficiency levels for each equipment class are shown in Table 5.5.1.

Table 5.5.1 Baseline Thermal Efficiency Levels for CWH Equipment

Equipment Class		Specifications	Thermal Efficiency
Commercial gas-fired storage water heaters		>105 kBtu/h or >120 gal	80%
Residential-duty gas-fired storage water heaters*		≤105 kBtu/h and ≤120 gal	80%
Gas-fired instantaneous water heaters and hot water supply boilers	Tankless water heaters	<10 gal	80%
	Hot water supply boilers	All†	80%
Electric storage water heaters		N/A	-

* To be classified as a residential-duty water heater, a water heater must, if requiring electricity, use single-phase external power supply, and not be designed to heat water at temperatures greater than 180 °F. 79 FR 40542, 40586 (July 11, 2014).

DOE used the current energy conservation standards for standby loss to set the baseline standby loss levels. Table 5.5.2 shows these baseline standby loss levels for representative equipment for each equipment class.

Table 5.5.2 Baseline Standby Loss Levels for Representative CWH Equipment

Equipment Class		Specifications	Representative Storage Volume (gal)*	Representative Input Capacity (kBtu/h or kW)	Baseline Standby Loss Level (Btu/h)
Commercial gas-fired storage water heaters		>105 kBtu/h or >120 gal	100	199 kBtu/h	1349
Residential-duty gas-fired storage water heaters**		≤105 kBtu/h and ≤120 gal	75	76 kBtu/h	1048
Gas-fired instantaneous water heaters and hot water supply boilers	Tankless water heaters	<10 gal	-	250 kBtu/h	-
	Hot water supply boilers	All	-	399 kBtu/h	-
Electric storage water heaters		N/A	119 (rated), 114 (measured)	18 kW	353

* For all equipment classes where not specified, the representative volume is a rated storage volume, not a measured storage volume.

5.5.2 Intermediate and Max-Tech Efficiency Levels

For each equipment class, DOE analyzes several efficiency levels and determines the manufacturing cost at each of these levels. For the NOPR, DOE developed thermal efficiency levels based on a review of available equipment. As discussed in detail in chapter 3 of this TSD (Market and Technology Assessment), DOE compiled a database of CWH equipment to determine what kinds of equipment are currently available to commercial consumers. For each equipment class, DOE surveyed various manufacturers' equipment offerings to identify the commonly-available efficiency levels. By identifying the most prevalent energy efficiency levels in the range of available equipment and examining models at these levels, DOE can establish a technology path that manufacturers would typically use to increase the thermal efficiency of CWH equipment.

DOE established intermediate thermal efficiency levels for each equipment class. The intermediate thermal efficiency levels are representative of the most common efficiency levels and those that represent significant technological changes in the design of CWH equipment. For commercial gas-fired storage water heaters, DOE chose four efficiency levels between the baseline and max-tech levels for analysis. For residential-duty gas-fired storage water heaters, DOE chose three efficiency levels between the baseline and max-tech levels for analysis. For commercial gas-fired instantaneous water heaters (including tankless water heaters and hot water supply boilers), DOE chose four efficiency levels between the baseline and max-tech levels for analysis.

As part of the engineering analysis, DOE determined the maximum technologically feasible improvement in energy efficiency for CWH equipment as required by EPCA. (42 U.S.C. 6313(a)(6)(A)(ii)(II)) DOE conducted a survey of its CWH equipment database, manufacturers' websites, and technical literature to determine the highest feasible CWH equipment thermal efficiency levels. DOE also discussed the appropriate max-tech level with manufacturers during interviews. All selected thermal efficiency levels are shown in Table 5.5.3.

Table 5.5.3 Baseline, Intermediate, and Max-Tech Thermal Efficiency Levels for Representative CWH Equipment

		Thermal Efficiency Levels					
Equipment Class		Baseline - E_t EL0	E_t EL1	E_t EL2	E_t EL3	E_t EL4*	E_t EL5**
Electric storage water heaters		-	-	-	-	-	-
Commercial gas-fired storage water heaters and gas-fired storage-type instantaneous water heaters		80%	82%	90%	92%	95%	99%
Residential-duty gas-fired storage water heaters		80%	82%	90%	95%	97%	-
Gas-fired instantaneous water heaters and hot water supply boilers	Tankless water heaters	80%	82%	84%	92%	94%	96%
	Hot water supply boilers	80%	82%	84%	92%	94%	96%

* E_t EL4 is the max-tech efficiency level for residential-duty gas-fired storage water heaters.
** E_t EL5 is the max-tech efficiency level for commercial gas-fired storage water heaters and storage-type instantaneous water heaters, as well as for gas-fired instantaneous water heaters and hot water supply boilers.

DOE established intermediate and max-tech standby loss levels for each equipment class of storage water heaters. Standby loss is a function of rated volume for gas-fired storage water heaters; however, in the NOPR, DOE proposes changes to its certification, compliance, and enforcement regulations that would require the rated volume to be based on the mean of the measured volumes in the sample. DOE believes that to be compliant with these proposed changes, most manufacturers with units having a rated storage volume that does not equal the measured volume would, if the proposed changes are adopted, re-rate the storage volumes of their current models based on the measured volumes, as opposed to changing their designs so that the measured storage volume increases to the current rated volume. Therefore, in analyzing market standby loss data for the NOPR, DOE accounted for this change by calculating the maximum standby loss levels under consideration using the measured volume as reported in the AHRI Directory for each model.

Standby loss is a function of storage volume (and input for gas-fired storage water heaters) and is affected by many aspects of the design of a water heater. Additionally, standby loss is not widely reported in manufacturer literature. DOE was not able to find any CWH equipment literature that reported standby loss, and therefore relied on data obtained from the AHRI Directory. However, a there is significant variation in reported standby loss values in the AHRI Directory – *i.e.*, standby loss values for power-vented non-condensing residential-duty gas-fired storage water heaters range from 48% to 102%[a] of the current standby loss standard. Also, most manufacturers do not disclose the presence of technology options that affect standby loss, including insulation thickness and type, and baffle design, in their publicly-available literature. Therefore, DOE analyzed technology options commonly used on the market to help guide its selection of standby loss levels.

One possible source of variation in reported standby loss values is variation in unreported technology options. Additionally, during manufacturer interviews, manufacturers explained that the current standby loss test procedure leads to significant variation in test results from lab to lab, and sometimes even within the same lab. Several reasons given for this include any draft in the area around the test stand, the wide tolerance for ambient temperature, lack of humidity specification, variation in venting, and insulation of connections. DOE addressed some of these sources of variation in the revised standby loss test procedures for CWH equipment proposed in the 2016 CWH TP NOPR. (See EERE-2014-BT-TP-0008)

DOE developed its incremental and max-tech standby loss levels by considering levels currently on the market, designs detailed in publicly-available equipment literature, observations from equipment teardowns, and feedback from manufacturer interviews. For commercial gas-fired storage water heaters, DOE determined that the current Federal standard can be met with 1 inch of fiberglass insulation around the walls of the tank. Therefore, DOE considered 1 inch of fiberglass insulation to correspond to the baseline standby loss efficiency level. DOE then considered the next incremental standby loss level to correspond to the use of sprayed polyurethane foam insulation instead of fiberglass insulation. From a survey of units on the market, DOE considers switching from 1 inch of fiberglass insulation to 1 inch of foam insulation a more commonly used pathway to decrease standby loss than using 2 inches of fiberglass insulation. From equipment teardowns and manufacturer interviews, DOE believes the highest insulation thickness available for commercial gas-fired water heaters to be 2 inches. Therefore, DOE considered the next incremental standby loss level, SL EL2, to correspond to 2

[a] Because DOE calculated the maximum standby loss using measured storage volume instead of the rated storage volume, some units at or near the maximum allowable standby loss level have a standby loss level that exceeds the current standard when calculated using the measured volume.

inches of polyurethane foam. While more-stringent standby loss levels than SL EL2 exist on the market, these more-stringent values are only rated for condensing units with specific heat exchanger designs. Because DOE does not wish to mandate specific heat exchanger designs for achieving condensing thermal efficiency levels, standby loss levels more stringent than SL EL2 were not analyzed. Therefore, DOE considered SL EL2 as the max-tech standby loss level for commercial gas-fired storage water heaters. Table 5.5.4 shows the technology options identified for each standby loss level for commercial gas-fired storage water heaters.

Based on a review of available equipment on the market and feedback from manufacturers, DOE analyzed all non-condensing commercial gas-fired storage water heaters (*i.e.*, water heaters rated at thermal efficiency levels between 80 percent and 82 percent) as including electromechanical flue dampers. Electromechanical flue dampers were only included in the analysis for non-condensing commercial gas-fired storage water heaters because flue dampers are not used with mechanical draft systems, which are required for condensing units. In place of standby loss reduction from electromechanical flue dampers, DOE included standby loss reduction from mechanical draft systems for all condensing commercial gas-fired storage water heaters in its calculated standby loss levels. Therefore, for commercial gas-fired storage water heaters, DOE considered baseline non-condensing equipment to include electromechanical flue dampers and baseline condensing equipment to include mechanical draft systems, both of which act to reduce standby losses out the flue.

Table 5.5.4 Technology Options Identified at Each Standby Loss Level for Commercial Gas-Fired Storage Water Heaters

Standby Loss Level	Technology Options
SL EL0 - Baseline	1” fiberglass insulation
SL EL1	1” foam insulation
SL EL2	2” foam insulation

For residential-duty gas-fired storage water heaters, DOE has tentatively concluded that the current Federal standard may be met through use of 1 inch of polyurethane foam insulation. From surveying commercially-available equipment, DOE notes that all baseline residential-duty gas-fired storage water heaters have a standing pilot and do not use flue dampers. Therefore, in addition to increasing the thickness of foam insulation, DOE also considered electromechanical flue dampers and electronic ignition as technology options for reducing standby loss. Electromechanical flue dampers were only considered as a technology option for non-condensing residential-duty gas-fired storage water heaters, because flue dampers are not used with mechanical draft systems. DOE believes that flue dampers can be used with residential-duty water heaters because all atmospherically-vented commercial gas-fired storage water heaters and some residential gas-fired storage water heaters use flue dampers. Therefore, for residential-duty gas-fired storage water heaters, DOE considered electromechanical flue dampers to be a technology option not featured in baseline non-condensing equipment, and considered mechanical draft systems to be featured in baseline condensing equipment. Similarly to commercial gas-fired storage water heaters, both of these technologies act to reduce standby losses out the flue.

For condensing residential-duty gas-fired storage water heaters, rated standby loss market data show that the most-efficient standby levels are only achieved by models with particular condensing heat exchanger designs. Specifically, DOE observed that the most-efficient standby loss level on the market is only achieved by a model with 90-percent thermal efficiency. It is not evident that this level can be reached by heat exchanger designs that also yield more-efficient condensing thermal efficiency levels. DOE chose not to analyze standby loss levels that have not been demonstrated to be achievable with more-efficient thermal efficiency level designs, because thermal efficiency typically will have a greater impact on the energy use of CWH equipment than standby loss. To ensure the continued availability of condensing CWH equipment with thermal efficiencies above 90 percent, DOE considered a standby loss level of 48 percent of the current standby loss standard as the max-tech standby loss level. This standby loss level can be achieved by all condensing market for residential-duty gas-fired storage water heaters currently on the market. To inform the selection of SL EL0 for condensing residential-duty gas-fired storage water heaters, DOE considered the increase in standby loss that would occur from reducing the thickness of polyurethane foam insulation from 2 inches to 1 inch. Table 5.5.5 shows the standby loss technology options selected for the analysis of residential-duty gas-fired storage water heaters.

Table 5.5.5 Technology Options Identified at Each Standby Loss Level for Residential-Duty Gas-Fired Storage Water Heaters

Standby Loss Level	Technology Options
SL EL0 - Baseline	1” foam insulation, standing pilot
SL EL1	2” foam insulation, electronic ignition
SL EL2	1” foam insulation, electronic ignition, electromechanical flue damper
SL EL3	2” foam insulation, electronic ignition, electromechanical flue damper

DOE was not able to identify any electric storage water heater models with less than 2 inches of polyurethane foam insulation, and therefore considered the current Federal standard to correspond to 2 inches of polyurethane foam insulation. Therefore, this technology was used as the baseline design option. The more stringent standby loss level that DOE considered, representing the max-tech efficiency level, corresponded to 3 inches of polyurethane foam insulation. Table 5.5.6 shows the standby loss levels and technology options identified at each level for electric storage water heaters.

Table 5.5.6 Technology Options Identified at Each Standby Loss Level for Electric Storage Water Heaters

Standby Loss Level	Technology Options
SL EL0 – Baseline	2” foam insulation
SL EL1	3” foam insulation

To inform the selection of standby loss levels, DOE performed heat loss calculations for representative equipment for each equipment class. These calculations yielded more stringent standby loss levels corresponding to the identified technology options. Section 5.5.3 below provides details on these heat loss calculations. Table 5.5.7, Table 5.5.8, and Table 5.5.9 show the calculated standby loss levels for commercial gas-fired storage water heaters, residential-duty gas-fired storage water heaters, and electric storage water heaters, respectively, in terms of Btu/h for the representative equipment. However, to modify the current federal standard, factors were developed to multiply by the current maximum standby loss equation for each equipment class, based on the ratio of standby loss at each efficiency level to the current Federal standard. The translation from maximum standby loss values at the representative storage volume and input rating to maximum standby loss equations is described in further detail in section 5.11.

For commercial and residential-duty gas-fired storage water heaters, standby loss is measured predominantly as a function of fuel flow used to heat the stored water during the standby loss test, with a small contribution of electric power consumption (if the unit requires a power supply). Because standby loss is calculated using the fuel consumed during the test to maintain the water temperature, the standby loss is dependent on the thermal efficiency of the water heater. DOE used data from independent testing of CWH equipment at a third-party laboratory to estimate the fraction of standby loss that can be attributed to fuel consumption or electric power consumption. For a given standby loss level, DOE scaled down the portion of the standby loss attributable to fuel consumption as thermal efficiency increased. Section 5.5.3 below explains these calculations and the interdependence of thermal efficiency and standby loss in more detail. However, for condensing thermal efficiency levels for residential-duty gas-fired storage water heaters, DOE did not include dependence on thermal efficiency in its standby loss levels. As previously discussed, the most stringent standby loss level examined was a level that can be achieved by all condensing residential-duty gas-fired storage water heaters currently on the market. Because the examined level is currently met by all equipment at condensing thermal efficiency levels, DOE did not lower the stringency of the standby loss level for lower condensing thermal efficiency levels. Table 5.5.7, Table 5.5.8, and Table 5.5.9 show the examined standby loss levels for commercial gas-fired storage water heaters, residential-duty gas-fired storage water heaters, and electric storage water heaters, respectively.

Table 5.5.7 Standby Loss Levels for Commercial Gas-Fired Storage Water Heaters, 100 Gallon Rated Storage Volume, 199,000 Btu/h Input Capacity

Thermal Efficiency Level	Thermal Efficiency	Standby Loss (Btu/h)		
		SL EL0	SL EL1	SL EL2
E_t EL0	80%	1349	1148	993
E_t EL1	82%	1316	1120	969
E_t EL2	90%	1225	1043	902
E_t EL3	92%	1199	1021	883
E_t EL4	95%	1163	989	856
E_t EL5	99%	1117	951	823

Table 5.5.8 Standby Loss Levels for Residential-Duty Gas-Fired Storage Water Heaters, 75 Gallon Rated Storage Volume, 76,000 Btu/h Input Capacity

Thermal Efficiency Level	Thermal Efficiency	Standby Loss (Btu/h)			
		SL EL0	SL EL1	SL EL2	SL EL3
E_t EL0	80%	1048	836	811	707
E_t EL1	82%	1022	816	791	690
E_t EL2	90%	624	503	-	-
E_t EL3	95%	624	503	-	-
E_t EL4	97%	624	503	-	-

Table 5.5.9 Standby Loss Levels for Electric Storage Water Heaters, 114 Gallon Measured Storage Volume

Thermal Efficiency	Standby Loss (Btu/h)		Standby Loss (%/h)	
	SL EL0	SL EL1	SL EL0	SL EL1
98%	353	298	0.54%	0.45%

Because DOE used heat loss calculations corresponding to commonly used technology options in addition to market standby loss data to inform the selection of standby loss levels, the most stringent analyzed standby loss level does not necessarily reflect the current market max-tech level for each equipment class. For some equipment thermal efficiency levels, the most stringent analyzed standby loss level may be less efficient than that of some rated units on the market, and for other levels, it may be more efficient. While there may not be units on the market with a rated standby loss as efficient as some of the examined standby loss levels, DOE has determined these levels would be achievable through various technology options, including, but not limited to, those DOE examined for this analysis. Several technology options with the potential to reduce standby loss that DOE did not analyze are discussed below.

- *Changing tank aspect ratio* can be used to decrease the standby loss of a storage water heater. Changing the aspect ratio of a cylinder changes the surface area/volume ratio, and therefore, the surface area for a given tank volume. For cylinders, the theoretical optimum height/diameter ratio for surface area reduction is 1:1. Therefore, for all tanks with aspect ratios higher than this, a decrease in tank aspect ratio should decrease the surface area of the tank, and therefore decrease the heat lost. However, such a change in aspect ratio may not always decrease the standby loss. In some equipment designs, the increase in diameter of the top of the tank resulting from a decrease in aspect ratio may counterbalance the heat lost from a smaller wall surface area because the hottest water in the tank is located at the top. Also, condensing storage water heaters typically use a higher aspect ratio than non-condensing water heaters to increase temperature stratification to allow for increased condensation at the bottom of the tank. Therefore, a decrease in aspect ratio may decrease the amount of flue gas that can be condensed, reducing thermal efficiency. For these reasons, DOE did not analyze a change in aspect ratio as an option for reducing standby loss.

- *Mechanical drafting* can be used to decrease the flue losses of a gas-fired storage water heater. In an induced draft design, the blower sits at the top of the flue tube and obstructs convection of heat out the flue tube when the water heater is in standby mode. DOE did not analyze the effect of mechanical drafting on standby loss for non-condensing storage water heaters because DOE determined that an equivalent standby loss reduction could be achieved using an electromechanical flue damper, as both serve to limit flue losses. DOE considered a flue damper as a technology option instead of mechanical draft for non-condensing storage water heaters because of the lower cost of flue dampers. DOE did consider standby loss reduction from mechanical draft systems in condensing storage water heaters, because mechanical drafting is required for condensing operation.

- *Improved insulation on the tank top and bottom* can decrease the shell losses of a storage water heater. Similarly to the tank walls, the tank top and bottom can be better insulated using alternative insulation types (sprayed PU foam instead of fiberglass), thicker insulation, or insulating a larger fraction of the area. The tank bottom cannot be insulated on some bottom-fired gas-fired storage water heaters with the burner located below the tank, though the combustion chamber insulation can be improved. More expensive ceramic insulation may be needed in close proximity to the burner. DOE did not consider insulation of the top or bottom of the tank as design options for reducing standby loss for gas-fired storage water heaters because different heat exchanger designs for condensing water heater require different designs of tank top and bottom. DOE did not want to require use of certain designs that manufacturers use to achieve condensing operation, and therefore did not consider top or bottom insulation. However, DOE did consider increasing the insulation thickness on the tank top and bottom for electric storage water heaters, for which the concerns regarding burner location and heat exchanger design do not apply.

- *Greater coverage of PU foam insulation* can be used to decrease the shell losses of a storage water heater. Most gas-fired and oil-fired storage water heaters insulated with PU foam still have a section of fiberglass insulation at the bottom of the tank, as well as fiberglass insulation around ports and valves. Maximizing the tank area insulated with PU foam will decrease the standby loss of the water heater. DOE did not analyze greater coverage of PU foam insulation as a technology option because tank designs vary in the number of ports and sensors that require uninsulated area. In addition, the need for fiberglass insulation will likely vary with the design of the water heater (*i.e.*, top-fired or bottom-fired). DOE does not want to require the use of certain designs to meet energy conservation standards and therefore did not consider greater coverage of PU foam.

- *Improved baffling* can decrease the flue losses of a gas-fired storage water heater by providing an air flow restriction. This restriction reduces convective heat losses through the flue pipes. DOE did not analyze the effect of improved baffling on standby loss because of a lack of sufficient data to develop an estimated standby loss reduction.

5.5.3 Calculation of Standby Loss Efficiency Levels

Because of the aforementioned variation of standby loss data in the AHRI Directory, DOE performed heat loss calculations to determine the reduction in standby loss corresponding to each design option. For each storage water heater equipment class analyzed, DOE estimated the standby loss of representative equipment (see section 5.4). For each equipment class, DOE calculated the maximum standby loss from the current standby loss standard equation. DOE then calculated the heat loss from the water heater using the baseline standby loss level, as identified in section 5.5.1. DOE then calculated the heat loss with the identified technology options implemented, and calculated the difference between heat loss of a water heater at the baseline and heat loss of a water heater with each technology option. This difference was subtracted from the maximum standby loss to yield the value (in Btu/h) for each standby loss level.

Heat loss from a water heater was calculated by dividing the water heater into six zones of equal height. Within each zone, the temperature was held constant. DOE used standby loss test data from tested commercial storage water heaters to approximate the water temperature within each zone. The same temperature data and tank dimensions were used for non-condensing and condensing gas-fired storage water heaters. The formula used to calculate the heat loss through the tank walls (Q_{wall}) is shown below, where A is the wall area for each zone (tank wall area divided by six), T_i is the constant water temperature for each zone (°F), T_{amb} is the ambient air temperature (74 °F), l is the insulation thickness (in), and R_i is the R-value of insulation covering each zone (°F·ft^2·h/(Btu·in)).

$$Q_{wall} = \sum_{i=1}^{6} \frac{A * (T_i - T_{amb})}{l * R_i}$$

For tank insulation, R-values used were 6.25 °F·ft^2·h/(Btu·in) for PU foam and 3.5 °F·ft^2·h/(Btu·in) for fiberglass. For gas-fired storage water heaters, DOE estimated that 10 percent of the water heater area was un-insulated (due to inlet and outlet water pipes, valves, cleanout hole, and condensing flue pipe outlets for some units). DOE research suggests that the lowest 5 inches of the tank wall is insulated with fiberglass regardless of the material used to insulate the rest of the tank (all torn-down gas-fired storage water heaters featured such a panel); therefore, DOE did not vary insulation in this area for its heat loss calculations. For electric storage water heaters, DOE estimated that 93 percent of the tank wall area was insulated.

To calculate the standby loss reduction from switching to electronic ignition from a standing pilot, DOE used a pilot consumption rate of 500 Btu/h and a standby electronic ignition consumption rate of 3W. The thermal efficiency of a pilot light was estimated to be equivalent to the burner thermal efficiency, based upon a 2013 NREL study.[3] Based on a 2008 LBNL study, an electromechanical flue damper was estimated to reduce the standby loss of a natural draft gas-fired water heater by 14 percent.[4] DOE believes that 14 percent is a conservative estimate of the standby loss reduction from a flue damper for several reasons. First, this reduction was measured for a residential gas-fired water heater rated at 40 gallons storage volume and 40,000 Btu/h input capacity. Because residential-duty and commercial storage water heaters have significantly larger diameters than 40-gallon residential water heaters, flue losses are relatively higher than shell losses in residential-duty and commercial storage water heaters due to the decreased surface area-to-volume ratio. Relatively higher flue losses would correspond to a higher standby loss reduction from a flue damper. In addition, many commercial storage water heaters have multiple vented flue pipes, meaning that there is significantly more opportunity for standby loss reduction from a flue damper. Another reason DOE believes this is a conservative estimate for standby loss reduction from a flue damper is that this study examined a buoyancy-operated damper on a water heater with a pilot. The buoyancy-operated damper had a gap in between "wings" and did not completely close on the sides, in order to vent flue gases from the pilot light. An electromechanical flue damper would be combined with an electronic ignition system on a storage water heater and would therefore provide a complete obstruction of the top of the flue, with no need to remain partially open to vent pilot flue gases.

DOE did not consider insulation of the top or bottom of the tank for heat loss calculations or standby loss levels for gas-fired storage water heaters. This is because different condensing water heater heat exchanger designs require different designs of tank top and bottom. DOE did not want to dictate the design that manufacturers use to achieve condensing operation, and therefore did not consider top or bottom insulation. Specifically, multi-pass heat exchangers require return plenums on the tank top and bottom through which flue gases are re-directed to a new set of flue tubes. Because these plenums contain flue gases, they reach high temperatures and cannot be insulated with PU foam. However, DOE encourages manufacturers to optimize the insulation of the top and bottom of all storage water heater designs to minimize standby loss. DOE did consider the top and bottom of the tank for electric storage water heaters. For the baseline and max-tech standby loss levels (corresponding to increased insulation thickness) for electric storage water heaters, DOE research suggests that the insulation thickness would be relatively uniform around the tank.

Condensing gas-fired storage water heaters typically have higher aspect ratios (*i.e.*, larger height, smaller diameter) than non-condensing gas-fired storage water heaters with the same volume in order to increase stratification of water temperature within the tank. This stratification allows for more effective condensation of flue gases near the bottom of the tank. However, this difference was not taken into account in the standby loss calculations because DOE chose not to include varying tank dimensions as a technology option for reducing standby loss. As discussed in section 5.5.2, DOE did not consider varying the tank aspect ratio as a technology option because such a technology option could restrict equipment designs that manufacturers might use to meet energy conservation standards.

As discussed above, standby loss for gas-fired and oil-fired storage water heaters is measured predominantly as a function of fuel flow used to heat the stored water during the standby loss test, with a small contribution of electric power consumption (if the unit requires a power supply). Because standby loss is calculated using the fuel consumed during the test to maintain the water temperature, the measured standby loss is dependent on the thermal efficiency of the water heater. As discussed in the NOPR, DOE proposed to include this dependence by multiplying the proposed standby loss standard by a factor corresponding to the proposed thermal efficiency standard, as opposed to including a thermal efficiency term in the standby loss equation. The factor corresponding to each thermal efficiency level was calculated using the thermal efficiency and the water heater electrical power consumption, because while the vast majority of standby loss is calculated based upon fuel flow and would therefore decrease with increasing thermal efficiency, a small fraction of the standby loss is due to standby electric consumption that is unaffected by thermal efficiency. DOE used data from independent testing of CWH equipment at a third-party laboratory to estimate the fraction of standby loss that can be attributed to fuel consumption or electric power consumption. However, for condensing thermal efficiency levels for residential-duty gas-fired storage water heaters, DOE did not include dependence on thermal efficiency in its standby loss levels. As discussed above in section 5.5.2, the most stringent standby loss level examined for condensing residential-duty gas-fired storage water heaters was the least-efficient level currently on the market for condensing residential-duty gas-fired storage water heaters. Because the examined level is currently met by all equipment at condensing thermal efficiency levels, DOE did not lower the stringency of the standby loss level for lower condensing thermal efficiency levels for residential-duty gas-fired storage water heaters. Reduction of standby loss due to thermal efficiency is discussed in more detail in section 5.11.

5.6 TEARDOWN ANALYSIS

To assemble BOMs and calculate the manufacturing costs of the different components in CWH equipment at various efficiency levels, DOE disassembled units into their source components and estimated the material, labor, depreciation, and overhead cost attributed to each component. DOE refers to this process as a "physical teardown", which starts with a unit as-shipped (*e.g.*, boxed, crated, on a pallet, etc.) and ends with all components having been disassembled and entered into the BOM. One alternative to the teardown method is to instead conduct price surveys to determine the production cost, but this price survey approach only provides insight into costs under the current standards, whereas the teardown approach provides insight into how products may change due to amended energy conservation standards.

A supplementary method, called a "catalog teardown," uses published manufacturer catalogs and supplementary component data to estimate the manufacturing cost of a unit that was not physically torn down. Bills of materials for catalog teardowns are generated by modifying the BOM of a similar unit that has been physically torn down to reflect major physical differences. These modifications are based on data taken from manufacturer specification sheets and supplementary component data.

The teardown analysis included a total of 11 physical teardowns and 21 catalog teardowns.

5.6.1 Selection of Units

When selecting units for teardown, DOE considered three main questions:

- What efficiency levels should be captured in the teardown analysis?
- Are there model lines on the market that capture all potential efficiency levels?
- Which of the available units are most representative of the marketplace?

In responding to these questions, DOE adopted the following criteria for selecting units for the teardown analysis:

- The selected equipment should span the full range of efficiency levels for each equipment class under consideration.
- The selected models should come primarily from manufacturers with large market share in that equipment class, although the highest efficiency models were chosen irrespective of manufacturer.
- The selected models should have non-efficiency related features that are the same or similar to features of other models in the same equipment class and for a range of efficiency levels.

DOE reviewed the CWH industry and identified models available to commercial consumers. DOE then applied the aforementioned criteria and selected baseline, intermediate, and max-tech units that met the equipment descriptions, energy efficiency levels, and included the common technology options identified during the market review and discussions with manufacturers. In several cases, DOE substituted a catalog teardown in the place of a physical teardown.

Using the data gathered from the physical teardowns, DOE characterized each component according to its weight, dimensions, material, quantity, and the manufacturing processes used to fabricate and assemble it. For supplementary catalog teardowns, DOE gathered equipment data such as dimensions, weight, and design features from publicly available manufacturer catalogs, installation manuals, or engineering specification sheets. DOE obtained information and data not typically found in catalogs and brochures from the physical teardowns of similar equipment or by estimations based on industry knowledge. DOE collected additional component information during manufacturer interviews.

DOE used physical teardowns of 11 water heaters and hot water supply boilers to develop its cost estimates for CWH equipment. These models included eight storage water heaters and three instantaneous water heaters and hot water supply boilers. Additionally, DOE used catalog teardowns of 21 water heaters and hot water supply boilers. Torn-down models were selected at varying efficiency levels.

5.6.2 Common Technologies Used at Each Efficiency Level

To determine common technology options manufacturers use to increase thermal efficiency of CWH equipment, DOE reviewed manufacturers' equipment literature and conducted physical and catalog teardowns for some of the models found at these efficiency levels. DOE also discussed with manufacturers the technologies that are typically implemented at each efficiency level. DOE lists the common technology options used by manufacturers to achieve each thermal efficiency level in Table 5.6.1 through Table 5.6.4 below.

Additional features and functionality that do not impact efficiency of CWH equipment are often used to address non-efficiency-related consumer demands (*e.g.*, related to comfort or noise when operating). DOE did not include the additional costs for options such as advanced building communication and control systems or powered anode rods that are included in many of the high-efficiency units currently on the market, as they do not improve efficiency but do add cost to the unit. Non-efficiency related features and functionality were hence equalized across units at all efficiency levels.

For example, modulating burners were not analyzed for storage water heaters (because they do not improve efficiency as measured by DOE's test procedure and are not found on baseline designs), but were included in the analysis of all gas-fired tankless water heaters and condensing hot water supply boilers (because they are found in these designs). Though many, but not all, hot water supply boilers come with recirculation pumps, DOE did not include such pumps in its engineering analysis because recirculation pumps are not always included in the baseline design, and because they do not improve the rated efficiency. Technologies that DOE identified and included in the analysis for each equipment class and thermal efficiency level are shown in Table 5.6.1 through Table 5.6.4.

Table 5.6.1 Technologies Identified at Each Thermal Efficiency Level for Commercial Gas-Fired Storage Water Heaters

Thermal Efficiency Level	Thermal Efficiency	Design Changes*
E_t EL0	80%	-
E_t EL1	82%	Increased heat exchanger area
E_t EL2	90%	Condensing heat exchanger, forced draft blower, premix burner
E_t EL3	92%	Condensing heat exchanger, forced draft blower, premix burner, increased heat exchanger surface area
E_t EL4	95%	Condensing heat exchanger, forced draft blower, premix burner, increased heat exchanger surface area
E_t EL5	99%	Condensing heat exchanger, forced draft blower, premix burner, increased heat exchanger surface area

* The condensing heat exchanger surface area incrementally increases at each EL from E_t EL2 to E_t EL5.

Table 5.6.2 Technologies Identified at Each Thermal Efficiency Level for Residential-Duty Gas-Fired Storage Water Heaters

Thermal Efficiency Level	Thermal Efficiency	Design Changes*
E_t EL0	80%	-
E_t EL1	82%	Increased heat exchanger area
E_t EL2	90%	Condensing heat exchanger, induced draft blower
E_t EL3	95%	Condensing heat exchanger, forced draft blower, premix burner, increased heat exchanger surface area
E_t EL4	97%	Condensing heat exchanger, forced draft blower, premix burner, increased heat exchanger surface area

* The condensing heat exchanger surface area incrementally increases at each EL from E_t EL2 to E_t EL4.

Table 5.6.3 Technologies Identified at Each Thermal Efficiency Level for Gas-Fired Tankless Water Heaters

Thermal Efficiency Level	Thermal Efficiency	Design Changes*
E_t EL0	80%	-
E_t EL1	82%	Increased heat exchanger area
E_t EL2	84%	Increased heat exchanger area
E_t EL3	92%	Secondary condensing heat exchanger
E_t EL4	94%	Secondary condensing heat exchanger, increased heat exchanger surface area
E_t EL5	96%	Secondary condensing heat exchanger, increased heat exchanger surface area

* The heat exchanger surface area incrementally increases at each EL from E_t EL0 to E_t EL2 and E_t EL3 to E_t EL5.

Table 5.6.4 Technologies Identified at Each Thermal Efficiency Level for Gas-Fired Hot Water Supply Boilers

Thermal Efficiency Level	Thermal Efficiency	Design Changes*
E_t EL0	80%	-
E_t EL1	82%	Increased heat exchanger area
E_t EL2	84%	Increased heat exchanger area, inducer blower
E_t EL3	92%	Condensing heat exchanger, forced draft blower, premix burner
E_t EL4	94%	Condensing heat exchanger, forced draft blower, premix burner, increased heat exchanger surface area
E_t EL5	96%	Condensing heat exchanger, forced draft blower, premix burner, increased heat exchanger surface area

* The heat exchanger surface area incrementally increases at each EL from E_t EL0 to E_t EL2 and E_t EL3 to E_t EL5.

The only significant design change for many efficiency levels is an increased heat exchanger surface area. Based upon heat exchanger calculations and feedback from manufacturer interviews, DOE used factors by which heat exchanger surface areas would need to grow to reach higher thermal efficiency levels for each thermal efficiency level and equipment class. These factors were higher for condensing efficiency levels than for non-condensing efficiency levels. As described in section 5.6.3, these factors were determined using a combination of manufacturer feedback and heat exchanger sizing calculations.

DOE based dimensions for its MPC estimates using published dimensions of units currently on the market for all equipment classes. For all equipment classes, DOE modeled that the tank or cabinet size would increase for significant increases in heat exchanger size. DOE based its estimates of how equipment accommodates increasing heat exchanger surface area/volume on the following methodology:

- Storage water heaters increase the tank diameter to accommodate displaced water.
- Tankless water heaters and non-condensing hot water supply boilers increase in width.
- Condensing hot water supply boilers do not increase in overall size if a limited number of additional coils are added because most condensing heat exchanger designs currently used on the market can accommodate a large variation in number of coils without expanding the cabinet.

Additionally, DOE research and manufacturer feedback suggest that the burner and control technology must change in some CWH equipment to achieve higher efficiencies.

- Commercial gas-fired storage water heaters require a power burner assembly (forced draft blower and premix burner) to reach all condensing thermal efficiency levels.
- Residential-duty gas-fired storage water heaters only need a power burner assembly at higher condensing levels (E_t EL3 and E_t EL4), and E_t EL2 (90 percent thermal efficiency) can be achieved with a baseline atmospheric burner when used with an induced draft blower.
- For all condensing gas-fired CWH equipment, DOE teardowns suggested the need for more sophisticated controls to control power burners and blowers.

DOE research identified two different heat exchanger designs used in condensing gas-fired storage water heaters: helical and multi-pass. In the helical design, the flue gases are forced through a helically-wound heat exchanger. The flue gases are then exhausted out the end of this tube. In the multi-pass design, the flue gases are forced through flue tubes that span the length of the tank multiple times. Typically the flue gases are re-directed back through the tank via return plenums located above and below the tank. A variety of tube diameters and baffles are typically used to facilitate heat transfer to the stored water. DOE used both of these designs to calculate its MPC estimates, calculating a weighted average cost based on manufacturer market shares.

DOE modeled different types of condensing heat exchangers for each equipment class. For condensing gas-fired storage water heaters, the most common heat exchanger material is glass enamel-coated hot-rolled steel. Manufacturer feedback suggested that the condensing heat exchanger flue tubes either need to be made of an inherently corrosion-resistant alloy (*i.e.*, cupronickel, stainless steel, etc.) or that they require corrosion-resistant coatings (*i.e.*, multiple coats of enamel) to protect the underlying material from the acidic condensate. DOE modeled these technologies and weighted the corresponding MPC estimates by market share.

For tankless gas-fired water heaters, most manufacturers use condensing secondary heat exchangers made of either stainless steel or corrosion-resistant aluminum alloys. Flue gases first pass through the primary heat exchanger, exchanging most of the sensible heat to the water, and then flow to the secondary heat exchanger. In the secondary heat exchanger, condensation of the flue gases begins, heating the incoming cold water through latent and sensible heat transfer. In condensing tankless gas-fired water heaters, DOE modeled secondary heat exchanger designs for both materials (*i.e.*, stainless steel and aluminum alloys) and used a weighted average by market share to calculate market-average MPC estimates.

For hot water supply boilers, most manufacturers use a single condensing stainless steel heat exchanger to achieve higher thermal efficiency levels. This heat exchanger typically consists of bundles of coils through which water flows and is heated by the passing flue gases.

Per the ASME Boiler and Pressure Vessel Code, ASME-rated construction is required for all CWH equipment that exceed any of the following criteria: 120 gallons in capacity, a water temperature of 210 °F, an operating water pressure of 150 psig, or an input rate of 200,000 Btu/h.[5] Most US states require that CWH equipment follow the ASME Boiler and Pressure Vessel Code, so DOE modeled ASME-rated production of tankless water heaters and hot water supply boilers because the examined representative input capacities for both groups on equipment are greater than 200,000 Btu/h. DOE used a 20% markup to MPC for increased costs of materials, labor, and inspection associated with ASME-rated construction. However, DOE did not apply this markup to the heat exchanger cost for condensing hot water supply boilers because most manufacturers purchase these condensing heat exchangers already certified with an ASME-rated construction stamp. DOE did not analyze ASME construction for storage water heaters because the representative equipment analyzed falls below the specified ASME input and volume criteria.

5.6.3 Heat Exchanger Sizing Calculations

To determine the additional heat exchanger area needed to achieve each thermal efficiency level, DOE used a combination of manufacturer feedback and results from heat exchanger sizing calculations. These calculations were based on data from equipment tear-downs, publicly-available equipment literature, and manufacturer feedback. For DOE's heat exchanger calculations, the following inputs were used:

- An ambient air temperature of 77 °F,
- 20% excess air for combustion,
- A flue gas dew point temperature of 140 °F, and
- An entering water temperature of 68 °F.

First, the combustion temperature was calculated using an energy balance. Heat exchanger areas needed for sensible heat transfer were calculated using the heat exchanger design equation, in terms of the log mean temperature difference (ΔT_{LM}, °F), heat transfer rate (Q, Btu/h), and overall heat transfer coefficient (U, Btu/(h·ft^2·°F)). DOE used the log mean temperature difference to approximate the heat transfer of the heat exchangers in CWH equipment.

$$Q = U * A * \Delta T_{LM}$$

Instead of deriving the overall heat transfer coefficient for each heat exchanger configuration and input rate, the heat exchanger area needed for each efficiency level was calculated relative to a torn-down "reference" unit. The heat exchanger areas for these reference units were calculated, so that the area needed for a modified heat exchanger with a different thermal efficiency level could be calculated based on the heat transferred and ΔT_{LM}. This scaling equation is shown below.

$$\frac{A_2}{A_1} = \left(\frac{Q_2}{Q_1}\right)\left(\frac{\Delta T_{LM,1}}{\Delta T_{LM,2}}\right)$$

For non-condensing water heaters, the exiting flue gas temperature was calculated using an energy balance shown in the equation below, where T_f and T_i are the final and initial flue gas temperatures (°F), HHV is the higher heating value of methane (Btu/lb), E_t is the thermal efficiency, $\dot{m}$ is the mass ratio of each compound (relative to lbs methane), and C_p is the heat capacity of each compound (Btu/(lb·°F)). The products of mass ratio and heat capacity were added for all compounds present in the flue gases in significant quantities – carbon dioxide, water vapor, and air.

$$T_f = T_i - \frac{HHV * E_t}{\sum_i \dot{m}_i * C_{p_i}}$$

The final flue gas temperature was calculated for each thermal efficiency level and used in the heat exchanger design equation to calculate the heat exchanger area required, relative to a torn-down reference unit with known heat exchanger area.

For condensing water heaters, the heat transferred as the flue gas temperature dropped from its temperature entering the heat exchanger (T_i, °F) to the dew point temperature (T_{DP}, °F) was calculated as sensible heat transfer. The terms for mass ratio and heat capacity ($\dot{m}$ and C_p, respectively) of each compound present in flue gases are explained above.

$$Q = (T_i - T_{DP}) * \sum_i \dot{m}_i * C_{p_i}$$

DOE then considered two different methods to calculate the final flue gas temperatures. In the first method, DOE modeled condensation occurring isothermally at the dew point temperature, after which sensible heat was transferred as the temperature dropped below the dew point temperature. In the second method, DOE used psychrometric properties to calculate the temperature that the flue gases would decrease to for the required amount of sensible and latent heat to be transferred as the flue gas temperature decreases.

In the first method, the total latent heat available was calculated as the difference between the higher and lower heating values of methane. The final flue gas temperature was calculated based on the sensible heat needed to reach the corresponding thermal efficiency, using a heat equation similar to the one above for heat transfer above the dew point temperature.

In the second method, the heat required to reach the corresponding thermal efficiency after cooling to the dew point temperature was subtracted from the enthalpy of the flue gas at the dew point temperature. This enthalpy was then input into a psychrometric calculator, which yielded the temperature at which the flue gas would have that enthalpy, or the final flue gas temperature.

In both methods, the heat exchanger design equation (in terms of ΔT_{LM}) was used to calculate the heat exchanger areas needed for sensible and latent heat transfer, relative to a torn-down reference unit with known heat exchanger area.

For the units DOE compared, the two methods yielded very similar results (less than 5% difference). Therefore, for simplicity of calculation, DOE applied the first method to all units, and used this method to scale the heat exchanger multiplier for condensing units, as described below.

From the first method, DOE calculated average heat exchanger area multipliers of 1.00657 per % increase in thermal efficiency for non-condensing water heaters and 1.01008 per % increase in thermal efficiency for condensing water heaters. These results show a 57% higher heat exchanger area multiplier needed for condensing water heaters over non-condensing water heaters. However, manufacturer feedback suggested that these multipliers were too low, and that 1.05 per % increase in thermal efficiency would be a more reasonable multiplier. DOE recognizes the limitations of theoretical calculations, and as a result DOE chose to use the multiplier suggested by manufacturers, which are based on performance of actual units.

DOE applied the 57% factor for condensing over non-condensing heat exchanger area, found from its calculations, to the multiplier from manufacturers, yielding 1.05 per % increase in thermal efficiency for non-condensing water heaters and 1.08 per % increase in thermal efficiency for condensing water heaters. DOE used these multipliers for all analyzed gas-fired CWH equipment classes. The heat exchanger size increases used for each equipment class are shown in Table 5.6.5 through Table 5.6.8. Heat exchanger area increases are shown separately for non-condensing and condensing equipment in each class to be consistent with DOE's analysis – areas calculated for condensing equipment were based off torn-down condensing equipment, not scaled up from non-condensing equipment.

Table 5.6.5 Heat Exchanger Area Increases for Commercial Gas-Fired Storage Water Heaters

Non-Condensing		Condensing	
Thermal Efficiency	% Increase in Heat Exchanger Area	Thermal Efficiency	% Increase in Heat Exchanger Area
80%	0%	90%	0%
82%	10%	92%	12%
		95%	38%
		99%	81%

Table 5.6.6 Heat Exchanger Area Increases for Residential-Duty Gas-Fired Storage Water Heaters

Non-Condensing		Condensing	
Thermal Efficiency	% Increase in Heat Exchanger Area	Thermal Efficiency	% Increase in Heat Exchanger Area
80%	0%	90%	0%
82%	10%	95%	39%
		97%	56%

Table 5.6.7 Heat Exchanger Area Increases for Gas-Fired Tankless Water Heaters

Non-Condensing		Condensing	
Thermal Efficiency	% Increase in Heat Exchanger Area	Thermal Efficiency	% Increase in Heat Exchanger Area
80%	0%	92%	0%
82%	11%	94%	15%
84%	22%	96%	33%

Table 5.6.8 Heat Exchanger Area Increases for Gas-Fired Hot Water Supply Boilers

Non-Condensing		Condensing	
Thermal Efficiency	% Increase in Heat Exchanger Area	Thermal Efficiency	% Increase in Heat Exchanger Area
80%	0%	92%	0%
82%	11%	94%	14%
84%	20%	96%	31%

5.7 COST ESTIMATES

5.7.1 Generation of Bills of Materials

During teardowns, every layer of the product is peeled back, cataloged, photographed, and examined. The bill of materials (BOM) captures every part, every value-added step, and the likely assembly order of components to accurately model the resources required to make a product.

The BOM incorporates all materials, components, and fasteners classified as either raw materials (*i.e.*, materials that are modified by the manufacturer from a basic state as part of a fabrication process) or purchased parts and assemblies, which the manufacturer simply assembles into a product. The designations as raw materials or purchased parts were based on DOE's previous industry experience, recent information in trade publications, and discussions with high- and low-volume original equipment manufacturers (OEMs). DOE also visited several manufacturing plants to reinforce its understanding of the industry's current manufacturing practices.

The BOM also categorizes the parts by sub-assembly, allowing comparisons between various suppliers by sub-assembly. Breaking out sub-assemblies in this manner also allows further analysis, such as the most likely cost for an out-sourced solution versus in-house production. The end result of each teardown is a structured BOM, which describes each equipment part and its relationship to the other parts in the estimated order in which the manufacturer would have assembled them.

The BOMs describe each fabrication and assembly operation in detail, including the type of equipment needed (*e.g.*, presses, drills), process cycle times, and labor associated with each manufacturing step. The result is a thorough and explicit model of the production process, including space, conveyor, equipment, and tooling requirements by planned production level. DOE developed structured BOMs for each of the physical and catalog teardowns.

The price of purchased parts is estimated based on volume-variable price quotations and detailed discussions with manufacturers and component suppliers. For fabricated parts, non-metal raw materials are based on the most current prices available to DOE. Metal prices are averaged over a 5-year period to reduce impacts of recent price fluctuations on the estimated MPC (see section 5.7.4.4).

5.7.2 Structure for Development of Cost Estimates

DOE estimated the cost of labor, materials, depreciation, and overhead for each part. To determine the costs, DOE followed one of two different paths, depending on whether a subassembly was purchased (out-sourced) or produced in-house. For purchased parts, DOE gathered price quotations from major suppliers at different production volumes. For parts produced in-house, DOE reconstructed manufacturing processes for each part based on internal expertise. For example, for an access panel, DOE deduced the time required for setup, handling, changeover, and punching holes, as well as the number of holes and hits. By repeating this process, DOE was able to assign labor time, equipment utilization, and other important factors to each subassembly in each of the units considered for this analysis. The last step was to convert the information into dollar values. To perform this task, DOE collected information on such factors as labor rates, tooling depreciation, and costs of purchased raw materials. DOE estimated the values for these parameters using internal expertise and feedback from manufacturers.

In sum, DOE assigned costs of labor, materials, and overhead to each part, whether purchased or produced in-house. DOE then aggregated single-part costs into major assemblies (*e.g.,* packaging, cabinet assembly, heat exchanger, burner system/gas train, exhaust subassembly, fan system, controls) and summarized these costs in a spreadsheet. DOE repeated this same process to calculate an MPC estimate for each unit in the engineering analysis, representing a specific efficiency level at the chosen capacity, and mapped the resulting cost-efficiency points to use as a basis for developing the cost-efficiency relationships.

During engineering interviews with manufacturers, DOE contractors typically share cost estimates of purchased parts, raw materials, and assemblies with manufacturers under non-disclosure agreements. Manufacturers provide feedback that is reviewed and, as appropriate, incorporated into the analysis.

5.7.3 Definitions for Development of Cost Estimates

As mentioned in previous sections, DOE used a bottom-up approach to develop cost estimates and divided factory costs into costs for materials, labor, depreciation, and overhead, as well the sub-categories listed in Table 5.7.1.

Table 5.7.1 Categories and Descriptions for Development of Cost Estimates

Major Category	Sub-Category	Description
Material Costs	Direct	Raw materials (*e.g.*, coils of sheet metal) and purchased parts (*e.g.*, fan motors, gas valves)
	Indirect	Material used during manufacturing (*e.g.*, welding rods, press die oil, release media)
Manufacturing Labor	Assembly	Part/unit assembly on manufacturing line
	Fabrication	Conversion of raw materials into parts ready for assembly
	Indirect	Fraction of overall labor not associated directly with product manufacturing (*e.g.*, forklift drivers, quality control)
	Supervisory	Labor required to supervise all other labor categories.
Depreciation	Equipment, Conveyor, Building	Straight line depreciation over expected life
	Tooling	Cost is allocated on a per-use basis or obsolescence, whichever results in a higher cost
Other Overhead	Utilities	A fixed fraction of all material costs meant to cover electricity and other utility costs
	Maintenance	Based on installed equipment and tooling investment
	Property Tax and Insurance	A fixed fraction based on total unit costs

5.7.4 Overview of Cost Estimate Development

As discussed in the previous section, manufacturer practices and cost structure play an important role in estimating the final equipment cost. Results varied among manufacturers, depending on market position, manufacturing practices, and manufacturing volume.

In converting physical information about the equipment into cost information, DOE reconstructed manufacturing processes for each component using internal expertise and knowledge of the methods used by the industry. For example, DOE re-creates all process steps needed to convert a piece of raw material into a finished part, ready for assembly. The requirements for manufacturing process equipment, labor, etc. are tallied and used to determine the most likely cost for the part prior to assembly.

DOE then summed the values of the components into assembly costs and, finally, the MPC. The MPC includes the material, labor, depreciation, and overhead costs associated with the manufacturing facility. DOE refined its labor and overhead cost estimates using information obtained during interviews with CWH equipment manufacturers. The next sections discuss fabrication estimates, production volumes, factory parameters, and material prices. The inputs into the analysis are aggregated to represent industry averages and to prevent the disclosure of business-sensitive information.

5.7.4.1 Fabrication Estimates

DOE characterized parts based on whether manufacturers purchased them from outside suppliers or fabricated them in-house. For purchased parts, DOE estimated the purchase price. For fabricated parts, DOE estimated the price of raw materials (*e.g.*, tube, sheet metal) and the cost of transforming them into finished parts. DOE bases its modeling of manufacturing operations on internal expertise, interviews with manufacturers, and visits to manufacturing facilities. Table 5.7.2 presents the major manufacturer processes identified and developed for the spreadsheet model. Fabrication process cycle times were estimated and entered into the BOM.

Table 5.7.2 Major Manufacturing Processes for CWH Equipment

Fabrication	Finishing	Assembly/Joining	Quality Control
Fixturing	Powder Coating	Adhesive Bonding	Inspection and Testing
Stamping/Pressing	De-Burring	Spot Welding	Water/gas leak testing
Turret Punch	Polishing	Packaging	
Tube Forming		Clinching	
Laser Cutting		Brazing	
Cutting and Shearing		Tig/Mig Welding	
Enameling		Lacing	
Manual Bending		Tube Expansion	
Foaming		Evacuation/ Fill	

Variability in the costs of purchased parts can account for large changes in the overall MPC estimates calculated. The purchased part prices used in this analysis were typical values based on estimated purchased part volumes and other factors. Some parts, such as inner steel tank tops and bottoms, may be produced in-house by some manufacturers and purchased by others. The choice between these options would result in changes to the calculated overall system costs. Manufacturer feedback was solicited on these costs and used to further calibrate the numbers prior to conducting the analyses to minimize the uncertainty caused by the variability in costs.

5.7.4.2 Production Volume Inputs for Cost Estimates

Manufacturer production volumes vary depending on several factors, including overall market size, individual company market share, the product or equipment produced, and whether the manufacturer produces other similar products or equipment that utilize the same materials and components. DOE based the production volumes it used for CWH equipment on industry knowledge and information gathered during manufacturer interviews.

DOE included in its estimates similar products or equipment that are manufactured by a manufacturer but not within the scope of this rulemaking (*e.g.*, large residential products) in determining its representative production volume estimates. The costs of tooling are also spread across a smaller number of units than are the costs of equipment. Therefore, separate production volumes were used for equipment and tooling. DOE's average production volume estimates for each equipment class are shown in Table 5.7.3.

Table 5.7.3 Production Volumes Used for MPC Estimates

Equipment Class	Equipment Production Volume	Tooling Production Volume
Commercial Gas-Fired Storage	22,500	5,500
Residential-Duty Gas-Fired Storage*	293,000	73,000
Gas-Fired Tankless*	1,000,000	250,000
Gas-Fired Hot Water Supply Boilers	50,000	16,500
Electric Storage	22,500	6,000

*Production volumes for residential-duty gas-fired storage water heaters and gas-fired tankless water heaters includes production of residential water heaters.

5.7.4.3 Factory Parameters

DOE used information gathered from publicly available literature, manufacturer interviews, and analysis of common industry practices to formulate industry-average factory parameters, which were reviewed by manufacturers, and revised as necessary. Table 5.7.4 lists DOE's estimates for factory parameters for manufacturers of CWH equipment.

Table 5.7.4 CWH Equipment Factory Parameters Used in Analysis

Parameter	Estimate
Work Days Per Year (days)	250
Assembly Shifts Per Day (shifts)	2
Fabrication Shifts Per Day (shifts)	2
Assembly Labor Wages ($/hr)	$16
Fabrication Labor Wages ($/hr)	$16
Length of Shift (hrs)	8
Average Equipment Installation Cost (% of purchase price)	10%
Fringe Benefits Ratio	50%
Indirect to Direct Labor Ratio	33%
Average Scrap Recovery Value	30%
Worker Downtime per shift	10%
Burdened Assembly Labor Wage ($/h)	$24
Burdened Fabrication Labor Wage ($/h)	$24
Supervisor Span (workers/supervisor)	25
Supervisor Wage Premium (over fabrication and assembly wage)	30%

5.7.4.4 Material Prices

DOE determined the cost of raw materials using publicly available information such as the American Metals Market[6], interviews with manufacturers, and discussions with material suppliers. The fabricated parts that DOE observed in its analysis of CWH equipment were predominantly made from raw metals, insulation, and plastic. To minimize the impact of large fluctuations in metal prices in recent years, DOE uses a 5-year average for its metal prices. Table 5.7.5 shows the 5-year average material metal prices DOE used for the analysis. Table 5.7.6 and Table 5.7.7 show current market price estimates for non-metal raw material inputs into the analysis.

Table 5.7.5 Five-Year Average Metal Material Prices (2010-2015)

Metal	Five Year Cost Avg. ($/lb 2/2010-1/2015)
Cold Rolled Steel (CRS)	$0.45
Hot Rolled Steel (HRS)	$0.39
Aluminized CRS	$0.55
Galvanized CRS	$0.54
Pre-Painted CRS	$0.68
Stainless Steel 409	$1.17
Stainless Steel 316	$2.49
Aluminum	$1.13
Copper	$3.65
HRS Tube	$0.65
CRS Tube	$0.83
SS316 Tube	$4.23
Plain Copper Tube, ≤0.75" OD	$4.25

Table 5.7.6 Plastics Raw Material Prices

Resin	Cost ($/lb) As of 1/2015
ABS	$1.16
ABS with Glass Fiber	$1.82
EPDM Rubber	$0.42
Polypropylene (PP)	$0.93
PP with Glass Fiber	$1.26
Polystyrene (PS)	$1.00
HDPE	$0.74
LDPE	$0.98
Styrofoam	$0.79
PVC (Hard)	$0.73
PVC (Flexible)	$0.68
High Temperature Silicone	$6.66
Silicone	$4.76
SBR Rubber (Buna)	$0.88

Table 5.7.7 Other Raw Material Prices

Material Description	Cost ($/lb) As of 1/2015
Plain Cardboard for Shipping	$0.50
2-Color Cardboard for Shipping	$0.72
Paper	$0.59
Wood for Shipping	$0.30
Fiberglass	$1.01
Foil Faced Fiberglass	$1.51
Flexible high-alumina ceramic (*i.e.*, "Fiberfrax")	$2.00
Molded high-alumina ceramic (*i.e.*, "Durafrax")	$3.48
Polyurethane Foam	$1.61
Glass Enamel	$1.35

5.7.5 Manufacturing Production Cost

DOE totaled the cost of materials, labor, depreciation, and overhead used to manufacture each analyzed model of CWH equipment in order to calculate the MPC. DOE used the cost estimates from teardowns on a market-share weighted average basis to determine the MPC increase to move from one efficiency level to the next for each equipment class.

The full cost of CWH equipment is broken down into two main costs: the full production cost or MPC, and the nonproduction cost. The nonproduction cost is equal to the manufacturer markup minus profits. The manufacturer markup is discussed further in section 5.9. Figure 5.7.1 shows the breakdown of production and non-production costs by sub-categories.

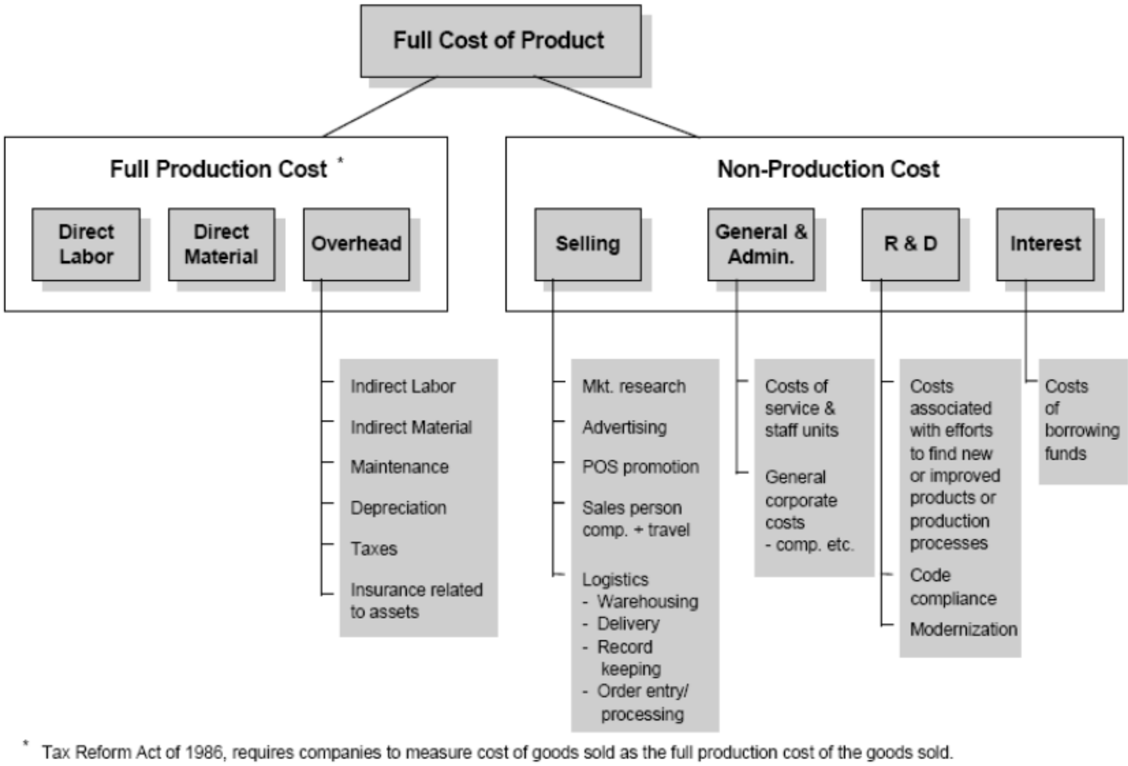

Figure 5.7.1 Breakdown of Costs Associated with Manufacturing CWH Equipment

5.8 COST VERSUS EFFICIENCY CURVES

One output of the engineering analysis is the cost-efficiency curves, which show the relationship between equipment cost and efficiency. In order to determine the increase in production cost at each efficiency level, DOE conducted a number of physical and catalog teardowns, as described previously in this document.

After calculating the MPC for each teardown, DOE constructed cost-efficiency curves that show the cost of increasing thermal efficiency from the baseline to intermediate and max-tech efficiency levels. The resulting MPCs from the physical and catalog teardowns of CWH equipment allowed DOE to develop cost versus efficiency curves for commercial gas-fired storage water heaters, residential-duty gas-fired storage water heaters, gas-fired tankless water heaters, and gas-fired hot water supply boilers, shown in Figure 5.8.1 through Figure 5.8.4. MPC estimates were calculated for electric storage water heaters at one standby loss level above baseline, but these costs are not shown graphically in a figure below. MPC and MSP estimates for all efficiency levels and equipment classes are shown in tables in section 5.10.

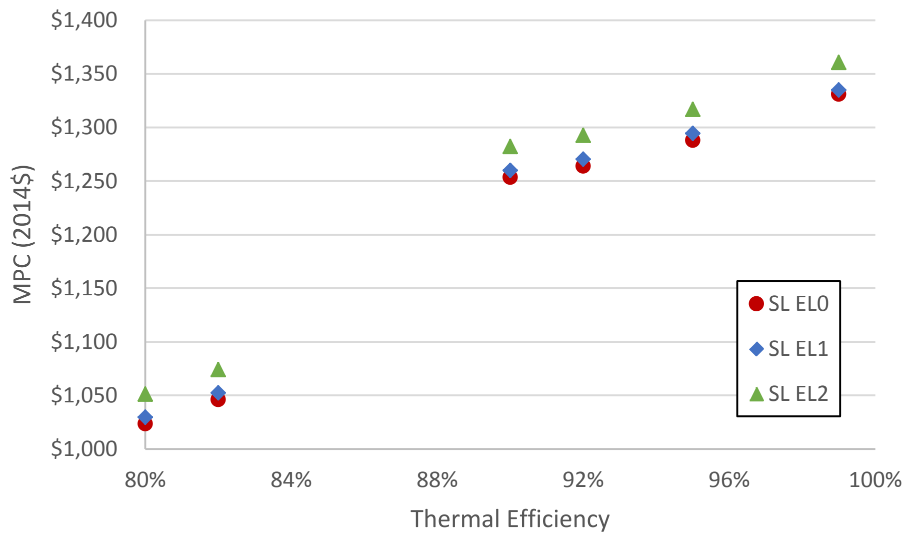

Figure 5.8.1 MPC (2014$) versus Thermal Efficiency for Commercial Gas-Fired Storage Water Heaters

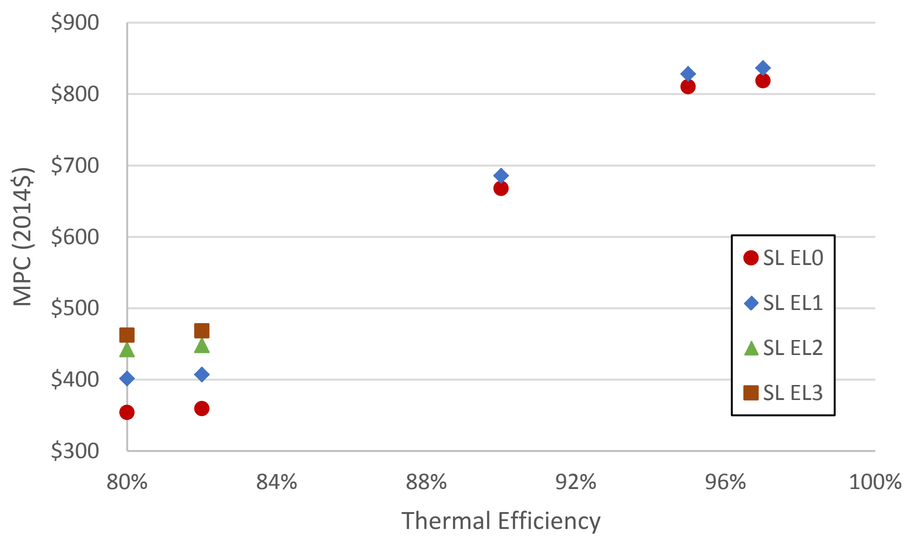

Figure 5.8.2 MPC (2014$) versus Thermal Efficiency for Residential-Duty Gas-Fired Storage Water Heaters

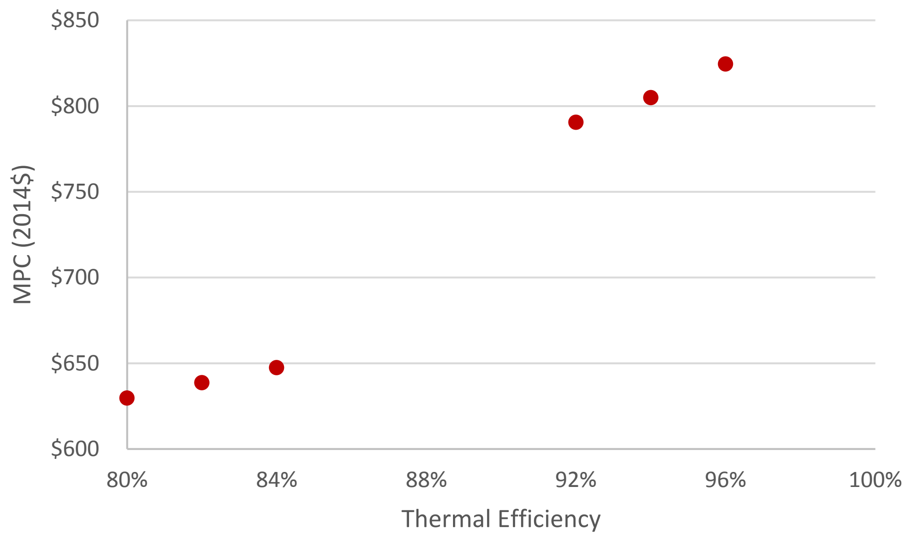

Figure 5.8.3 MPC (2014$) versus Thermal Efficiency for Gas-Fired Tankless Water Heaters

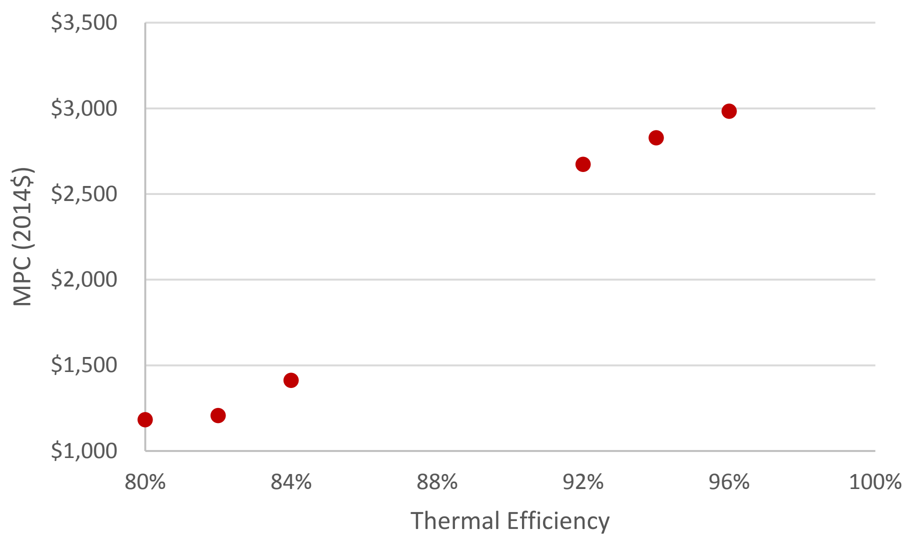

Figure 5.8.4 MPC (2014$) versus Thermal Efficiency for Gas-Fired Hot Water Supply Boilers

All cost-efficiency curves show an increase in cost with increasing efficiency. The slopes between points can be explained based on the technology options used to reach certain efficiency levels. The largest cost increases for each equipment class are seen for moving from non-condensing equipment to condensing equipment. However, there are significant cost increases within certain equipment classes that are not related to the transition from non-condensing to condensing operation.

For example, residential-duty gas-fired storage water heaters require a transition to power burners as thermal efficiency is increased from 90 to 95 percent. For hot water supply boilers, an inducer fan assembly is typically used to make the transition from 82 percent to 84 percent thermal efficiency. Additionally, for equipment operating within a given efficiency range (*i.e.*, non-condensing or condensing), the heat exchanger area is scaled to reflect higher or lower thermal efficiency requirements.

5.9 MANUFACTURER SELLING PRICE

A manufacturer markup is applied to the MPC of the product to arrive at the manufacturer selling price (MSP). In general, the manufacturer markup should ensure that the MSP of the product is high enough to recover the full cost of the product (*i.e.*, full production and nonproduction costs), and yield a satisfactory profit. The MSP is the price the manufacturer charges its first customer. DOE calculated the MSP for CWH equipment by multiplying the MPCs by the calculated manufacturer markup and adding equipment shipping costs, as explained below.

To meet new or amended energy conservation standards, manufacturers often introduce design changes to their product lines, to meet the minimum standards with the lowest increase in MPC. Depending on the competitive environment for these particular equipment classes, some or all of the increased production costs can be "passed through" to retailers and eventually to commercial consumers in the form of higher purchase prices. As the complexity of the goods increases, manufacturers also typically incur additional overhead at the factory and corporate levels. The MSP must cover both of these contributions to overhead if a company is to maintain profitability. As discussed previously, overhead costs in the DOE model are a function of investments, material costs, labor costs, or total costs, depending on the overhead category. Together, materials, labor, depreciation, and overhead make up the full production cost. DOE applies another multiplier to the full production cost to account for corporate nonproduction costs and profit. This multiplier, the nonproduction cost markup, is the focus of this section.

In this section, DOE presents its methodology for converting the MPCs to MSPs, which is done using the nonproduction cost markup ("manufacturer markup"). The manufacturer markup is an integral part of the overall markup, which also includes the markups in the distribution chain (*e.g.*, wholesalers, distributors, retailers, contractors). The distribution chain markups (discussed in chapter 6 of this TSD) convert MSP to commercial consumer price. The commercial consumer prices and installation costs are key inputs to the LCC and PBP analyses, and the NIA. Using manufacturer and distribution chain markups and installation costs, DOE can calculate the first costs that commercial consumers would face under each efficiency level. DOE evaluates the tradeoff between the increase in first cost and the resulting changes in operating costs at each efficiency level in the LCC and PBP analyses (chapter 8), and NIA (chapter 10).

The manufacturer markup also has an important bearing on profitability. A high markup under a standards scenario suggests manufacturers can pass through the increased variable costs and some of the capital and product conversion costs (one-time expenditures). A low markup implies that manufacturers will not be able to recover as much of the necessary investment in plant and equipment.

DOE analyzed the shipping cost (typically considered a nonproduction cost and included in the manufacturer markup) separately from the manufacturer markup for the NOPR analyses. DOE calculated the MSP by multiplying the MPC by the manufacturer markup, and then adding the shipping cost.

5.9.1 Manufacturer Markup

Applying a manufacturer markup to the MPC of the equipment is the first step to calculating the MSP. To remain a profitable business, manufacturers have to ensure that the MSP of the equipment is high enough to recover the full cost of the equipment (*i.e.*, full production and nonproduction costs), and generate a satisfactory profit.

DOE used U.S. Security and Exchange Commission (SEC) 10-K reports from publicly traded manufacturers of CWH equipment to estimate markups for the covered equipment. The law requires publicly owned companies to disclose financial information on a regular basis by filing forms with the SEC.[7] The SEC form 10-K, filed by companies annually, provides an overview of the company's business and financial conditions. The 10-K report includes the company's revenues and direct and indirect costs. The income statement section of the 10-K often lists the figures necessary for calculating the manufacturer markup—the net sales, costs of sales, and gross profit. DOE averaged the financial figures spanning the years 2008 to 2013 in order to calculate the markups for CWH equipment.

DOE acknowledges that there are numerous manufacturers of CWH equipment that are privately-held companies, which do not file SEC 10-K reports. In addition, while the publicly-owned companies file SEC 10-K reports, the financial information summarized may not be exclusively for the CWH portion of their business and can also include financial information from other product sectors, whose margins could be quite different from that of the CWH industry. DOE calculated a market-share weighted manufacturer markup to represent the industry. DOE applied this manufacturer markup to the MPC to arrive at a final manufacturer selling price. This industry wide markup was further calibrated based on feedback received during manufacturer interviews. Table 5.9.1 shows the industry-average manufacturer markups that DOE estimated for each CWH equipment class.

Table 5.9.1 Manufacturer Markups for CWH Equipment Classes

<table>
<tr><th colspan="2">Equipment Class</th><th>Markup</th></tr>
<tr><td colspan="2">Commercial gas-fired storage water heaters and gas-fired storage-type instantaneous water heaters</td><td>1.45</td></tr>
<tr><td colspan="2">Residential-duty gas-fired storage water heaters</td><td>1.45</td></tr>
<tr><td rowspan="2">Gas-fired instantaneous water heaters and hot water supply boilers</td><td>Tankless water heaters</td><td>1.43</td></tr>
<tr><td>Hot water supply boilers</td><td>1.43</td></tr>
<tr><td colspan="2">Electric storage water heaters</td><td>1.41</td></tr>
</table>

5.9.2 Shipping Costs

Manufacturers of HVAC equipment typically pay for shipping to the first step in the distribution chain. Freight is not a manufacturing cost; but because it is a substantial cost incurred by the manufacturer and can vary with equipment efficiency (due to changes in equipment size), DOE is accounting for shipping costs of CWH equipment separately from other non-production costs that comprise the manufacturer markup. To calculate the MSP for CWH equipment, DOE multiplied the MPC at each efficiency level by the manufacturer markup and added shipping costs for equipment at the given efficiency level.

Shipping costs for all classes of CWH equipment were determined based on the area of floor space occupied by the unit. CWH equipment units other than tankless water heaters are typically too tall to be double-stacked in a vertical fashion, and they cannot be shipped in any other orientation other than vertical. DOE research suggests that CWH equipment are usually shipped together in fully loaded trailers, rather than in less than truckload (LTL) configurations, where the CWH equipment only occupy a portion of the trailer volume. Therefore, shipping costs were calculated based on a full trailer.

To calculate these shipping costs, DOE calculated the cost per area of a trailer, based on the standard dimensions of a 53-foot trailer and an estimated 5-year average cost per shipping load that approximates the cost of shipping the equipment from the middle of the country to either coast. Next, DOE examined the market-weighted average sizes of equipment in each equipment class at each efficiency level and determined the number of units that would fit in a trailer. DOE then calculated the average shipping cost per unit using the cost per trailer load. DOE modeled that gas-fired tankless water heaters could be double-stacked, due to the smaller size and weight of units in this equipment class. Most tankless water heaters are manufactured overseas, and therefore costs of shipping a 40-foot container on both a cargo ship and a truck were included.

As discussed in section 5.5.2, DOE modeled taller and narrower tanks for condensing storage water heaters than for non-condensing storage water heaters, based on dimensions of models currently on the market. Because commercial and residential-duty storage water heaters cannot be stacked in shipping, an increase in height does not affect shipping costs, and therefore condensing storage water heaters have lower shipping costs than do non-condensing storage water heaters. Condensing hot water supply boilers occupy less floor space and therefore have lower shipping costs than do non-condensing hot water supply boilers, based on DOE's research of dimensions of models currently on the market.

Table 5.9.2 through Table 5.9.6 show the average shipping dimensions of CWH equipment that DOE calculated for each equipment class and efficiency level, and Table 5.9.7 through Table 5.9.11 show the shipping costs estimated by DOE for each equipment class. These values were used for calculating the MSP.

Table 5.9.2 Shipping Dimensions for Commercial Gas-Fired Storage Water Heaters

	Height (in)			Diameter (in)		
	SL EL0	SL EL1	SL EL2	SL EL0	SL EL1	SL EL2
Thermal Efficiency	1 in Fiber Glass	1 in PU Foam	2 in PU Foam	1 in Fiber Glass	1 in PU Foam	2 in PU Foam
80%	71.0	71.0	71.0	30.3	30.3	32.3
82%	71.0	71.0	71.0	30.8	30.8	32.8
90%	75.7	75.7	75.7	26.7	26.7	28.7
92%	75.7	75.7	75.7	26.8	26.8	28.8
95%	75.7	75.7	75.7	27.0	27.0	29.0
99%	75.7	75.7	75.7	27.6	27.4	29.6

Table 5.9.3 Shipping Dimensions for Residential-Duty Gas-Fired Storage Water Heaters

	Height (in)				Diameter (in)			
Thermal Efficiency	SL EL0	SL EL1	SL EL2	SL EL3	SL EL0	SL EL1	SL EL2	SL EL3
80%	59.6	59.6	59.6	59.6	25.5	27.5	27.5	29.5
82%	59.6	59.6	59.6	59.6	25.8	27.8	27.8	29.8
90%	68.2	68.2	-	-	22.6	24.6	-	-
95%	68.2	68.2	-	-	22.8	24.8	-	-
97%	68.2	68.2	-	-	22.8	24.8	-	-

Table 5.9.4 Shipping Dimensions for Gas-Fired Tankless Water Heaters

Thermal Efficiency	Height (in)	Width (in)	Depth (in)
80%	24.5	16.5	9.7
82%	24.5	18.0	9.7
84%	24.5	19.5	9.7
92%	26.9	21.9	10.3
94%	26.9	23.6	10.3
96%	26.9	26.1	10.3

Table 5.9.5 Shipping Dimensions for Gas-Fired Hot Water Supply Boilers

Thermal Efficiency	Height (in)	Width (in)	Depth (in)
80%	67.5	31.8	26.5
82%	67.5	33.3	26.5
84%	67.5	34.5	26.5
92%	38.3	25.0	31.5
94%	38.3	25.0	31.5
96%	38.3	25.0	31.5

Table 5.9.6 Shipping Dimensions for Electric Storage Water Heaters

	Height (in)		Diameter (in)	
Thermal Efficiency	SL EL0	SL EL1	SL EL0	SL EL1
98%	63.3	64.3	30.0	32.0

Table 5.9.7 Shipping Costs for Commercial Gas-Fired Storage Water Heaters

	Shipping Cost (2014$)		
Thermal Efficiency	SL EL0	SL EL1	SL EL2
80%	$55.34	$55.34	$59.03
82%	$59.03	$59.03	$59.03
90%	$52.09	$52.09	$55.34
92%	$52.09	$52.09	$55.34
95%	$52.09	$52.09	$55.34
99%	$52.09	$52.09	$55.34

Table 5.9.8 Shipping Costs for Residential-Duty Gas-Fired Storage Water Heaters

	Shipping Cost (2014$)			
Thermal Efficiency	SL EL0	SL EL1	SL EL2	SL EL3
80%	$26.83	$28.11	$28.11	$31.07
82%	$26.83	$29.52	$29.52	$31.07
90%	$23.61	$25.67	-	-
95%	$24.60	$25.67	-	-
97%	$24.60	$25.67	-	-

Table 5.9.9 Shipping Costs for Gas-Fired Tankless Water Heaters

Thermal Efficiency	Shipping Cost (2014$)
80%	$13.38
82%	$14.72
84%	$15.50
92%	$19.08
94%	$19.08
96%	$22.90

Table 5.9.10 Shipping Costs for Gas-Fired Hot Water Supply Boilers

Thermal Efficiency	Shipping Cost (2014$)
80%	$52.09
82%	$55.34
84%	$55.34
92%	$42.17
94%	$42.17
96%	$42.17

Table 5.9.11 Shipping Costs for Electric Storage Water Heaters

	Shipping Cost (2014$)	
Thermal Efficiency	**SL EL0**	**SL EL1**
98%	$55.34	$59.03

5.10 ENGINEERING ANALYSIS SUMMARY OF RESULTS

The results from the engineering analysis are used in the LCC analysis to determine prices to commercial consumers for CWH equipment. By applying the calculated manufacturer markup and shipping costs to the MPCs, DOE calculated the MSPs of the CWH equipment at the baseline and more efficient levels.

5.10.1 Summary of Results for Representative Models

Each of the MPCs and MSPs developed in the engineering analysis for the representative capacity are shown in Table 5.10.1 through Table 5.10.5. As described in section 5.9, the MSP for CWH equipment is calculated by multiplying the MPC by the manufacturer markup and then adding the shipping cost.

Table 5.10.1 MPC and MSP Estimates for Commercial Gas-Fired Storage Water Heaters, 100 Gallon Rated Storage Volume, 199,000 Btu/h Input Capacity

	MPC (2014$)			MSP (2014$)		
Thermal Efficiency	**SL EL0**	**SL EL1**	**SL EL2**	**SL EL0**	**SL EL1**	**SL EL2**
80%	$ 1,023.59	$1,029.70	$1,051.20	$1,539.55	$1,548.40	$1,583.27
82%	$ 1,046.14	$1,052.31	$1,074.10	$1,575.94	$1,584.89	$1,616.48
90%	$ 1,253.56	$1,259.97	$1,282.19	$1,869.75	$1,879.04	$1,914.53
92%	$ 1,263.93	$1,270.35	$1,292.63	$1,884.78	$1,894.09	$1,929.66
95%	$ 1,288.05	$1,294.51	$1,316.95	$1,919.77	$1,929.13	$1,964.93
99%	$ 1,331.09	$1,335.00	$1,360.66	$1,982.17	$1,987.84	$2,028.30

Table 5.10.2 MPC and MSP Estimates for Residential-Duty Gas-Fired Storage Water Heaters, 75 Gallon Rated Storage Volume, 76,000 Btu/h Input Capacity

	MPC (2014$)				MSP (2014$)			
Thermal Efficiency	**SL EL0**	**SL EL1**	**SL EL2**	**SL EL3**	**SL EL0**	**SL EL1**	**SL EL2**	**SL EL3**
80%	$354.00	$401.35	$441.95	$462.14	$540.13	$610.07	$668.94	$701.17
82%	$359.37	$407.06	$447.89	$468.18	$547.91	$619.76	$678.96	$709.94
90%	$667.75	$685.67	-	-	$991.86	$1,019.88	-	-
95%	$810.33	$828.15	-	-	$1,199.58	$1,226.48	-	-
97%	$818.60	$836.43	-	-	$1,211.57	$1,238.49	-	-

Table 5.10.3 MPC and MSP Estimates for Gas-Fired Tankless Water Heaters, 250,000 Btu/h Input Capacity

Thermal Efficiency	MPC (2014$)	MSP (2014$)
80%	$629.67	$913.81
82%	$638.62	$927.95
84%	$647.38	$941.25
92%	$790.45	$1,149.43
94%	$804.87	$1,170.05
96%	$824.45	$1,201.86

Table 5.10.4 MPC and MSP Estimates for Gas-Fired Hot Water Supply Boilers, 399,000 Btu/h Input Capacity

Thermal Efficiency	MPC (2014$)	MSP (2014$)
80%	$1,182.00	$1,742.35
82%	$1,205.56	$1,779.30
84%	$1,411.17	$2,073.31
92%	$2,671.86	$3,862.92
94%	$2,826.90	$4,084.63
96%	$2,981.94	$4,306.34

Table 5.10.5 MPC and MSP Estimates for Electric Storage Water Heaters, 114 Gallon Measured Storage Volume

	MPC (2014$)		MSP (2014$)	
Thermal Efficiency	SL EL0	SL EL1	SL EL0	SL EL1
98%	$854.25	$883.40	$1,259.83	$1,304.62

5.11 MAXIMUM STANDBY LOSS EQUATIONS

As part of the engineering analysis for commercial and residential-duty storage water heaters, DOE reviewed the maximum standby loss equations that define the existing Federal energy conservation standards for gas-fired and electric storage water heaters. The equations allow DOE to expand the analysis of the representative rated input capacity and storage volume to the full range of values covered under the existing Federal energy conservation standards.

DOE uses equations to characterize the relationship between rated input capacity, rated storage volume, and standby loss. The equations allow DOE to account for the increases in standby loss as input capacity (for gas-fired and oil-fired equipment) and tank volume increase. As the tank storage volume increases, the tank surface area increases. The larger surface area results in higher heat transfer rates that result in higher jacket losses. As the input capacity increases for gas-fired and oil-fired water heaters, the surface area of flue tubes may increase, providing additional area for heat loss through the flue tubes. The current equations show that the allowable standby loss increases as the rated storage volume and input rating (for gas-fired and oil-fired equipment) increase. The current form of the standby loss standard (in Btu/h) for commercial and residential-duty gas-fired and oil-fired water heaters is shown in the multivariable equation below, depending upon both rated input (Q, Btu/h) and rated storage volume (V_r, gal).

$$SL = \frac{Q}{800} + 110\sqrt{V_r}$$

The current form of the standby loss standard (in %/h) for electric storage water heaters is shown below, dependent only on measured storage volume (V_m, gal). Standby loss for electric storage water heaters is not dependent on input capacity because there are no flue tubes or heat exchangers, and a higher input capacity is typically met with a combination of either more heating elements or higher-power heating elements. Neither of these options for increasing input capacity of electric storage water heaters would increase the standby loss from the tank.

$$S = 0.3 + \frac{27}{V_m}$$

However, in the NOPR, DOE proposes to change its certification, compliance, and enforcement regulations to require the rated storage volume to equal the mean of the measured volumes in a sample, and to replace the measured storage volume with rated storage volume in the standby loss equation for electric storage water heaters. If these changes are ultimately adopted, the standby loss equation for electric storage water heaters would be based on rated storage volume, as shown below.

$$S = 0.3 + \frac{27}{V_r}$$

DOE has tentatively decided to modify the current maximum standby loss equations by multiplying the entire equations by a reduction factor. This reduction factor is the product of two multipliers: one that reduces the standard based upon thermal efficiency, and one that reduces the standard based upon heat loss calculations for standby loss-reducing technology options identified by DOE (see section 5.5.3). The multiplier based upon thermal efficiency uses the ratio of the proposed thermal efficiency level to the current thermal efficiency standard, and takes into account the portion (if any) of standby loss attributable to electric power consumption. The multiplier based upon heat loss calculations uses the ratio of standby loss at each standby loss efficiency level (at the baseline thermal efficiency level) to the current standby loss standard. However, as discussed in section 5.5.2, DOE used market standby loss data instead of heat loss calculations and thermal efficiency levels to develop standby loss reduction factors for condensing residential-duty gas-fired storage water heaters. Table 5.11.1 and Table 5.11.2 show the standby loss multipliers based upon thermal efficiency and heat loss, respectively. Table 5.11.3, Table 5.11.4, and Table 5.11.5 show the overall standby loss reduction factors for each equipment class and efficiency level. The overall reduction factors corresponding to the proposed TSL in the NOPR were multiplied by the current standby loss equations to yield the proposed maximum standby loss equations for each equipment class.

Table 5.11.1 Thermal Efficiency-Based Standby Loss Multipliers

	Equipment Class		
Thermal Efficiency Level	**Commercial Gas-Fired Storage**	**Residential-Duty Gas-Fired Storage**	**Electric Storage**
E_t EL0	1.00	1.00	1.00
E_t EL1	0.98	0.98	-
E_t EL2	0.91	*	-
E_t EL3	0.89	*	-
E_t EL4	0.86	*	-
E_t EL5	0.83	-	-

* Dependence on thermal efficiency was not included for the analyzed standby loss levels for condensing residential-duty water heaters, because the standby loss reduction factors for these levels were derived from market standby loss data in order to prevent including levels that reduce standby loss at the expense of thermal efficiency. The selection of these standby loss levels is discussed in greater detail in section 5.5.2.

Table 5.11.2 Heat Loss-Based Standby Loss Multipliers

	Standby Loss Efficiency Level			
Equipment Class	**SL EL0**	**SL EL1**	**SL EL2**	**SL EL3**
Commercial Gas-Fired Storage	1.00	0.85	0.74	-
Residential-Duty Gas-Fired Storage*	1.00	0.80	0.77	0.67
Electric Storage	1.00	0.84	-	-

* These factors only apply to non-condensing units, because the standby loss reduction factors for condensing levels for residential-duty gas-fired storage water heaters were derived from market standby loss data in order to prevent including levels that reduce standby loss at the expense of thermal efficiency. The selection of these standby loss levels is discussed in greater detail in section 5.5.2.

Table 5.11.3 Overall Standby Loss Reduction Factors for Commercial Gas-Fired Storage Water Heaters

Thermal Efficiency Level	Thermal Efficiency	Standby Loss Reduction Factor		
		SL EL0	**SL EL1**	**SL EL2**
E_t EL0	**80%**	1.00	0.85	0.74
E_t EL1	**82%**	0.98	0.83	0.72
E_t EL2	**90%**	0.91	0.77	0.67
E_t EL3	**92%**	0.89	0.76	0.65
E_t EL4	**95%**	0.86	0.73	0.63
E_t EL5	**99%**	0.83	0.70	0.61

Table 5.11.4 Overall Standby Loss Reduction Factors for Residential-Duty Gas-Fired Storage Water Heaters

Thermal Efficiency Level	Thermal Efficiency	Standby Loss Reduction Factor			
		SL EL0	SL EL1	SL EL2	SL EL3
E_t EL0	80%	1.00	0.80	0.77	0.67
E_t EL1	82%	0.98	0.78	0.76	0.66
E_t EL2	90%	0.60	0.48	-	-
E_t EL3	95%	0.60	0.48	-	-
E_t EL4	97%	0.60	0.48	-	-

Table 5.11.5 Overall Standby Loss Reduction Factors for Electric Storage Water Heaters

Thermal Efficiency	Standby Loss Reduction Factor	
	SL EL0	SL EL1
98%	1.00	0.84

5.12 CONVERSION OF STANDARDS TO UNIFORM ENERGY FACTOR

As part of the analysis in this rulemaking, DOE analyzed efficiency levels for residential-duty water heaters in terms of the thermal efficiency and standby loss metrics to which these equipment are currently rated. However, in a final rule for test procedures for residential water heaters and certain commercial water heaters published on July 11, 2014, DOE established that residential-duty water heaters would be covered by the new uniform energy factor (UEF) metric. 79 FR 40542, 40586. In a NOPR for residential water heaters and certain commercial water heaters published on April 14, 2015 ("April 2015 NOPR"), DOE proposed, among other things, conversion factors from thermal efficiency and standby loss to UEF for residential-duty water heaters. 80 FR 20116, 20143. In the NOPR, DOE converted its proposed standards for residential-duty gas-fired water heaters from thermal efficiency and standby loss to UEF using the following conversion factors proposed in the April 2015 NOPR for residential-duty water heaters for all four draw patterns: high, medium, low, and very small. *Id.* In the following equations, E_t is the thermal efficiency (%), SL is the standby loss (Btu/h), c_1 is a coefficient that varies with draw pattern (values of c_1 for each draw pattern are shown in Table 5.12.1), UEF_{WHAM} is the analytical UEF for residential-duty gas-fired storage water heaters based on a modified water heater analysis model (WHAM), and UEF is the overall UEF for residential-duty gas-fired storage water heaters.

$$UEF_{WHAM} = \frac{1}{\frac{1}{E_t} + c_1 * SL}$$

$$UEF = 0.1413 + 0.7300 * UEF_{WHAM}$$

Table 5.12.1 Coefficients for Conversion of Residential-Duty Water Heater Ratings to UEF by Draw Pattern

Draw Pattern	C_1
Very Small	3.575×10^{-3}
Low	9.408×10^{-4}
Medium	6.500×10^{-4}
High	4.256×10^{-4}

For residential-duty storage water heaters, DOE applied its proposed standby loss standard equation to each unit on the market, calculating the proposed maximum standby loss. The UEF was then calculated for each unit for each draw pattern using this proposed maximum standby loss and the proposed thermal efficiency level. Because the energy conservation standards proposed for residential-duty water heaters in the April 2015 NOPR were denominated in terms of UEF and had linear equations dependent only on rated volume, in this NOPR DOE developed UEF standard equations for residential-duty gas storage water heaters consistent with this equation format. 80 FR 20116, 20147 (April 14, 2015). A linear regression was performed between the rated volume of each unit and the calculated UEF for each unit, yielding a line of best-fit. Therefore, a line of best-fit was drawn relating UEF to rated volume for each of the four draw patterns. For each line of best-fit, the intercept was then decreased to translate the line down to pass through the point furthest below the line of best-fit (the point with the largest negative residual), creating a minimum line. DOE used these minimum lines as the proposed energy conservation standards in terms of the UEF metric for residential-duty water heaters in the NOPR.

Table 5.12.2 shows the UEF levels calculated for each combination of thermal efficiency level and standby loss level, using the conversion factors published in the April 2015 NOPR and presented above.

Table 5.12.2 UEF Levels Corresponding to Thermal Efficiency and Standby Loss Levels

Thermal Efficiency Level	Thermal Efficiency	Standby Loss Efficiency Level			
		SL EL0	SL EL1	SL EL2	SL EL3
E_t EL0	80%	0.57	0.60	0.60	0.61
E_t EL1	82%	0.58	0.61	0.61	0.62
E_t EL2	90%	0.67	0.69	-	-
E_t EL3	95%	0.69	0.72	-	-
E_t EL4	97%	0.70	0.73	-	-

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CHAPTER 6. MARKUPS ANALYSIS

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CHAPTER 6. MARKUPS ANALYSIS

6.1 INTRODUCTION

To carry out its analyses of markups for commercial water-heating equipment (CWH), the U.S. Department of Energy (DOE) determines the cost to the commercial consumer of baseline equipment and the cost of more efficient units the commercial consumer would purchase under new energy conservation standards. DOE calculates such costs based on engineering estimates of manufacturing costs plus appropriate markups for the various distribution channels of CWH equipment.

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

Generally, companies mark up the price of equipment to cover their business costs and profit margin. In financial statements, gross margin is the difference between the company revenue and the company cost of sales or cost of goods sold (CGS). The gross margin takes account of the expenses of companies in the distribution channel, including overhead costs (*e.g.*, sales, general, and administration); research and development (R&D) and interest expenses; depreciation; and taxes—and company profits. For sales of equipment to contribute positively to company cash flow, the equipment's markup must be greater than the corporate gross margin. Certain equipment could command lower or higher markups, depending on company expenses associated with that particular equipment and the degree of market competition.

6.2 DISTRIBUTION CHANNELS

The appropriate markups for determining commercial consumer equipment prices depend on the type of distribution channels through which the equipment moves from manufacturers to purchasers. In the case of CWH equipment, the fraction of shipments to commercial and residential applications depends on the equipment class. Thus, DOE calculates the markups separately for both commercial and residential applications of CWH equipment.

Within each application, two primary types of markets describe the way most equipment passes from the manufacturer to the commercial consumer: (1) CWH equipment installed in replacement markets or by new owners, and (2) CWH equipment installed in new construction. Distribution channels and their fraction of shipments vary between equipment classes for replacement and new construction markets.

Amongst the replacement distribution channels for CWH equipment, the manufacturer most often sells the equipment to a wholesaler, who in turn sells it to a mechanical contractor, who in turn sells it to the commercial consumer. The manufacturer may also utilize a manufacturer's representative to sell the equipment to a mechanical contractor, who then sells it to the commercial consumer. The manufacturer may sell the equipment to a retailer, who in turn may sell it to a mechanical contractor, who in turn sells it to a commercial consumer. Lastly, the retailer also may sell directly to the commercial consumer.

The new construction distribution channel for CWH equipment includes an additional link in the chain—the general contractor. Amongst the new construction distribution channels, the manufacturer most often sells the equipment to a wholesaler, who in turn sells it to a mechanical contractor, who in turn sells it to a general contractor, who then sells and installs the equipment as part of the commercial consumer's construction project. As is the case with the replacement market, new construction also has a distribution channel featuring a manufacturer's representative. The manufacturer uses a manufacturer's representative to sell the equipment to a mechanical contractor, who then sells it to a general contractor, who in turn sells and installs it in the commercial consumer's construction project. Lastly, the manufacturer may sell the equipment to a retailer, who in turn sells it to a general contractor, who then sells and installs it as part of the commercial consumer's construction project.

Manufacturers tend to sell large commercial equipment through partnered representatives who are specialized in the capability, performance and siting of the equipment, and have established strong ties with the clientele. The role of the manufacturer's representative is similar to the wholesaler in distribution channel. Even though the manufacturer's representative may receive a discount from the partnered manufacturers, the other market participants may redistribute the profit throughout the distribution channel. Because DOE does not have enough information at this point to estimate separate markups for manufacturer's representatives, DOE assumes that the manufacturer's representative markup is the same as the wholesaler markup.

In addition to these conventional distribution channels, DOE also considers two unique distribution channels that exist in both replacement and new construction markets. The first is when a manufacturer sells equipment to the commercial customer directly through a national account. This national account distribution channel is applicable when the commercial consumer orders customized CWH equipment directly from a manufacturer, or when the commercial consumer orders equipment in bulk. The second is when a manufacturer sells CWH equipment to a retailer, who in turn sells it to the commercial consumer. In these instances, installation is typically achieved by site personnel. Figure 6.2.1 illustrates the main distribution channels for CWH equipment.

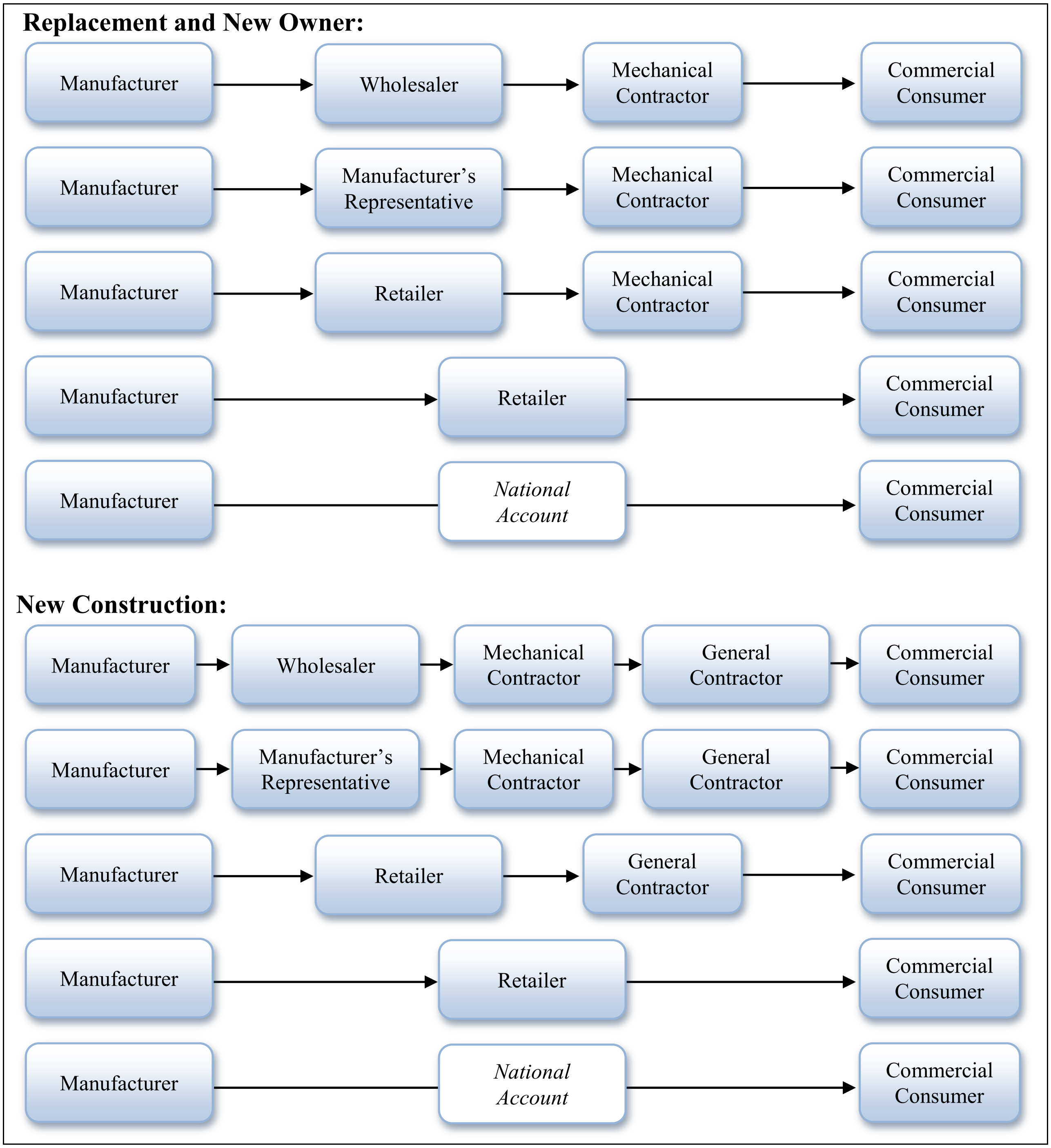

Figure 6.2.1 Distribution Channels for Commercial Water-Heating Equipment

6.3 APPROACH FOR MANUFACTURER MARKUP

DOE uses manufacturer markups to transform a manufacturer's production cost into the manufacturer selling price. The methodology used to derive manufacturer markups is described in detail in the engineering analysis, chapter 5 of this technical support document.

6.4 APPROACH FOR WHOLESALER, RETAILER AND CONTRACTOR MARKUPS

DOE examines how wholesaler, retailer, and contractor markups may change in response to changes in CWH equipment efficiency levels and other factors. Using available data, DOE estimates that there are differences between *incremental* markups on incremental costs of higher efficiency equipment and the *baseline* markup on direct business costs of equipment with baseline efficiency.

DOE derives wholesaler, retailer, and contractor markups from three key assumptions about the costs associated with CWH equipment. In general, DOE bases wholesaler markups on firm-level income statement data and derives retailer, general contractor, and mechanical contractor markups based on U.S. Census Bureau data. DOE obtained income statements about wholesalers from the Heating, Air-conditioning & Refrigeration Distributors International (HARDI) *2013 Profit Report* and about mechanical contractors from the Air Conditioning Contractors of America (ACCA) 2005 Financial Analysis for the HVACR Contracting Industry: 2005.[1,2] HARDI and ACCA are trade associations representing wholesalers and mechanical contractors, respectively. DOE used the financial data from the 2007 Economic Census of the United States for developing mechanical and general contractor markups and from the U.S. Census 2012 Annual Retail Trade Survey[3] for developing retail markups in the same form as the income statement data for wholesalers. These income statements break down the components of all costs incurred by firms that supply and install plumbing, heating and air-conditioning equipment.[a] The key assumptions used to estimate markups using these financial data are as follows:

1) The firm income statements faithfully represent the various average costs incurred by firms distributing and installing CWH equipment.

2) These costs can be divided into two categories: (1) costs that vary in proportion to the MSP of CWH equipment (variant costs), and (2) costs that do not vary with the MSP of CWH equipment (invariant costs).

3) Overall, wholesale, retail, and contractor prices for CWH equipment vary in proportion to the wholesaler, retailer, and contractor costs for CWH equipment included in the income statements.

In support of the first assumption, income statements itemize firm costs into a number of expense categories, including direct costs to purchase or install the equipment, operating labor and occupancy costs, and other operating costs and profit. Although wholesalers, retailers and contractors tend to handle multiple commodity lines, the data provide the most accurate available indication of expenses associated with CWH equipment.

Information obtained from the trade literature of selected heating, ventilating, and air-conditioning (HVAC) wholesalers, contractors, and consultants tends to support the second assumption about cost categories. The gathered information indicates that wholesale, retail, and contractor markups vary according to the quantity of labor and materials used to distribute, sell,

[a] The reports refer to wholesalers and mechanical contractors who handle multiple commodity lines.

and install the equipment. DOE assumes a division of costs between those that do not scale with the manufacturer price (labor and occupancy expenses) and those that do (operating expenses and profit).

In support of the third assumption, the CWH equipment wholesaler, retailer, and contractor industry is competitive, and commercial consumer demand for plumbing, heating, and air conditioning is inelastic, *i.e.,* the demand is not expected to decrease significantly with an increase in the price of equipment. The large number of firms listed in the 2007 Census indicates the competitive nature of this market. For example, there are more than 1,000 manufacturers of commercial machinery, 6,900 wholesalers of plumbing and heating equipment, 50,000 retailers of electronics and appliances, 170,000 general residential contractors, 36,000 commercial and institutional building contractors, and 91,000 plumbing, heating, and air-conditioning contractors listed in the 2007 Census.[4,5,6,7] Following standard economic theory, competitive firms facing inelastic demand either set prices in line with costs or quickly go out of business.[8]

DOE concluded that markups for more-efficient equipment are unlikely to be proportional to every direct cost. When the wholesaler's purchase price of equipment increases, for example, only a fraction of a business' expenses increases, while the remainder may stay relatively constant. For example, if the unit price of CWH equipment increases by 30 percent due to improved efficiency, it is unlikely that the cost of secretarial support in an administrative office will increase by 30 percent too. Therefore, DOE assumes that incremental markups cover only those costs that scale with a change in the MSP (variant costs).

6.4.1 Wholesaler Markups

In view of the above assumptions, DOE developed baseline and incremental markups for wholesalers using the firm income statement from the HARDI 2013 Profit Report (detailed wholesaler cost data in appendix 6A of this technical support document). The baseline markups cover wholesaler costs (both *invariant costs* and *variant costs*). In this instance, variant costs are defined as costs that likely vary in proportion to the change in MSP induced by increased efficiency standards; in contrast, invariant costs are defined as costs that are unlikely to vary in proportion to the change in MSP that is due to increased efficiency standards. DOE calculates the baseline markup for wholesalers using the following equation:

$$MU_{BASE} = \frac{CGS_{WHOLE} + GM_{WHOLE}}{CGS_{WHOLE}} = \frac{CGS_{WHOLE} + (IVC_{WHOLE} + VC_{WHOLE})}{CGS_{WHOLE}}$$

Eq. 6.1

Where:

MU_{BASE} = baseline wholesaler markup,
CGS_{WHOLE} = wholesaler cost of goods sold,
GM_{WHOLE} = wholesaler gross margin,
IVC_{WHOLE} = wholesaler invariant costs, and
VC_{WHOLE} = wholesaler variant costs.

Incremental markups are coefficients that relate the change in the MSP of more-energy-efficient models, or the equipment that meets the requirements of new energy conservation standards, to the change in the wholesaler sales price. Incremental markups cover only those costs that scale with a change in the MSP (variant costs, *VC*). DOE calculates the incremental markup (MU_{INCR}) for wholesalers using the following equation:

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

Eq. 6.2

Where:

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

6.4.2 Retail Markups

DOE based the retailer markups for CWH equipment on financial data for electronics and appliance stores from the 2012 U.S. Census Annual Retail Trade Survey, which includes industry-wide detailed operating expenses for that economic sector. DOE organized the financial data into statements that break down cost components incurred by firms within the economic sector.

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

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

Eq. 6.3

Where:

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

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

To estimate incremental retailer markups, DOE divides retailers' operating expenses into two categories: (1) those that do not change when CGS increases because of amended efficiency standards ("invariant"), and (2) those that increase proportionately with CGS ("variant"). DOE defines invariant costs as including labor and occupancy expenses because those costs likely will not increase as a result of a rise in CGS. All other expenses, as well as net profit, are assumed to vary in proportion to CGS.

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

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

Eq. 6.4

Where:

MU_{INC} = incremental retailer markup,
CGS_{RTL} = retailer cost of goods sold, and
VC_{RTL} = retailer variant costs.

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

6.4.3 Mechanical and General Contractor Markups

The type of financial data used to estimate markups for wholesalers is also available for mechanical contractors and general contractors from the 2007 Economic Census and ACCA 2005 Financial Analysis. To estimate mechanical contractor markups for CWH equipment, DOE collected financial data from the *Plumbing and HVAC Contractors* (NAICS 23822) series from the 2007 Economic Census and from ACCA 2005 Financial Analysis. To estimate general contractor markups for CWH equipment in commercial applications, DOE collected data from the 2007 Economic Census Commercial Building Construction series (NAICS 236220). To estimate general contractor markups for CWH equipment in residential applications, DOE collected data from the 2007 Economic Census Residential Building Construction series, which is the aggregation of *New Single-Family General Contractors* (NAICS 236115), *New Multifamily Housing Construction* (NAICS 236116), *New Housing Operative Builders* (NAICS 236117), and *Residential Remodelers* (NAICS 236118).

ACCA financial data provide gross margin (GM) as percent of sales for the mechanical contractor industry. For mechanical contractors, the baseline markup can be derived from the ACCA data with the following equation:

$$MU_{BASE} = \frac{Sales\ (\%)}{Sales\ (\%) - GM\ (\%)}$$

Eq. 6.5

The U.S. Census data include the number of establishments, payroll for construction workers, value of construction, cost of materials, and cost of subcontracted work at both state and national levels. DOE calculates the baseline markup for mechanical contractors and general contractors using the following equation:

$$MU_{BASE} = \frac{V_{CONSTRUCT}}{Pay + MatCost + SubCost}$$

Eq. 6.6

Where:

MU_{BASE} = baseline mechanical contractor or general contractor markup,
$V_{CONSTRUCT}$ = value of construction,
Pay = payroll for construction workers,
$MatCost$ = cost of materials, and
$SubCost$ = cost of subcontracted work.

Similarly, DOE estimates the incremental mechanical contractor and general contractor markups by marking up those costs that scale with a change in the MSP (variant costs, *VC*) for more-energy-efficient equipment. As stated previously, DOE assumes 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 categorizes the Census cost data in each major cost category and estimated markups using the following equation:

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

Eq. 6.7

Where:

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

6.5 DERIVATION OF MARKUPS

6.5.1 Manufacturer Markup

DOE used U.S. Security and Exchange Commission (SEC) 10-K reports covering the period from 2009 to 2013 from publicly owned CWH equipment manufacturing companies to estimate manufacturer markups. Table 6.5.1 presents manufacturer markups for the five different equipment classes considered in this analysis.

Table 6.5.1 Manufacturer Markups by Commercial Water-Heating Equipment Class

Equipment Class	Baseline Markup
Commercial Gas-Fired Storage Water Heater	1.45
Residential-Duty Gas-Fired Storage Water Heater	1.45
Commercial Gas-Fired Instantaneous Water Heater	1.43
Commercial Gas-Fired Instantaneous Hot Water Supply Boiler	1.43
Commercial Electric Storage Water Heater	1.43

6.5.2 Wholesaler Markup

Wholesalers reported median data in a confidential survey that HARDI conducted of member firms. In the survey, HARDI itemized revenues and costs into cost categories, including direct equipment expenses (cost of goods sold), labor expenses, occupancy expenses, other operating expenses, and profit. DOE presents these data in full in appendix 6A. Table 6.5.2 summarizes them at the notational aggregated level as cost-per-dollar sales revenue in the first data column. These wholesaler markups are applicable to CWH equipment in both commercial and residential applications.

Table 6.5.2 Wholesaler Expenses and Markups

Description	Per Dollar Sales Revenue *$*	Per Dollar Cost of Goods *$*
Direct Cost of Equipment Sales: Cost of goods sold	0.722	1.000
Labor Expenses: Salaries and benefits	0.165	0.229
Occupancy Expense: Rent, maintenance, and utilities	0.034	0.047
Other Operating Expenses: Depreciation, advertising, and insurance.	0.053	0.073
Operating Profit	0.026	0.036
Wholesaler Baseline Markup ($MU_{WHOLE\ BASE}$)		**1.385**
Incremental Markup ($MU_{WHOLE\ INCR}$)		**1.109**

Source: Heating, Air Conditioning & Refrigeration Distributors International. 2013 Profit Report (2012 Data). 2013. Air Conditioning & Plumbing Business Segment.

In this case, direct equipment expenses (cost of goods sold) represent about $0.72 per dollar sales revenue, so for every $1 wholesalers take in as sales revenue, $0.72 is used to pay the direct equipment costs. Labor expenses represent $0.165 per dollar sales revenue, occupancy expenses represent $0.034, other operating expenses represent $0.053, and profit accounts for $0.026 per dollar sales revenue.

DOE converted the expenses per dollar sales into expenses per dollar cost of goods sold, by dividing each figure in the first data column by $0.722 (*i.e.,* cost of goods sold per dollar of sales revenue). The data in the second column show that, for every $1.00 the wholesaler spends on equipment costs, the wholesaler allocates $0.229 to cover labor costs, $0.047 to cover occupancy expenses, $0.073 for other operating expenses, and $0.036 in profits. This totals to $1.385 in sales revenue earned for every $1.00 spent on equipment costs. Therefore, the wholesaler baseline markup ($MU_{WHOLE\ BASE}$) is 1.385 ($1.385 ÷ $1.00).

DOE also used the data in the second column to estimate the incremental markup. The incremental markup depends on which of the costs in Table 6.5.2 are variant and which are invariant with MSP. For example, for a $1.00 increase in the MSP, if all of the other costs scale with the MSP (*i.e.,* all costs are variant), the increase in wholesale price will be $1.385, implying that the incremental markup is 1.385, or the same as the baseline markup. At the other extreme, if none of the other costs are variant, then a $1.00 increase in the MSP will lead to a $1.00 increase in the wholesale price, for an incremental markup of 1.0. DOE believes that the labor and occupancy costs will be invariant and that the other operating costs and profit will scale with the MSP (*i.e.,* be variant). In this case, for a $1.00 increase in the MSP, the wholesale price will increase to match changes in "other" operating costs and operating profit of $0.079, which when divided by 72.2 cents in cost of goods sold yields an increase of $0.109, giving a wholesaler incremental markup ($MU_{WHOLE\ INCR}$) of 1.109. See appendix 6A for cost details.

6.5.3 Retailer Markups

DOE used financial data from the U.S. Census 2012 Annual Retail Trade Survey, in the "Electronics and Appliance Stores" category, to calculate markups used by retailers of CWH equipment.

Table 6.5.3 shows the data that DOE used and the retail markups for these appliances that DOE estimated following the method described in section 6.4.2. More detailed information regarding these values can be found in appendix 6A.

Table 6.5.3 Data Used to Calculate Retailer Markup

Item	*Million 2012$*	Per Dollar Sales Revenue *$*	Per Dollar COGS *$*
Sales (revenue)	102,998	1.000	1.393
Cost of Goods Sold (COGS)	73,946	0.718	1.000
Gross Margin (GM)	29,052	0.282	0.393
Non-Labor Scaling Costs	10,552	0.102	0.143
Baseline Markup ($MU_{RTL\ BASE}$)			**1.393**
Incremental Markup ($MU_{RTL\ INCR}$)			**1.143**

Source: U.S. Census Bureau. Annual Retail Trade Survey. Electronics and Appliances Stores. Sector 443. 2012.

In this case, direct equipment expenses (cost of goods sold) represent about $0.72 per dollar sales revenue, so for every $1 wholesalers take in as sales revenue, $0.72 is used to pay the direct equipment costs.

DOE converted the expenses per dollar sales into expenses per dollar cost of goods sold, by dividing each figure in the first data column by $0.718 (*i.e.*, cost of goods sold per dollar of sales revenue). The data indicate that for every $1.00 the retailer spends on costs, the retailer allocates $0.393 to cover labor costs, occupancy expenses, other operating expenses, and profits. This totals to $1.393 in sales revenue earned for every $1.00 spent on costs. Therefore, the retailer baseline markup ($MU_{RTL\ BASE}$) is 1.393 ($1.393 ÷ $1.00).

The incremental markup depends on which of the costs are variant and which are invariant with MSP. For example, for a $1.00 increase in the MSP, if all of the other costs scale with the MSP (*i.e.*, all costs are variant), the increase in retail price will be \$1.393, implying that the incremental markup is 1.393, or the same as the baseline markup. At the other extreme, if none of the other costs are variant, then a \$1.00 increase in the MSP will lead to a \$1.00 increase in the wholesale price, for an incremental markup of 1.0. DOE believes that the labor and occupancy costs will be invariant and that the other operating costs and profit will scale with the MSP (*i.e.*, be variant). In this case, for a \$1.00 increase in the MSP, the retail price will increase to match changes in "other" operating costs and operating profit of \$0.102, which when divided by \$0.718 in cost of goods sold yields an increase of \$0.143, giving a retailer incremental markup ($MU_{RTL\ INCR}$) of 1.143. See appendix 6A for cost details.

6.5.4 Mechanical Contractor Markups

6.5.4.1 Aggregate Markups for Mechanical Contractors

The 2007 Economic Census provides Geographic Area Series for the *Plumbing and HVAC Contractors* (NAICS 23822) sector, which contains national average sales and cost data, including value of construction, cost of subcontract work, cost of materials, and payroll for construction workers. It also provides the cost breakdown of gross margin, including labor expenses, occupancy expenses, other operating expenses, and profit. The gross margin provided by the U.S. Census is disaggregated enough that DOE is able to determine the invariant (labor and occupancy expenses) and variant (other operating expenses and profits) costs for this particular sector. DOE uses the aforementioned equation to estimate baseline and incremental markups. The markup results representing the plumbing and HVAC contractor industry at the national aggregated level are presented in Table 6.5.4. (Appendix 6A contains the full set of data.)

Table 6.5.4 Mechanical Contractor Expenses and Markups Based on Census Bureau Data

Description	Mechanical Contractor Expenses or Revenue	
	Per Dollar Sales Revenue *\$*	Per Dollar Cost of Goods *\$*
Direct Cost of Equipment Sales: Cost of goods sold	0.678	1.000
Labor Expenses: Salaries (indirect) and benefits	0.175	0.258
Occupancy Expense: Rent, maintenance, and utilities	0.022	0.032
Other Operating Expenses: Depreciation, advertising, and insurance.	0.086	0.127
Net Profit Before Taxes	0.039	0.058
Baseline Markup ($MU_{MECH\ CONT\ BASE}$): Revenue per dollar cost of goods		**1.474**
Incremental Markup ($MU_{MECH\ CONT\ INCR}$): Increased revenue per dollar increase in cost of goods sold		**1.184**

Source: U.S. Census Bureau. 2007. Plumbing, Heating, and Air-Conditioning Contractors. Sector 23: 238220. Construction: Industry Series, Preliminary Detailed Statistics for Establishments, 2007.

The first data column in Table 6.5.4 provides the cost of goods sold and a list of gross margin components as expenses per dollar of sales revenue. As shown in the table, the direct cost of sales represents about \$0.68 per dollar sales revenue to the mechanical contractor, and the gross margin totals \$0.32 per dollar sales revenue. DOE converted these expenses per dollar sales into revenue per dollar cost of goods sold by dividing each figure in the first data column by \$0.68. For every \$1.00 the mechanical contractor spends on equipment costs, the mechanical contractor earns \$1.00 in sales revenue to cover the equipment cost and \$0.47 to cover the other costs. This totals \$1.474 in sales revenue earned for every \$1.00 spent on equipment costs. This is equivalent to a baseline markup ($MU_{MECH\ CONT\ BASE}$) of 1.474 for mechanical contractors.

DOE was also able to use the data in the second column of Table 6.5.4 to estimate the incremental markups, after classifying the costs as either invariant or variant. At one extreme, if all of the other costs scale with the equipment price (*i.e.,* all costs are variant), the increase in general contractor price will be \$1.474, implying that the incremental markup is 1.474 or the same as the baseline markup. At the other extreme, if none of the other costs are variant, then a \$1.00 increase in the equipment price will lead to a \$1.00 increase in the general contractor price, for an incremental markup of 1.0. DOE believes that the labor and occupancy costs are invariant and the other operating costs and profit scale with the equipment price (*i.e.,* are variant). In this case, for a \$1.00 increase in the equipment price, the general contractor price will increase by \$1.184, giving a general contractor incremental markup ($MU_{MECH\ CONT\ INCR}$) of 1.184.

6.5.4.2 Markups for Mechanical Contractors in the Replacement and New Construction Markets

DOE derived the baseline and incremental markups for both replacement and new construction markets using the 2007 Economic Census industrial cost data supplemented with the most recent ACCA 2005 financial data.[9,2] The 2007 Economic Census provides sufficient detailed cost breakdown for the *Plumbing and HVAC Contractors* (NAICS 23822) sector so that DOE is able to estimate baseline and incremental markups for mechanical contractors. However, the 2007 Economic Census does not separate the mechanical contractor market into replacement and new construction markets. In order to calculate markups for these two markets, DOE utilized 2005 ACCA financial data, which reports gross margin data for the entire mechanical contractor market and for both the replacement and new construction markets.

The HVAC contractors, defined here as mechanical contractors, reported median cost data in an ACCA 2005 financial analysis of the HVAC industry. These data are shown in Table 6.5.5.

Table 6.5.5 Baseline Markup, All Mechanical Contractors

Description	Contractor Expenses or Revenue	
	Per Dollar Sales Revenue *\$*	**Per Dollar Cost of Goods *\$***
Direct Cost of Equipment Sales: Cost of goods sold	0.729	1.00
Gross Margin: Labor, occupancy, operating expenses, and profit	0.271	0.372
Revenue: Baseline revenue earned per dollar cost of goods		**1.372**
Baseline Markup ($MU_{MECH\ CONT\ BASE}$)		**1.372**

Source: Air Conditioning Contractors of America. Financial Analysis for the HVACR Contracting Industry. 2005.

Table 6.5.6 summarizes the gross margin and resulting baseline markup data for all mechanical contractors that serve the replacement and new construction markets.

Table 6.5.6 Baseline Markups for the Replacement and New Construction Markets, All Mechanical Contractors

Description	Contractor Expenses or Revenue by Market Type			
	Replacement		New Construction	
	Per Dollar Sales Revenue *$*	Per Dollar Cost of Goods *$*	Per Dollar Sales Revenue *$*	Per Dollar Cost of Goods *$*
Direct Cost of Equipment Sales: Cost of goods sold	0.703	1.000	0.745	1.000
Gross Margin: Labor, occupancy, operating expenses, and profit	0.297	0.422	0.255	0.342
Baseline Markup ($MU_{MECH\ CONT\ BASE}$): Revenue per dollar cost of goods	NA	**1.422**	NA	**1.342**
% Difference from Aggregate Mechanical Contractor Baseline MU	NA	**+3.63%**	NA	**-2.20%**

Source: Air Conditioning Contractors of America. 2005. Financial Analysis for the HVACR Contracting Industry.

Using the baseline markup data from Table 6.5.6 and results from Table 6.5.5, DOE calculated that the baseline markups for the replacement and new construction markets are 3.63 percent higher and 2.20 percent lower, respectively, than for all mechanical contractors serving all markets.

The markup deviations (*i.e.,* 3.63-percent higher and 2.20 percent lower for the replacement and new construction markets, respectively) derived for all mechanical contractors were then applied to the baseline markup of 1.48 and the incremental markup of 1.18 estimated for the *Plumbing and HVAC Contractors* (NAICS 23822) sector in Table 6.5.4. DOE assumes that this deviation applies equally to the baseline and incremental markups calculated from the 2007 Economic Census. The results of the baseline and incremental markups for the replacement and new construction markets served by mechanical contractors are shown in Table 6.5.7.

Table 6.5.7 Markups for the Replacement and New Construction Markets

Market Type	Baseline Markup	Incremental Markup
Replacement Market	1.53	1.22
New Construction Market	1.44	1.16

6.5.5 General Contractor Markups

DOE derived markups for general contractors from U.S. Census Bureau data for the commercial building construction and residential building construction sectors to reflect the commercial and residential application of CWH equipment.[10] The commercial construction sector includes establishments primarily responsible for the construction of commercial and institutional buildings, whereas the residential construction sector includes establishments primarily engaged in construction work, including new construction work, additions, alterations, and repairs of residential buildings.[11] The U.S. Census Bureau data for the construction sector include detailed statistics for establishments with payrolls, similar to the data reported by HARDI for wholesalers. The primary difference is that the U.S. Census Bureau reports itemize revenues and expenses for the construction industry as a whole in total dollars rather than in typical values for an average or representative business. Because of this, DOE assumes that the total dollar values that the U.S. Census Bureau reports, once converted to a percentage basis, represent revenues and expenses for an average or typical contracting business. Similar to the data for wholesalers, Table 6.5.8 summarizes the expenses for general contractors in commercial building construction at the national aggregated level as expenses per dollar sales revenue in the first data column. (See appendix 6A for a table that contains the full set of data.)

Table 6.5.8 Commercial Building General Contractor Expenses and Markups

Description	Wholesale Firm Expenses or Revenue	
	Per Dollar Sales Revenue ***$***	**Per Dollar Cost of Goods** ***$***
Direct Cost of Equipment Sales: Cost of goods sold	0.76	1
Labor Expenses: Salaries (indirect) and benefits	0.08	0.10
Occupancy Expense: Rent, maintenance, and utilities	0.01	0.01
Other Operating Expenses: Depreciation, advertising, and insurance.	0.03	0.04
Net Profit Before Taxes	0.12	0.15
Baseline Markup (*$MU_{COMM\ GEN\ CONT\ BASE}$*): Revenue per dollar cost of goods		**1.31**
Incremental Markup (*$MU_{COMM\ GEN\ CONT\ INCR}$*): Increased revenue per dollar increase cost of goods sold		**1.19**

Source: U.S. Census Bureau. Sector 236220 (Commercial Building Construction). Construction: Industry Series: Preliminary Detailed Statistics for Establishments: 2007. 2007.

As shown in the first column, the direct cost of sales represents about $0.76 per dollar sales revenue to the general contractor. Labor expenses represent $0.08 per dollar sales revenue, occupancy expenses represent $0.01 per dollar sales revenue, other operating expenses represent $0.03, and profit makes up $0.12 per dollar sales revenue.

DOE converted these expenses per dollar sales into revenue per dollar cost of goods sold, by dividing each figure in the first data column by $0.76. The data in column two show that, for every $1.00 the general contractor spends on equipment costs, the general contractor earns $1.00 in sales revenue to cover the equipment cost, $0.10 to cover labor costs, $0.01 to cover occupancy expenses, $0.04 for other operating expenses, and $0.15 in profits. This totals $1.31 in sales revenue earned for every $1.00 spent on equipment costs. Thus, the commercial building general contractor baseline markup ($MU_{COMM\ GEN\ CONT\ BASE}$) is 1.31.

DOE was also able to use the data in column two of Table 6.5.8 to estimate the incremental markups, after classifying the costs as either invariant or variant. At one extreme, if all of the other costs scale with the equipment price (*i.e.*, all costs are variant), the increase in general contractor price will be $1.31, implying that the incremental markup is 1.31, or the same as the baseline markup. At the other extreme, if none of the other costs are variant, then a $1.00 increase in the equipment price will lead to a $1.00 increase in the general contractor price, for an incremental markup of 1.0. DOE believes that the labor and occupancy costs are invariant, while the other operating costs and profit scale with the equipment price (*i.e.,* are variant). In this case, for a $1.00 increase in the equipment price, the general contractor price will increase by

$1.19, giving a commercial building general contractor incremental markup ($MU_{COMM\ GEN\ CONT\ INCR}$) of 1.19.

Table 6.5.9 summarizes the expenses for general contractors in residential building construction at the national aggregated level as expenses per dollar sales revenue in the first data column. (See appendix 6A for a table that contains the full set of data.)

Table 6.5.9 Residential Building General Contractor Expenses and Markups

Description	General Contractor Expenses or Revenue	
	Per Dollar Sales Revenue $	Per Dollar Cost of Goods $
Direct Cost of Equipment Sales: Cost of goods sold	0.68	1.00
Labor Expenses: Salaries (indirect) and benefits	0.08	0.12
Occupancy Expense: Rent, maintenance, and utilities	0.01	0.01
Other Operating Expenses: Depreciation, advertising, and insurance.	0.06	0.09
Net Profit Before Taxes	0.17	0.25
Baseline Markup ($MU_{RES\ GEN\ CONT\ BASE}$): Revenue per dollar cost of goods		**1.47**
Incremental Markup ($MU_{RES\ GEN\ CONT\ INCR}$): Increased revenue per dollar increase in cost of goods sold		**1.34**

Source: U.S. Census Bureau. Residential Building Construction. Sector 23: 236115-236118. Construction: Industry Series: Preliminary Detailed Statistics for Establishments: 2007. 2007.

As shown in the first column, the direct cost of sales represents about $0.68 per dollar sales revenue to the general contractor. Labor expenses represent $0.08 per dollar sales revenue, occupancy expenses represent $0.01 per dollar sales revenue, other operating expenses represent $0.06, and profit makes up $0.17 per dollar sales revenue.

DOE converted the expenses per dollar sales into revenue per dollar cost of goods sold, by dividing each figure in the first data column by $0.68. The data in the second column show that, for every $1.00 the general contractor spends on equipment costs, the general contractor earns $1.00 in sales revenue to cover the equipment cost, $0.12 to cover labor costs, $0.01 to cover occupancy expenses, $0.09 for other operating expenses, and $0.25 in profits. This totals $1.47 in sales revenue earned for every $1.00 spent on equipment costs. Thus, the residential building general contractor baseline markup ($MU_{RES\ GEN\ CONT\ BASE}$) is 1.47.

DOE was also able to use the data in the second column in Table 6.5.9 to estimate the incremental markups, after classifying the costs as either invariant or variant. At one extreme, if all of the other costs scale with the equipment price (*i.e.,* all costs are variant), the increase in general contractor price will be $1.47, implying that the incremental markup is 1.47, or the same as the baseline markup. At the other extreme, if none of the other costs are variant, then a $1.00 increase in the equipment price will lead to a $1.00 increase in the general contractor price, for an incremental markup of 1.0. DOE believes that the labor and occupancy costs are invariant while the other operating costs and profit scale with the equipment price (*i.e.,* are variant). In this case, for a $1.00 increase in the equipment price, the general contractor price will increase by $1.34, giving a general contractor incremental markup ($MU_{RES\ GEN\ CONT\ INCR}$) of 1.34.

6.6 DERIVATION OF REGIONAL MARKUPS

In this analysis, DOE considers five different CWH equipment classes. DOE assumed a market saturation rate for each equipment class, which varies by geographical region that is defined by the Commercial Building Energy Consumption Survey (CBECS), and Residential Energy Consumption Survey (RECS), and is based on the population projection for the year of 2013.[12,13] Therefore, regional markups are calculated for each CWH equipment class in both commercial and residential applications.

Wholesalers, mechanical contractors and general contractors in the CWH equipment industry are divided into the nine Census Divisions provided by the latest CBECS for the commercial building survey and also are divided into the 27 Reportable Domains provided by the latest RECS for the residential application. Regional baseline and incremental markups are derived using the region/state level data from the 2013 HARDI Profit Report and the 2007 Economic Census.

6.6.1 Estimation of Wholesaler Markups

The regional income statements from the 2013 HARDI Profit Report represent data collected for all HARDI business segments for the corresponding regions. DOE's wholesaler baseline and incremental markups for the United States were developed from the Air Conditioning and Plumbing business segment as this segment better represents CWH equipment wholesalers. To account for the data discrepancy between the national data for the Air Conditioning and Plumbing segment and regional data for all business segments, DOE adjusted the baseline and incremental markups for the seven HARDI regions (Northeastern, Mid-Atlantic, Southwestern, Great Lakes, Central, Southwestern, and Western) by using the ratio of the national Air Conditioning & Plumbing segment baseline and incremental markups to the national all business segment baseline and incremental markups. Then, these baseline and incremental ratios were applied to each region's baseline and incremental markup for all business segments to determine the estimated Air Conditioning and Plumbing baseline and incremental markups for each region. The results are shown in Table 6.6.1 and Table 6.6.2.

Table 6.6.1 Wholesaler Expenses and Markups for All Business Segments

Description	Per Dollar Sales Revenue *$*	Per Dollar Cost of Goods *$*
Direct Cost of Equipment Sales: Cost of goods sold	0.739	1.000
Labor Expenses: Salaries and benefits	0.151	0.204
Occupancy Expense: Rent, maintenance, and utilities	0.035	0.047
Other Operating Expenses: Depreciation, advertising, and insurance.	0.052	0.070
Operating Profit	0.023	0.031
Wholesaler Baseline Markup—All Business Segments		**1.353**
Incremental Markup—All Business Segments		**1.101**

Source: Heating, Air Conditioning & Refrigeration Distributors International. 2013 Profit Report (2012 Data). 2013.

Table 6.6.2 Ratios of Wholesaler Markups for the Air Conditioning and Plumbing Segment to the Wholesaler Markups for All Business Segments

Description	Baseline Markup	Incremental Markup
Air Conditioning and Plumbing Segment	1.385	1.109
All Business Segment	1.353	1.101
% Difference	+2.35%	+0.72%
Regional Adjustment Factor	1.0235	1.0072

Next, each state in each Census Division was assigned the adjusted HARDI regional baseline and incremental markups for the region to which it belongs. DOE assigned all states to one of the nine Census Divisions in the analysis and then calculated population-weighted baseline and incremental markup averages for each division. The results are summarized in Table 6.6.3.

Table 6.6.3 Wholesaler Markups for Commercial Water-Heating Equipment in Commercial Applications by Census Division

CBECS Division ID	Census Division	Baseline MU	Incremental MU
1	New England	1.402	1.083
2	Middle Atlantic	1.391	1.096
3	East North Central	1.390	1.112
4	West North Central	1.396	1.123
5	South Atlantic	1.368	1.104
6	East South Central	1.367	1.105
7	West South Central	1.379	1.120
8	Mountain	1.422	1.119
9	Pacific	1.438	1.118

In residential applications, DOE assigned all states and the District of Columbia to one of the 27 RECS Reportable Domains in the analysis and then calculated population-weighted baseline and incremental markup averages for each region in the residential applications. The results are summarized in Table 6.6.4.

Table 6.6.4 Wholesaler Markups for Commercial Water-Heating Equipment in Residential Application by RECS Reportable Domain

RECS Domain ID	State(s)	Baseline MU	Incrementa l MU
1	Connecticut, Maine, New Hampshire, Rhode Island, Vermont	1.402	1.083
2	Massachusetts	1.402	1.083
3	New York	1.396	1.090
4	New Jersey	1.387	1.100
5	Pennsylvania	1.386	1.103
6	Illinois	1.396	1.123
7	Indiana, Ohio	1.385	1.105
8	Michigan	1.385	1.105
9	Wisconsin	1.396	1.123
10	Iowa, Minnesota, North Dakota, South Dakota	1.396	1.123
11	Kansas, Nebraska	1.396	1.123
12	Missouri	1.396	1.123
13	Virginia	1.387	1.100
14	Delaware, District of Columbia, Maryland, West Virginia	1.387	1.101
15	Georgia	1.361	1.105
16	North Carolina, South Carolina	1.361	1.105
17	Florida	1.361	1.105
18	Alabama, Kentucky, Mississippi	1.370	1.105
19	Tennessee	1.361	1.105
20	Arkansas, Louisiana, Oklahoma	1.379	1.120
21	Texas	1.379	1.120
22	Colorado	1.396	1.123
23	Idaho, Montana, Utah, Wyoming	1.434	1.118
24	Arizona	1.438	1.118
25	Nevada, New Mexico	1.413	1.119
26	California	1.438	1.118
27	Alaska, Hawaii, Oregon, Washington	1.438	1.118

6.6.2 Estimation of Mechanical Contractor Markups

The 2007 Economic Census provides Geographic Area Series for the *Plumbing and HVAC Contractors* (NAICS 23822) sector, which contains state-level sale and cost data, including value of construction, cost of subcontract work, cost of materials, and payroll for construction workers. By using the equations mentioned in Section 6.4.3, DOE estimated baseline markups for each state. Because the Census does not provide more disaggregated cost data, DOE didn't differentiate between invariant and variant cost.

Alternatively, DOE calculated the national baseline and incremental markups (Table 6.6.1) and found that the incremental markups are approximately 20 percent lower than the baseline markups. DOE further derived the state-level incremental markups by applying this ratio to the baseline markups in each state, assuming that this deviation applies equally to all states. (See appendix 6A for a table that contains the full set of data.)

To estimate the baseline and incremental markups for both replacement and new construction markets for each state, DOE applied the markup deviations (*i.e.,* 3.6 percent higher and 2.2 percent lower for the replacement and new construction markets, respectively), derived above in section 6.5.4.2, to the statewide baseline and incremental markups. DOE assumes that this deviation of replacement and new construction markets applies equally to the baseline and incremental markups.

In commercial applications, DOE divided all states among the nine Census Divisions and then calculated population-weighted average baseline and incremental markups for mechanical contractors for each region, as shown in Table 6.6.5.

Table 6.6.5 Population-Weighted Mechanical Contractor Markups for Commercial Water-Heating Equipment in Commercial Applications

CBECS Division ID	Census Division	Replacement Baseline MU	Replacement Incremental MU	New Construction Baseline MU	New Construction Incremental MU
1	New England	1.538	1.231	1.452	1.162
2	Middle Atlantic	1.548	1.238	1.461	1.169
3	East North Central	1.542	1.234	1.455	1.164
4	West North Central	1.489	1.191	1.405	1.124
5	South Atlantic	1.496	1.197	1.412	1.130
6	East South Central	1.498	1.198	1.414	1.131
7	West South Central	1.500	1.200	1.416	1.133
8	Mountain	1.525	1.220	1.439	1.151
9	Pacific	1.523	1.218	1.437	1.150

Last, DOE divided all states among the 27 RECS Reportable Domains and then calculated population-weighted average baseline and incremental markups for mechanical contractors for each region in residential applications, as shown in Table 6.6.6.

Table 6.6.6 Population-Weighted Mechanical Contractor Markups for Commercial Water-Heating Equipment in Residential Applications

RECS Domain ID	State(s)	Replacement Baseline MU	Replacement Incremental MU	New Construction Baseline MU	New Construction Incremental MU
1	Connecticut, Maine, New Hampshire, Rhode Island, Vermont	1.548	1.238	1.461	1.169
2	Massachusetts	1.527	1.222	1.441	1.153
3	New York	1.589	1.271	1.499	1.200
4	New Jersey	1.572	1.258	1.484	1.187
5	Pennsylvania	1.468	1.174	1.385	1.108
6	Illinois	1.566	1.252	1.478	1.182
7	Indiana, Ohio	1.551	1.241	1.464	1.171
8	Michigan	1.519	1.215	1.433	1.147
9	Wisconsin	1.499	1.199	1.414	1.131
10	Iowa, Minnesota, North Dakota, South Dakota	1.519	1.215	1.434	1.147
11	Kansas, Nebraska	1.449	1.160	1.368	1.094
12	Missouri	1.468	1.175	1.386	1.109
13	Virginia	1.546	1.237	1.459	1.167
14	Delaware, District of Columbia, Maryland, West Virginia	1.487	1.189	1.403	1.122
15	Georgia	1.463	1.170	1.381	1.105
16	North Carolina, South Carolina	1.490	1.192	1.406	1.125
17	Florida	1.501	1.201	1.417	1.134
18	Alabama, Kentucky, Mississippi	1.514	1.212	1.429	1.143
19	Tennessee	1.466	1.173	1.384	1.107
20	Arkansas, Louisiana, Oklahoma	1.531	1.224	1.445	1.156
21	Texas	1.487	1.190	1.404	1.123
22	Colorado	1.520	1.216	1.434	1.147
23	Idaho, Montana, Utah, Wyoming	1.480	1.184	1.397	1.117
24	Arizona	1.569	1.255	1.481	1.184
25	Nevada, New Mexico	1.526	1.221	1.440	1.152
26	California	1.595	1.276	1.506	1.204
27	Alaska, Hawaii, Oregon, Washington	1.606	1.285	1.515	1.212

6.6.3 Estimation of General Contractor Markups

To derive regional general contractor markups for the commercial building construction sector from the 2007 Economic Census, DOE used the Commercial Building Construction series (NAICS 236220) from the 2007 Economic Census. Similarly, DOE combined four Geographic Area Series: (1) *New Single-Family General Contractors* (NAICS 236115), (2) *New Multifamily Housing Construction* (NAICS 236116), (3) *New Housing Operative Builders* (NAICS 236117), and (4) *Residential Remodelers* (NAICS 236118) to derive regional general contractor markups for the residential application of CWH equipment.

Each series consists of statewide cost data required to calculate baseline markups for each state, as illustrated in section 6.4.3. Although there is only a new construction (no replacement) channel for general contractors, the same technique shown for mechanical contractors can still be employed to estimate regional baseline and incremental markups. First, DOE estimated the statewide incremental markups by applying the ratio of national baseline and incremental markups (*i.e.,* the national incremental markup is around 8.9 and 9 percent lower than the national baseline markup in commercial and residential application, respectively) to the baseline markups for each state. Then, DOE divided all states among the nine Census Divisions for commercial applications and 27 RECS Reportable Domains for residential applications. Last, DOE calculated population-weighted average baseline and incremental markups for general contractors for each region in both commercial and residential applications. The final results are summarized below in Table 6.6.7 for commercial applications and in Table 6.6.8 for residential applications (See appendix 6A for tables that contain the full set of data.)

Table 6.6.7 General Contractor Markups for Commercial Water-Heating Equipment in Commercial Applications

CBECS Division ID	Census Division	Baseline MU	Incremental MU
1	New England	1.336	1.217
2	Middle Atlantic	1.418	1.292
3	East North Central	1.331	1.213
4	West North Central	1.287	1.172
5	South Atlantic	1.341	1.221
6	East South Central	1.332	1.213
7	West South Central	1.314	1.197
8	Mountain	1.267	1.154
9	Pacific	1.265	1.152

Table 6.6.8 General Contractor Markups for Commercial Water-Heating Equipment in Residential Applications

RECS Domain ID	State(s)	Baseline MU	Incremental MU
1	Connecticut, Maine, New Hampshire, Rhode Island, Vermont	1.411	1.284
2	Massachusetts	1.343	1.222
3	New York	1.393	1.267
4	New Jersey	1.503	1.368
5	Pennsylvania	1.362	1.239
6	Illinois	1.589	1.446
7	Indiana, Ohio	1.378	1.254
8	Michigan	1.537	1.399
9	Wisconsin	1.340	1.219
10	Iowa, Minnesota, North Dakota, South Dakota	1.368	1.245
11	Kansas, Nebraska	1.351	1.229
12	Missouri	1.325	1.206
13	Virginia	1.450	1.320
14	Delaware, District of Columbia, Maryland, West Virginia	1.443	1.313
15	Georgia	1.428	1.300
16	North Carolina, South Carolina	1.390	1.265
17	Florida	1.528	1.391
18	Alabama, Kentucky, Mississippi	1.355	1.233
19	Tennessee	1.353	1.231
20	Arkansas, Louisiana, Oklahoma	1.373	1.249
21	Texas	1.499	1.364
22	Colorado	1.499	1.364
23	Idaho, Montana, Utah, Wyoming	1.307	1.190
24	Arizona	1.707	1.553
25	Nevada, New Mexico	1.638	1.490
26	California	1.717	1.562
27	Alaska, Hawaii, Oregon, Washington	1.481	1.348

6.7 SALES TAX

The sales tax represents state and local sales taxes that are applied to the commercial consumer price of the equipment. The sales tax is a multiplicative factor that increases the commercial consumer equipment price. DOE only applies the sales tax to the commercial consumer price of the equipment in the replacement market, not the new construction market. The common practice for selling larger commercial appliances, such as CWH equipment, in the new construction market is for general contractors (or builders) to bear the added sales tax for equipment in addition to the cost of equipment, and then mark up the entire cost in the final listing price to commercial consumers. Therefore, no additional sales tax is necessary to calculate the commercial consumer equipment price for the new construction market.

DOE derives state and local taxes from data provided by the Sales Tax Clearinghouse.[14] These data represent weighted averages that include county and city rates. DOE then derives population-weighted average tax values for each Census Division for commercial applications and RECS Reportable Domain for residential applications to match the regional markups for wholesalers and mechanical and general contractors, as shown in Table 6.7.1 and Table 6.7.2. Detailed sales tax data by each state can be found in appendix 6A.

Table 6.7.1 Average Sales Tax Rates by CBECS Region

CBECS Division ID	Census Division	Population Estimation (2013)	2014 Tax Rate %
1	New England	14,618,806	5.69
2	Middle Atlantic	41,324,267	7.48
3	East North Central	46,662,180	6.90
4	West North Central	20,885,710	7.10
5	South Atlantic	61,783,647	6.45
6	East South Central	18,716,202	8.04
7	West South Central	37,883,604	8.18
8	Mountain	22,881,245	6.47
9	Pacific	51,373,178	7.51
Population-Weighted National Average			**7.16**

Table 6.7.2 Average Sales Tax Rates by RECS Region

RECS Domain ID	State(s)	Population Estimation (2013)	2014 Tax Rate %
1	Connecticut, Maine, New Hampshire, Rhode Island, Vermont	7,925,982	5.21
2	Massachusetts	6,692,824	6.25
3	New York	19,651,127	8.45
4	New Jersey	8,899,339	6.95
5	Pennsylvania	12,773,801	6.35
6	Illinois	12,882,135	8.00
7	Indiana, Ohio	18,141,710	7.06
8	Michigan	9,895,622	6.00
9	Wisconsin	5,742,713	5.45
10	Iowa, Minnesota, North Dakota, South Dakota	10,079,066	6.84
11	Kansas, Nebraska	4,762,473	7.17
12	Missouri	6,044,171	7.45
13	Virginia	8,260,405	5.60
14	Delaware, District of Columbia, Maryland, West Virginia	9,355,316	5.40
15	Georgia	9,992,167	7.00
16	North Carolina, South Carolina	14,622,899	6.97
17	Florida	19,552,860	6.65
18	Alabama, Kentucky, Mississippi	12,220,224	7.29
19	Tennessee	6,495,978	9.45
20	Arkansas, Louisiana, Oklahoma	11,435,411	8.70
21	Texas	26,448,193	7.95
22	Colorado	5,268,367	6.10
23	Idaho, Montana, Utah, Wyoming	6,110,831	5.26
24	Arizona	6,626,624	7.20
25	Nevada, New Mexico	4,875,423	7.42
26	California	38,332,521	8.45
27	Alaska, Hawaii, Oregon, Washington	13,040,657	5.30
Population-Weighted National Average			**7.16**

6.8 OVERALL MARKUPS

The overall markup for each distribution channel is the product of the appropriate markups, as well as the sales tax in the case of replacement applications. DOE uses the overall baseline markup to estimate the commercial consumer equipment price of baseline models, given the manufacturer cost of the baseline models. As stated previously, DOE considers baseline models to be equipment sold under existing market conditions (*i.e.,* without new energy conservation standards). The following equation shows how DOE uses the overall baseline markup to determine the equipment price for baseline models.

$$CPP_{BASE} = COST_{MFG} \times \left(MU_{MFG} \times MU_{BASE} \times Tax_{SALES} \right) = COST_{MFG} \times MU_{OVERALL\_BASE}$$

Eq. 6.8

Where:

CPP_{BASE} = commercial consumer equipment price for baseline models,
$COST_{MFG}$ = manufacturer cost for baseline models,
MU_{MFG} = manufacturer markup,
MU_{BASE} = baseline replacement or new home channel markup,
Tax_{SALES} = sales tax (replacement applications only), and
$MU_{OVERALL\_BASE}$ = baseline overall markup.

Similarly, DOE uses the overall incremental markup to estimate changes in the commercial consumer equipment price, given changes in the manufacturer cost from the baseline model cost resulting from an energy conservation standard to raise equipment energy efficiency. The total commercial consumer equipment prices for more-energy-efficient models are composed of two components: the commercial consumer equipment price of the baseline model and the change in commercial consumer equipment price associated with the increase in manufacturer cost to meet the new energy conservation standard. The following equation shows how DOE uses the overall incremental markup to determine the commercial consumer equipment price for more-energy-efficient models (*i.e.,* models meeting new energy conservation standards).

$$\begin{aligned} CPP_{STD} &= COST_{MFG} \times MU_{OVERALL\_BASE} + \Delta COST_{MFG} \times \left(MU_{MFG} \times MU_{INCR} \times Tax_{SALES} \right) \\ &= CPP_{BASE} + \Delta COST_{MFG} \times MU_{OVERALL\_INCR} \end{aligned}$$

Eq. 6.9

Where:

CPP_{STD} = commercial consumer equipment price for models meeting new energy conservation standards,
CPP_{BASE} = commercial consumer equipment price for baseline models,
$COST_{MFG}$ = manufacturer cost for baseline models,
$\Delta COST_{MFG}$ = change in manufacturer cost for more-energy-efficient models,
MU_{MFG} = manufacturer markup,
MU_{INCR} = incremental replacement or new home channel markup,
Tax_{SALES} = sales tax (replacement applications only),
$MU_{OVERALL\_BASE}$ = baseline overall markup (equipment of manufacturer markup, baseline replacement or new home channel markup, and sales tax), and
$MU_{OVERALL\_INCR}$ = incremental overall markup.

National weighted average baseline and incremental markups for each market and sector are summarized in Table 6.8.1, Table 6.8.2, Table 6.8.3, and Table 6.8.4. The values represent the weighted-average markups based on the state-level markup values and population estimation by state as weight. Note that the overall markup values may not equal the product of associated markup values shown due to rounding. Detailed overall markup data can be found in appendix 6A.

Table 6.8.1 Summary of Overall Markups for Commercial Water-Heating Equipment in Commercial Sector, New Construction Market

Commercial New Construction		
Equipment Class	**Baseline Markup**	**Incremental Markup**
Commercial Gas-fired Storage Water Heater	3.47	2.14
Residential-duty Gas-fired Storage Water Heater	3.41	2.12
Commercial Gas-fired Tankless Water Heater	3.39	2.10
Commercial Gas-fired Hot Water Supply Boiler	3.57	2.15
Commercial Electric Storage Water Heater	3.22	2.06

Table 6.8.2 Summary of Overall Markups for Commercial Water-Heating Equipment in Residential Sector, New Construction Market

Residential New Construction		
Equipment Class	**Baseline Markup**	**Incremental Markup**
Commercial Gas-fired Storage Water Heater	3.85	2.36
Residential-duty Gas-fired Storage Water Heater	3.78	2.35
Commercial Gas-fired Tankless Water Heater	3.77	2.32
Commercial Gas-fired Hot Water Supply Boiler	3.98	2.39
Commercial Electric Storage Water Heater	3.57	2.27

Table 6.8.3 Summary of Overall Markups for Commercial Water-Heating Equipment in Commercial Sector, Replacement Market

Commercial Replacement		
Equipment Class	**Baseline Markup**	**Incremental Markup**
Commercial Gas-fired Storage Water Heater	3.09	2.06
Residential-duty Gas-fired Storage Water Heater	3.06	2.05
Commercial Gas-fired Tankless Water Heater	3.02	2.02
Commercial Gas-fired Hot Water Supply Boiler	3.13	2.05
Commercial Electric Storage Water Heater	2.99	2.02

Table 6.8.4 Summary of Overall Markups for Commercial Water-Heating Equipment in Residential Sector, Replacement Market

Residential Replacement		
Equipment Class	**Baseline Markup**	**Incremental Markup**
Commercial Gas-fired Storage Water Heater	3.09	2.06
Residential-duty Gas-fired Storage Water Heater	3.08	2.06
Commercial Gas-fired Tankless Water Heater	3.02	2.02
Commercial Gas-fired Hot Water Supply Boiler	3.13	2.05
Commercial Electric Storage Water Heater	2.99	2.02

National weighted average baseline and incremental markups are summarized in Table 6.8.5 for each equipment class of CWH equipment. These values represent the weighted-average markups based on market and sector, as shown in Table 6.8.6.

Table 6.8.5 Summary of Total Markup by Commercial Water-Heating Equipment Class

Equipment Class	Baseline Markup	Incremental Markup
Commercial Gas-fired Storage Water Heater	3.17	2.08
Residential-duty Gas-fired Storage Water Heater	3.16	2.09
Commercial Gas-fired Instantaneous Water Heater	3.22	2.08
Commercial Gas-fired Hot Water Supply Boiler	3.30	2.10
Commercial Electric Storage Water Heater	3.06	2.04

Table 6.8.6 Market and Sector Weights

Equipment Class	Commercial		Residential	
	New Constr.*	Repl.**	New Constr.	Repl.
Commercial Gas-fired Storage Water Heater	16.1%	64.9%	2.4%	16.6%
Residential-duty Gas-fired Storage Water Heater	10.9%	37.1%	7.5%	44.5%
Commercial Gas-fired Instantaneous Water Heater	33.1%	33.9%	11.0%	22.0%
Commercial Gas-fired Hot Water Supply Boiler	30.4%	51.6%	4.7%	13.3%
Commercial Electric Storage Water Heater	19.6%	57.4%	3.7%	19.3%

* New construction market
** Replacement market

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APPENDIX 6A. DETAILED DATA FOR EQUIPMENT PRICE MARKUPS

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6A.1 DETAILED WHOLESALER COST DATA

Based on data provided by the Heating Air-conditioning & Refrigeration Distributors International (HARDI), chapter 6 of the technical support document (TSD) shows wholesaler revenues and costs in aggregated form. Table 6A.1.1 in this appendix provides the complete breakdown of costs and expenses. The column labeled "Scaling" in Table 6A.1.1 indicates which expenses the U.S. Department of Energy (DOE) assumes to scale with only the baseline markup, and which scale with both the baseline and incremental markups. As described in chapter 6, section 6.4.1, only those expenses that scale with both baseline and incremental costs are marked up when there is an incremental change in equipment costs.

Table 6A.1.1 Disaggregated Costs and Expenses for Wholesalers

Item*	Percent of Revenue %	Scaling
Cost of Goods Sold	**72.2**	
Gross Margin	**27.8**	
Payroll Expenses	**16.5**	Baseline
Executive Salaries & Bonuses	2.2	
Branch Manager Salaries and Commissions	1.5	
Sales Executive Salaries & Commissions	0.3	
Outside Sales Salaries & Commissions	2.0	
Inside/Counter Sales/Wages	2.8	
Purchasing Salaries/Wages	0.6	
Credit Salaries/Wages	0.1	
IT Salaries/Wages	0.3	
Warehouse Salaries/Wages	1.5	
Accounting	0.5	
Delivery Salaries/Wages	0.9	
All Other Salaries/Wages & Bonuses	0.5	
Payroll Taxes	1.1	
Group Insurance	1.4	
Benefit Plans	0.8	
Occupancy Expenses	**3.4**	Baseline
Utilities: Heat, Light, Power, Water	0.4	
Telephone	0.3	
Building Repairs & Maintenance	0.3	
Rent or Ownership in Real Estate	2.4	

Item*	Percent of Revenue %	Scaling
Other Operating Expenses	**5.3**	Baseline & Incremental
Sales Expenses (incl. advertising & promotion)	0.8	
Insurance (business liability & casualty)	0.3	
Depreciation	0.5	
Vehicle Expenses	1.3	
Personal Property Taxes/Licenses	0.1	
Collection Expenses	0.3	
Bad Debt Losses	0.2	
Data Processing	0.3	
Employee Training	0.1	
All Other Operating Expenses	1.4	
Total Operating Expenses	**25.2**	
Operating Profit	**2.6**	Baseline & Incremental
Other Income	0.4	
Interest Expense	0.3	
Other Non-operating Expenses	0.1	
Profit Before Taxes	**2.6**	

Source: Heating, Air-conditioning & Refrigeration Distributors International. 2013. *2013 Profit Report (2012 Data).* Air Conditioning & Plumbing Business Segment.
* The wholesaler costs and expenses are percentage values as opposed to the per-dollar of sales revenue values shown in chapter 6. Bolded items are the sum of items listed below.

6A.2 DETAILED RETAILER DATA

Chapter 6 of the TSD provides retailer revenues and costs in aggregated form by per dollar sales revenue and per dollar cost of goods sold. This table is based on data in the U.S. Census 2012 Annual Retail Trade Survey, Electronics and Appliance Stores category (Sector 443). A further disaggregated breakdown of the data is shown in Table 6A.2.1.

Table 6A.2.1 Disaggregated Costs and Expenses for Retailers

Business Item	Amount *$1,000,000*
Sales (revenue)	102,998
Cost of Goods Sold (CGS)	73,946
Gross Margin (GM)	29,052
Labor & Occupancy Expenses (Invariant)	
Payroll	11,371
Fringe Benefits	2,023
Contract Labor	209
Taxes and License Fees	451
Lease and Rental Payments	3,166
Telephone and Communications	365
Utilities	529
Repair and Maintenance	386
Subtotal	18,500
Other Operating Expenses & Profit (Variant)	
Expensed Equipment	75
Expensed Software	122
Packaging and Containers	47
Other Materials and Supplies (Not for Resale)	463
Advertising Services	1,961
Transportation, Shipping and Warehousing	567
Professional Services	1,117
Computer Services	50
Depreciation and Amortization Charges	1,564
Other Operating Expenses	2,113
Net Profit Before Taxes	2,473
Subtotal	10,552
Markup Type	**Markup**
Baseline Markup	**1.393**
Incremental Markup	**1.143**

6A.3 DETAILED MECHANICAL CONTRACTOR DATA

In chapter 6 of the TSD, Tables 6.5.4 and Table 6.5.5 provide mechanical contractor revenues and costs in aggregated form by "Cost of Goods Sold" and "Gross Margin." The tables are based on data in the 2005 edition of *Financial Analysis for the HVACR Contracting Industry,* published by the Air Conditioning Contractors of America (ACCA). The ACCA report does not provide a more disaggregated tabulation of these costs and expenses. As in section 6A.1, DOE assumes that the gross margin category scales only with the baseline markup.

A further disaggregated breakdown of costs used to scale the incremental markup is shown in Table 6A.3.1 both by dollar value and in percentage terms from the 2007 Census of Business. As the ACCA data are used to calculate the baseline markup, in Table 6A.3.1 only the categories in the "Scaling" column that are scaled with both the baseline and incremental markups are marked when there is an incremental change in equipment costs.

Table 6A.3.1 Mechanical Contractor Expenses and Markups Used To Scale the Incremental Markups

Item*	Dollar Value $1,000	Percentage %	Scaling
Total Cost of Equipment Sales	**107,144,428**	**67.80**	
Total payroll, construction workers wages	31,373,558	19.85	
Cost of materials, components, and supplies	59,023,964	37.35	
Cost of construction work subcontracted out to others	13,646,192	8.63	
Total cost of selected power, fuels, and lubricants	3,100,714	1.96	
Gross Margin	**50,895,129**	**32.20**	
Payroll Expenses	**28,065,632**	**17.76**	Baseline
Total payroll, other employee wages	14,041,336	8.88	
Total fringe benefits	13,585,040	8.60	
Temporary staff and leased employee expenses	439,256	0.28	
Occupancy Expenses	**3,436,208**	**2.17**	Baseline
Rental costs of machinery and equipment	1,047,026	0.66	
Rental costs of buildings	1,231,263	0.78	
Communication services	640,851	0.41	
Cost of repair to machinery and equipment	517,068	0.33	
Other Operating Expenses	**12,671,194**	**8.02**	Baseline & Incremental
Purchased professional and technical services	843,641	0.53	
Data processing and other purchased computer services	98,016	0.06	
Expensed computer hardware and other equipment	255,474	0.16	
Expensed purchases of software	64,195	0.04	
Advertising and promotion services	1,018,265	0.64	
All other expenses	6,944,674	4.39	
Refuse removal (including hazardous waste) services	153,241	0.10	
Taxes and license fees	996,138	0.63	
Total depreciation ($1,000)	2,297,550	1.45	
Net Profit Before Income Taxes	**6,722,095**	**4.25**	Baseline & Incremental

Sources: U.S. Census Bureau. 2007. *Plumbing, Heating, and Air-Conditioning Contractors: 2007*. Sector 23: 238220; Construction: Geographic Area Series. Detailed Statistics for Establishments: 2007.
* Mechanical contractor costs and expenses are first presented as *total dollar* values and then converted to *percentage* values. This is in contrast to the *cost per dollar of sales revenue* values shown in Table 6.5.4 of TSD chapter 6.

6A.4 DETAILED GENERAL CONTRACTOR COST DATA

In chapter 6 of the TSD, Tables 6.5.8 and 6.5.9 show aggregated U.S. Department of Census data for commercial and residential building general contractor revenues and costs as expenses per dollar sales revenue. Table 6A.4.1 provides further breakdown of the costs and expenses of commercial building contractors. The column labeled "Scaling" indicates which expenses DOE assumes to scale with only the baseline markup and which scale with both baseline and incremental markups. Only those expenses that scale with baseline and incremental costs are marked up when there is an incremental change in equipment costs. Table 6A.4.2 shows the similar analysis for residential building contractors.

Table 6A.4.1 Commercial General Contractor Expenses and Markups

Item[*]	Dollar Value *$1,000*	Percentage %	Scaling
Total Cost of Equipment Sales	**250,657,006**	**76.24**	
Total payroll, construction workers wages	16,449,830	5.00	
Cost of materials, components, and supplies	74,148,280	22.55	
Cost of construction work subcontracted out to others	157,873,840	48.02	
Total cost of selected power, fuels, and lubricants	2,185,056	0.66	
Gross Margin	**78,113,967**	**23.76**	
Payroll Expenses	**25,948,454**	**7.89**	Baseline
Total payroll, other employees' wages	16,652,791	5.07	
Total fringe benefits	8,666,079	2.64	
Temporary staff and leased employee expenses	629,584	0.19	
Occupancy Expenses	**3,301,046**	**1.00**	Baseline
Rental costs of machinery and equipment	1,403,979	0.43	
Rental costs of buildings	1,045,163	0.32	
Communication services	385,109	0.12	
Cost of repair to machinery and equipment	466,795	0.14	
Other Operating Expenses	**10,770,620**	**3.28**	Baseline & Incremental
Purchased professional and technical services	1,121,644	0.34	
Data processing and other purchased computer services	127,031	0.04	
Expensed computer hardware and other equipment	219,601	0.07	
Expensed purchases of software	67,977	0.02	
Advertising and promotion services	290,239	0.09	
All other expenses	6,321,197	1.92	
Refuse removal (including hazardous waste) services	233,831	0.07	
Taxes and license fees	807,872	0.25	
Total depreciation ($1,000)	1,581,228	0.48	
Net Profit Before Income Taxes	**38,093,847**	**11.59**	Baseline & Incremental

Source: U.S. Census Bureau. 2007. *Residential Building Construction*. Sector 23, EC0723I1: 236220 (Commercial Building Construction). Construction, Industry Series, Preliminary Detailed Statistics for Establishments: 2007.
* General contractor costs and expenses are first presented as *total dollar* values and then converted to *percentage* values. This is in contrast to the *cost per dollar of sales revenue* values shown in Table 6.5.8 of TSD chapter 6.

Table 6A.4.2 Residential General Contractor Expenses and Markups

Item*	Dollar Value *$1,000*	Percentage %	Scaling
Total Cost of Equipment Sales	**238,431,389**	**67.55**	
Total payroll, construction workers wages	16,629,321	4.71	
Cost of materials, components, and supplies	126,764,975	35.91	
Cost of construction work subcontracted out to others	90,956,668	25.77	
Total cost of selected power, fuels, and lubricants	4,080,425	1.16	
Gross Margin	**114,558,247**	**32.45**	
Payroll Expenses	**28,806,792**	**8.16**	Baseline
Total payroll, other employee wages	20,843,029	5.90	
Total fringe benefits	7,464,670	2.11	
Temporary staff and leased employee expenses	499,093	0.14	
Occupancy Expenses	**3,558,796**	1.01	Baseline
Rental costs of machinery and equipment	572,783	0.16	
Rental costs of buildings	1,532,841	0.43	
Communication services	810,436	0.23	
Cost of repair to machinery and equipment	642,736	0.18	
Other Operating Expenses	**21,341,175**	**6.05**	Baseline & Incremental
Purchased professional and technical services	1,834,816	0.52	
Data processing and other purchased computer services	141,344	0.04	
Expensed computer hardware and other equipment	261,701	0.07	
Expensed purchases of software	105,338	0.03	
Advertising and promotion services	2,544,687	0.72	
All other expenses	10,840,757	3.07	
Refuse removal (including hazardous waste) services	520,907	0.15	
Taxes and license fees	1,791,539	0.51	
Total depreciation ($1,000)	3,300,086	0.93	
Net Profit Before Income Taxes	**60,851,484**	**17.24**	Baseline & Incremental

Source: U.S. Census Bureau. 2007. Residential Building Construction. Sector 23, EC0723I1: 236115 through 236118. Construction, Industry Series, Preliminary Detailed Statistics for Establishments: 2007.
* General contractor costs and expenses are first presented as *total dollar* values and then converted to *percentage* values. This is in contrast to the *cost per dollar of sales revenue* values shown in Table 6.5.9 of TSD chapter 6.

6A.5 ESTIMATION OF CONTRACTOR MARKUPS BY STATE

Table 6.5.4 in chapter 6 of the TSD provides aggregated U.S. Department of Census data for mechanical contractor revenues and costs as expenses per dollar sales revenue. In chapter 6 of the TSD, Table 6.5.6 provides the replacement and new construction adjustments to the baseline and incremental mechanical contractor markups. In chapter 6 of the TSD, Table 6.5.7 provides the final aggregated markups for the United States. Table 6A.5.1, Table 6A.5.2, and Table 6A.5.3 of this appendix provide the final baseline and incremental markups by state for replacement and new construction markets.

Table 6A.5.1 Mechanical Contractor Markup Estimation by State, 2007

State*	Value of Const. *$1,000*	Cost of Goods Sold *$1,000***	Baseline MU	Incremental MU	Replace-ment Baseline MU	Replacement Incremental MU	New Const. Baseline MU	New Const. Incremental MU
Alabama	2,010,305	1,401,223	1.435	1.148	1.487	1.189	1.403	1.122

State*	Value of Const. *$1,000*	Cost of Goods Sold *$1,000***	Baseline MU	Incremental MU	Replace-ment Baseline MU	Replacement Incremental MU	New Const. Baseline MU	New Const. Incremental MU
Alaska	583,171	344,729	1.692	1.353	1.753	1.402	1.654	1.324
Arizona	3,522,116	2,326,475	1.514	1.211	1.569	1.255	1.481	1.184
Arkansas	1,065,754	743,395	1.434	1.147	1.486	1.189	1.402	1.122
California	16,726,969	10,865,201	1.539	1.232	1.595	1.276	1.506	1.204
Colorado	3,056,988	2,084,454	1.467	1.173	1.520	1.216	1.434	1.147
Connecticut	1,704,668	1,135,871	1.501	1.201	1.555	1.244	1.468	1.174
Delaware	481,900	D	1.421	1.137	1.472	1.178	1.390	1.112
District of Columbia	34,600	D	1.458	1.167	1.511	1.209	1.426	1.141
Florida	9,061,426	6,254,391	1.449	1.159	1.501	1.201	1.417	1.134
Georgia	4,700,799	3,329,842	1.412	1.129	1.463	1.170	1.381	1.105
Hawaii	800,221	455,122	1.758	1.407	1.822	1.458	1.720	1.376
Idaho	900,698	617,165	1.459	1.168	1.512	1.210	1.427	1.142
Illinois	7,641,642	5,058,047	1.511	1.209	1.566	1.252	1.478	1.182
Indiana	4,002,323	2,605,238	1.536	1.229	1.592	1.274	1.502	1.202
Iowa	1,868,483	1,305,883	1.431	1.145	1.483	1.186	1.399	1.119
Kansas	1,395,359	966,707	1.443	1.155	1.496	1.197	1.412	1.129
Kentucky	1,747,925	1,157,360	1.510	1.208	1.565	1.252	1.477	1.182
Louisiana	1,997,044	1,317,429	1.516	1.213	1.571	1.257	1.482	1.186
Maine	580,816	394,847	1.471	1.177	1.524	1.219	1.439	1.151
Maryland	5,329,135	3,739,560	1.425	1.140	1.477	1.181	1.394	1.115
Massachusetts	4,099,301	2,781,377	1.474	1.179	1.527	1.222	1.441	1.153
Michigan	4,420,638	3,015,948	1.466	1.173	1.519	1.215	1.433	1.147
Minnesota	3,402,921	2,315,330	1.470	1.176	1.523	1.218	1.437	1.150
Mississippi	1,025,452	715,571	1.433	1.146	1.485	1.188	1.402	1.121
Missouri	3,335,124	2,353,598	1.417	1.134	1.468	1.175	1.386	1.109
Montana	483,578	345,458	1.400	1.120	1.451	1.160	1.369	1.095
Nebraska	1,004,296	755,338	1.330	1.064	1.378	1.102	1.300	1.040
Nevada	2,327,842	1,600,555	1.454	1.164	1.507	1.206	1.422	1.138
New Hampshire	620,761	D	1.472	1.178	1.526	1.221	1.440	1.152
New Jersey	5,062,336	3,337,013	1.517	1.214	1.572	1.258	1.484	1.187
New Mexico	891,914	595,659	1.497	1.198	1.552	1.241	1.464	1.172
New York	10,364,779	6,760,337	1.533	1.227	1.589	1.271	1.499	1.200
North Carolina	5,111,396	3,631,802	1.407	1.126	1.458	1.167	1.376	1.101
North Dakota	360,683	255,057	1.414	1.131	1.465	1.172	1.383	1.106
Ohio	5,618,591	3,809,806	1.475	1.180	1.528	1.223	1.442	1.154
Oklahoma	1,352,943	924,264	1.464	1.171	1.517	1.214	1.432	1.145
Oregon	1,893,678	1,237,956	1.530	1.224	1.585	1.268	1.496	1.197
Pennsylvania	6,487,476	4,579,367	1.417	1.133	1.468	1.174	1.385	1.108
Rhode Island	631,202	410,653	1.537	1.230	1.593	1.274	1.503	1.203
South Carolina	1,991,303	1,326,690	1.501	1.201	1.555	1.244	1.468	1.174
South Dakota	386,186	239,017	1.616	1.293	1.674	1.339	1.580	1.264
Tennessee	2,595,613	1,834,242	1.415	1.132	1.466	1.173	1.384	1.107
Texas	10,810,308	7,532,064	1.435	1.148	1.487	1.190	1.404	1.123
Utah	1,746,398	1,235,004	1.414	1.131	1.465	1.172	1.383	1.106
Vermont	294,806	D	1.472	1.178	1.526	1.221	1.440	1.152
Virginia	4,623,151	3,099,329	1.492	1.193	1.546	1.237	1.459	1.167
Washington	4,111,543	2,734,093	1.504	1.203	1.558	1.247	1.471	1.177
West Virginia	655,100	D	1.464	1.171	1.517	1.213	1.431	1.145
Wisconsin	2,926,545	2,023,634	1.446	1.157	1.499	1.199	1.414	1.131
Wyoming	289,391	198,105	1.461	1.169	1.514	1.211	1.429	1.143

Sources: U.S. Bureau of the Census. American Factfinder: 2007. Sector 23: Plumbing, Heating, and Air-Conditioning Contractors (NAICS 238220), Detailed Statistics for Establishments: 2007 and Geographic Area Series: Detailed Statistics for Establishments: 2007.
* Notes: Markups may vary across states for several reasons, including differences in firm size. Due to sample size and/or magnitude of reporting error relative to the mean, disaggregated information is not provided for all of the costs of goods sold. In these cases, the state markup ratio is calculated as an average of neighboring states (ex. Delaware, District of Columbia, New Hampshire, Vermont, and West Virginia)
** The Census Bureau withheld data for the states denoted with a D.

Table 6A.5.2 Commercial Building General Contractor Baseline Markups by State

State	Value of Construction *$1,000*	Cost of Goods Sold *$1,000**	Baseline Markup	Incremental Markup
Alabama	7,553,561	5,966,033	1.266	1.153
Alaska	1,687,503	1,265,663	1.333	1.215
Arizona	12,151,583	9,218,504	1.318	1.201
Arkansas	3,187,913	2,524,259	1.263	1.151
California	43,866,759	32,549,870	1.348	1.228
Colorado	9,218,679	7,554,813	1.220	1.112
Connecticut	2,398,913	1,704,640	1.407	1.282
Delaware	727,553	D	1.309	1.192
District of Columbia	918,723	D	1.301	1.186
Florida	19,686,238	14,553,102	1.353	1.232
Georgia	10,541,824	7,189,660	1.466	1.336
Hawaii	2,341,014	1,802,494	1.299	1.183
Idaho	1,555,058	1,291,347	1.204	1.097
Illinois	13,909,785	10,206,749	1.363	1.242
Indiana	5,967,203	4,636,748	1.287	1.172
Iowa	3,405,782	2,585,432	1.317	1.200
Kansas	2,721,025	2,252,824	1.208	1.100
Kentucky	3,028,131	2,289,475	1.323	1.205
Louisiana	4,476,198	3,078,813	1.454	1.325
Maine	738,455	585,867	1.260	1.148
Maryland	8,299,684	6,472,850	1.282	1.168
Massachusetts	7,035,875	5,272,385	1.334	1.216
Michigan	5,363,993	3,824,364	1.403	1.278
Minnesota	8,203,910	5,908,604	1.388	1.265
Mississippi	3,593,463	2,094,843	1.715	1.563
Missouri	9,293,483	7,970,536	1.166	1.062
Montana	924,342	734,797	1.258	1.146
Nebraska	1,589,168	1,080,612	1.471	1.340
Nevada	6,285,128	4,704,160	1.336	1.217
New Hampshire	1,040,005	816,281	1.274	1.161
New Jersey	7,331,413	4,421,279	1.658	1.511
New Mexico	1,537,718	1,210,550	1.270	1.157
New York	19,752,366	14,491,190	1.363	1.242
North Carolina	8,605,888	6,566,496	1.311	1.194
North Dakota	659,818	542,850	1.215	1.107
Ohio	8,889,511	7,158,247	1.242	1.131
Oklahoma	3,307,370	2,875,301	1.150	1.048
Oregon	3,273,641	2,606,128	1.256	1.144
Pennsylvania	11,676,721	8,744,986	1.335	1.216
Rhode Island	847,621	627,945	1.350	1.230
South Carolina	3,532,858	2,885,636	1.224	1.115
South Dakota	912,508	D	1.315	1.198
Tennessee	7,004,112	5,784,562	1.211	1.103
Texas	26,821,716	20,332,044	1.319	1.202
Utah	3,141,938	2,604,471	1.206	1.099
Vermont	445,373	367,539	1.212	1.104
Virginia	8,926,148	6,759,203	1.321	1.203
Washington	9,936,986	8,276,568	1.201	1.094
West Virginia	563,473	D	1.301	1.185

State	Value of Construction *$1,000*	Cost of Goods Sold *$1,000**	Baseline Markup	Incremental Markup
Wisconsin	7,248,667	D	1.368	1.246
Wyoming	432,812	349,769	1.237	1.127

Sources: U.S. Bureau of the Census, American Factfinder. *2007 Economic Census*. Sector 23: Subsectors 236220 (Commercial Building Construction). Sector 23: EC0723A1: Construction: Geographic Area Series: Detailed Statistics for Establishments: 2007.

* The Census Bureau withheld data for the states denoted with a D.

Table 6A.5.3 Residential Building General Contractor Baseline Markups by State

State*	Value of Residential Construction *$1,000***	Cost of Goods Sold *$1,000***	Baseline Markup	Incremental Markup
Alabama	4,232,349	3,106,308	1.363	1.240
Alaska	598,572	322,897	1.854	1.687
Arizona	14,743,264	8,636,727	1.707	1.553
Arkansas	821,493	638,546	1.287	1.171
California	49,325,592	28,727,843	1.717	1.562
Colorado	9,711,667	6,478,218	1.499	1.364
Connecticut	2,835,015	1,914,706	1.481	1.347
Delaware	912,121	714,609	1.276	1.162
District of Columbia	177,004	115,545	1.532	1.394
Florida	33,290,091	21,780,175	1.528	1.391
Georgia	12,492,752	8,745,668	1.428	1.300
Hawaii	2,739,122	1,933,143	1.417	1.289
Idaho	2,565,176	2,014,522	1.273	1.159
Illinois	13,035,923	8,206,105	1.589	1.446
Indiana	4,637,976	3,418,576	1.357	1.235
Iowa	1,846,602	1,449,114	1.274	1.160
Kansas	1,940,745	1,443,265	1.345	1.224
Kentucky	3,074,656	2,244,283	1.370	1.247
Louisiana	2,429,529	1,650,884	1.472	1.339
Maine	821,980	630,393	1.304	1.187
Maryland	6,616,960	4,635,717	1.427	1.299
Massachusetts	7,693,991	5,728,767	1.343	1.222
Michigan	5,383,752	3,501,797	1.537	1.399
Minnesota	5,558,816	3,847,679	1.445	1.315
Mississippi	1,241,083	939,692	1.321	1.202
Missouri	4,754,552	3,588,694	1.325	1.206
Montana	1,148,453	919,206	1.249	1.137
Nebraska	577,746	424,822	1.360	1.238
Nevada	6,697,489	4,026,111	1.664	1.514
New Hampshire	292,227	228,854	1.277	1.162
New Jersey	8,492,015	5,649,618	1.503	1.368
New Mexico	2,236,262	1,395,073	1.603	1.459
New York	16,958,113	12,176,837	1.393	1.267
North Carolina	16,254,736	11,579,895	1.404	1.277
North Dakota	D	D	1.275	1.160
Ohio	6,788,825	4,883,462	1.390	1.265
Oklahoma	1,419,859	1,075,586	1.320	1.201
Oregon	5,519,819	4,019,693	1.373	1.250
Pennsylvania	9,971,624	7,323,399	1.362	1.239
Rhode Island	309,403	205,383	1.506	1.371
South Carolina	5,921,453	4,350,205	1.361	1.239
South Dakota	297,424	228,839	1.300	1.183
Tennessee	5,243,037	3,874,974	1.353	1.231
Texas	32,123,700	21,429,103	1.499	1.364
Utah	4,201,276	3,095,214	1.357	1.235
Vermont	527,837	387,905	1.361	1.238
Virginia	12,761,751	8,799,880	1.450	1.320

State*	Value of Residential Construction *$1,000***	Cost of Goods Sold *$1,000***	Baseline Markup	Incremental Markup
Washington	11,158,559	7,361,497	1.516	1.379
West Virginia	348,291	225,500	1.545	1.406
Wisconsin	3,820,533	2,850,921	1.340	1.219
Wyoming	524,809	418,215	1.255	1.142

Sources: U.S. Bureau of the Census, American Factfinder. 2007 Economic Census. Sector 23: Subsectors 236115 (residential single-family), 236116 (residential multifamily), 236117 (operative builders), and 236118 (residential remodelers). Sector 23: EC0723A1: Construction: Geographic Area Series: Detailed Statistics for Establishments: 2007.
* Notes: Markups may vary across states for several reasons, including differences in firm size. Due to sample size and/or magnitude of reporting error relative to the mean, disaggregated information not provided for all of the costs of goods sold. In these cases, the state markup ratio is calculated as an average of neighboring states (*e.g.,* North Dakota).
** The Census Bureau withheld data for the states denoted with a D.

6A.6 STATE SALES TAX RATES

DOE derives state and local taxes from data provided by the Sales Tax Clearinghouse. Table 6A.6.1 provides the disaggregated state tax rates that DOE used to develop the aggregated state tax rates in Tables 6.7.1 and 6.7.2 in chapter 6 of the TSD.

Table 6A.6.1 State Sales Tax Rates

State	Combined State and Local Tax Rate *%*	State	Combined State and Local Tax Rate *%*	State	Combined State and Local Tax Rate *%*
Alabama	8.60	Kentucky	6.00	North Dakota	6.00
Alaska	1.30	Louisiana	8.80	Ohio	7.10
Arizona	7.20	Maine	5.50	Oklahoma	8.40
Arkansas	8.95	Maryland	6.00	Oregon	--
California	8.45	Massachusetts	6.25	Pennsylvania	6.35
Colorado	6.10	Michigan	6.00	Rhode Island	7.00
Connecticut	6.35	Minnesota	7.20	South Carolina	7.10
Delaware	--	Mississippi	7.05	South Dakota	5.45
Dist. of Columbia	5.75	Missouri	7.45	Tennessee	9.45
Florida	6.65	Montana	--	Texas	7.95
Georgia	7.00	Nebraska	6.05	Utah	6.65
Hawaii	4.35	Nevada	7.95	Vermont	6.10
Idaho	6.00	New Hampshire	--	Virginia	5.60
Illinois	8.00	New Jersey	6.95	Washington	8.90
Indiana	7.00	New Mexico	6.70	West Virginia	6.05
Iowa	6.80	New York	8.45	Wisconsin	5.45
Kansas	7.90	North Carolina	6.90	Wyoming	5.45

Source: The Sales Tax Clearinghouse at https://thestc.com/STRates.stm (Last accessed on February 16, 2015).

6A.7 SUMMARY OF OVERALL MARKUPS FOR COMMERCIAL WATER-HEATING EQUIPMENT

In chapter 6 of the TSD, Tables 6.8.1 through 6.8.4 provide the aggregated markups for commercial water-heating equipment in the residential new construction, residential replacement, commercial new construction and commercial replacement markets. Table 6A.7.1

through Table 6A.7.5 provide the disaggregated markups for each equipment class. If a cell has one markup value, it indicates there is one markup for the category (*i.e.*, baseline and incremental markups are the same). Table 6A.7.6 provides a key for associating channel IDs with their corresponding distribution channel.

Table 6A.7.1 Summary of Overall Markups for Commercial Gas-fired Storage Water Heaters

Commercial Gas-fired Storage Water Heaters					
	Base/Incr	**Base/Incr**	**Base/Incr**	**Base/Incr**	**Base/Incr**
Commercial New Construction					
Channel ID	1	2	4	6	8
Manufacturer	1.45	1.45	1.45	1.45	1.45
Wholesaler	-	-	1.39/1.11	-	-
Manufacturer's Rep	-	1.39/1.11	-	-	-
Retailer	-	-	-	1.39/1.14	1.39/1.14
Mechanical Contractor	-	1.44/1.16	1.44/1.16	-	-
General Contractor	-	1.31/1.19	1.31/1.19	-	1.31/1.19
Sales Tax	1.07	-	-	1.07	-
Overall Markup	1.55	3.80/2.23	3.80/2.23	2.16/1.78	2.65/1.98
Assigned Distribution (Channel Mkt Share)	5%	10%	70%	10%	5%
Residential New Construction					
Channel ID	1	2	4	6	8
Manufacturer	1.45	1.45	1.45	1.45	1.45
Wholesaler	-	-	1.39/1.11	-	-
Manufacturer's Rep	-	1.39/1.11	-	-	-
Retailer	-	-	-	1.39/1.14	1.39/1.14
Mechanical Contractor	-	1.44/1.16	1.44/1.16	-	-
General Contractor	-	1.47/1.34	1.47/1.34	-	1.47/1.34
Sales Tax	1.07	-	-	1.07	-
Overall Markup	1.55	4.26/2.49	4.26/2.49	2.16/1.78	2.97/2.22
Assigned Distribution (Channel Market Share)	5%	10%	70%	10%	5%
Residential & Commercial Replacement					
Channel ID	1	3	5	6	7
Manufacturer	1.45	1.45	1.45	1.45	1.45
Wholesaler	-	-	1.39/1.11	-	-
Manufacturer's Rep	-	1.39/1.11	-	-	-
Retailer	-	-	-	1.39/1.14	1.39/1.14
Mechanical Contractor	-	1.53/1.23	1.53/1.23	-	1.53/1.23
General Contractor	-	-	-	-	-
Sales Tax	1.07	1.07	1.07	1.07	1.07
Overall Markup	1.55	3.29/2.12	3.29/2.12	2.16/1.78	3.31/2.18
Assigned Distribution (Channel Mkt Share)	5%	10%	65%	10%	10%

Table 6A.7.2 Summary of Overall Markups for Residential-Duty Gas-fired Storage Water Heaters

Residential-duty Gas-fired Storage Water Heaters					
	Base/Incr	**Base/Incr**	**Base/Incr**	**Base/Incr**	**Base/Incr**
Commercial New Construction					
Channel ID	1	2	4	6	8
Manufacturer	1.45	1.45	1.45	1.45	1.45
Wholesaler	-	-	1.39/1.11	-	-
Manufacturer's Rep	-	1.39/1.11	-	-	-
Retailer	-	-	-	1.39/1.14	1.39/1.14
Mechanical Contractor	-	1.44/1.16	1.44/1.16	-	-
General Contractor	-	1.31/1.19	1.31/1.19	-	1.31/1.19
Sales Tax	1.07	-	-	1.07	-
Overall Markup	1.55	3.80/2.23	3.80/2.23	2.16/1.78	2.65/1.98
Assigned Distribution (Channel Mkt Share)	5%	5%	70%	10%	10%
Residential New Construction					
Channel ID	1	2	4	6	8
Manufacturer	1.45	1.45	1.45	1.45	1.45
Wholesaler	-	-	1.39/1.11	-	-
Manufacturer's Rep	-	1.39/1.11	-	-	-
Retailer	-	-	-	1.39/1.14	1.39/1.14
Mechanical Contractor	-	1.44/1.16	1.44/1.16	-	-
General Contractor	-	1.47/1.34	1.47/1.34	-	1.47/1.34
Sales Tax	1.07	-	-	1.07	-
Overall Markup	1.55	4.26/2.49	4.26/2.49	2.16/1.78	2.97/2.22
Assigned Distribution (Channel Market Share)	5%	5%	70%	10%	10%
Commercial Replacement					
Channel ID	1	3	5	6	7
Manufacturer	1.45	1.45	1.45	1.45	1.45
Wholesaler	-	-	1.39/1.11	-	-
Manufacturer's Rep	-	1.39/1.11	-	-	-
Retailer	-	-	-	1.39/1.14	1.39/1.14
Mechanical Contractor	-	1.53/1.23	1.53/1.23	-	1.53/1.23
General Contractor	-	-	-	-	-
Sales Tax	1.07	1.07	1.07	1.07	1.07
Overall Markup	1.55	3.29/2.12	3.29/2.12	2.16/1.78	3.31/2.18
Assigned Distribution (Channel Mkt Share)	5%	5%	65%	12.5%	12.5%
Residential Replacement					
Channel ID	1	3	5	6	7
Manufacturer	1.45	1.45	1.45	1.45	1.45
Wholesaler	-	-	1.39/1.11	-	-
Manufacturer's Rep	-	1.39/1.11	-	-	-
Retailer	-	-	-	1.39/1.14	1.39/1.14
Mechanical Contractor	-	1.53/1.23	1.53/1.23	-	1.53/1.23
General Contractor	-	-	-	-	-
Sales Tax	1.07	1.07	1.07	1.07	1.07
Overall Markup	1.55	3.29/2.12	3.29/2.12	2.16/1.78	3.31/2.18
Assigned Distribution (Channel Mkt Share)	2.5%	2.5%	65%	15%	15%

Table 6A.7.3 Summary of Overall Markups for Commercial Gas-fired Instantaneous Tankless Water Heaters

Commercial Gas-fired Instantaneous Tankless Water Heaters					
	Base/Incr	**Base/Incr**	**Base/Incr**	**Base/Incr**	**Base/Incr**
Commercial New Construction					
Channel ID	1	2	4	6	8
Manufacturer	1.43	1.43	1.43	1.43	1.43
Wholesaler	-	-	1.39/1.11	-	-
Manufacturer's Rep	-	1.39/1.11	-	-	-
Retailer	-	-	-	1.39/1.14	1.39/1.14
Mechanical Contractor	-	1.44/1.16	1.44/1.16	-	-
General Contractor	-	1.31/1.19	1.31/1.19	-	1.31/1.19
Sales Tax	1.07	-	-	1.07	-
Overall Markup	1.53	3.75/2.20	3.75/2.20	2.13/1.75	2.61/1.95
Assigned Distribution (Channel Mkt Share)	10%	20%	60%	5%	5%
Residential New Construction					
Channel ID	1	2	4	6	8
Manufacturer	1.43	1.43	1.43	1.43	1.43
Wholesaler	-	-	1.39/1.11	-	-
Manufacturer's Rep	-	1.39/1.11	-	-	-
Retailer	-	-	-	1.39/1.14	1.39/1.14
Mechanical Contractor	-	1.44/1.16	1.44/1.16	-	-
General Contractor	-	1.47/1.34	1.47/1.34	-	1.47/1.34
Sales Tax	1.07	-	-	1.07	-
Overall Markup	1.53	4.20/2.46	4.20/2.46	2.13/1.75	2.93/2.19
Assigned Distribution (Channel Market Share)	10%	20%	60%	5%	5%
Commercial & Residential Replacement					
Channel ID	1	3	5	6	7
Manufacturer	1.43	1.43	1.43	1.43	1.43
Wholesaler	-	-	1.39/1.11	-	-
Manufacturer's Rep	-	1.39/1.11	-	-	-
Retailer	-	-	-	1.39/1.14	1.39/1.14
Mechanical Contractor	-	1.53/1.23	1.53/1.23	-	1.53/1.23
General Contractor	-	-	-	-	-
Sales Tax	1.07	1.07	1.07	1.07	1.07
Overall Markup	1.53	3.24/2.09	3.24/2.09	2.13/1.75	3.26/2.15
Assigned Distribution (Channel Mkt Share)	10%	20%	60%	5%	5%

Table 6A.7.4 Summary of Overall Markups for Commercial Gas-fired Instantaneous Hot Water Supply Boilers

Commercial Gas-fired Instantaneous Hot Water Supply Boilers					
	Base/Incr	**Base/Incr**	**Base/Incr**	**Base/Incr**	**Base/Incr**
Commercial New Construction					
Channel ID	1	2	4	6	8
Manufacturer	1.43	1.43	1.43	1.43	1.43
Wholesaler	-	-	1.39/1.11	-	-
Manufacturer's Rep	-	1.39/1.11	-	-	-
Retailer	-	-	-	1.39/1.14	1.39/1.14
Mechanical Contractor	-	1.44/1.16	1.44/1.16	-	-
General Contractor	-	1.31/1.19	1.31/1.19	-	1.31/1.19
Sales Tax	1.07	-	-	1.07	-
Overall Markup	1.53	3.75/2.20	3.75/2.20	2.13/1.75	2.61/1.95
Assigned Distribution (Channel Mkt Share)	5%	20%	70%	2.5%	2.5%
Residential New Construction					
Channel ID	1	2	4	6	8
Manufacturer	1.43	1.43	1.43	1.43	1.43
Wholesaler	-	-	1.39/1.11	-	-
Manufacturer's Rep	-	1.39/1.11	-	-	-
Retailer	-	-	-	1.39/1.14	1.39/1.14
Mechanical Contractor	-	1.44/1.16	1.44/1.16	-	-
General Contractor	-	1.47/1.34	1.47/1.34	-	1.47/1.34
Sales Tax	1.07	-	-	1.07	-
Overall Markup	1.53	4.20/2.46	4.20/2.46	2.13/1.75	2.93/2.19
Assigned Distribution (Channel Market Share)	5%	20%	70%	2.5%	2.5%
Commercial & Residential Replacement					
Channel ID	1	3	5	6	7
Manufacturer	1.43	1.43	1.43	1.43	1.43
Wholesaler	-	-	1.39/1.11	-	-
Manufacturer's Rep	-	1.39/1.11	-	-	-
Retailer	-	-	-	1.39/1.14	1.39/1.14
Mechanical Contractor	-	1.53/1.23	1.53/1.23	-	1.53/1.23
General Contractor	-	-	-	-	-
Sales Tax	1.07	1.07	1.07	1.07	1.07
Overall Markup	1.53	3.24/2.09	3.24/2.09	2.13/1.75	3.26/2.15
Assigned Distribution (Channel Mkt Share)	5%	20%	70%	2.5%	2.5%

Table 6A.7.5 Summary of Overall Markups for Commercial Electric Storage Water Heaters

Commercial Electric Storage Water Heaters					
	Base/Incr	**Base/Incr**	**Base/Incr**	**Base/Incr**	**Base/Incr**
Commercial New Construction					
Channel ID	1	2	4	6	8
Manufacturer	1.43	1.43	1.43	1.43	1.43
Wholesaler	-	-	1.39/1.11	-	-
Manufacturer's Rep	-	1.39/1.11	-	-	-
Retailer	-	-	-	1.39/1.14	1.39/1.14
Mechanical Contractor	-	1.44/1.16	1.44/1.16	-	-
General Contractor	-	1.31/1.19	1.31/1.19	-	1.31/1.19
Sales Tax	1.07	-	-	1.07	-
Overall Markup	1.53	3.75/2.20	3.75/2.20	2.13/1.75	2.61/1.95
Assigned Distribution (Channel Mkt Share)	5%	5%	60%	15%	15%
Residential New Construction					
Channel ID	1	2	4	6	8
Manufacturer	1.43	1.43	1.43	1.43	1.43
Wholesaler	-	-	1.39/1.11	-	-
Manufacturer's Rep	-	1.39/1.11	-	-	-
Retailer	-	-	-	1.39/1.14	1.39/1.14
Mechanical Contractor	-	1.44/1.16	1.44/1.16	-	-
General Contractor	-	1.47/1.34	1.47/1.34	-	1.47/1.34
Sales Tax	1.07	-	-	1.07	-
Overall Markup	1.53	4.20/2.46	4.20/2.46	2.13/1.75	2.93/2.19
Assigned Distribution (Channel Market Share)	5%	5%	60%	15%	15%
Commercial & Residential Replacement					
Channel ID	1	3	5	6	7
Manufacturer	1.43	1.43	1.43	1.43	1.43
Wholesaler	-	-	1.39/1.11	-	-
Manufacturer's Rep	-	1.39/1.11	-	-	-
Retailer	-	-	-	1.39/1.14	1.39/1.14
Mechanical Contractor	-	1.53/1.23	1.53/1.23	-	1.53/1.23
General Contractor	-	-	-	-	-
Sales Tax	1.07	1.07	1.07	1.07	1.07
Overall Markup	1.53	3.24/2.09	3.24/2.09	2.13/1.75	3.26/2.15
Assigned Distribution (Channel Mkt Share)	5%	5%	60%	15%	15%

Table 6A.7.6 Channel ID Key

Channel ID	**Distribution Channel**
1	Manufacturer → Comm Consumer (via National Account)
2	Manufacturer → Manufacturer's Rep → Mech Contractor → Gen Contractor → Comm Consumer
3	Manufacturer → Manufacturer's Rep → Mech Contractor → Comm Consumer
4	Manufacturer → Wholesaler → Mech Contractor → Gen Contractor → Comm Consumer
5	Manufacturer → Wholesaler → Mech Contractor → Comm Consumer
6	Manufacturer → Retailer → Comm Consumer
7	Manufacturer → Retailer → Mech Contractor → Comm Consumer
8	Manufacturer → Retailer → Gen Contractor → Comm Consumer

CHAPTER 7. ENERGY USE ANALYSIS

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CHAPTER 7. ENERGY USE ANALYSIS

7.1 INTRODUCTION

The purpose of the energy use analysis is to determine the annual energy consumption of commercial water heating (CWH) equipment in the United States market and to assess the energy savings potential of improvements in efficiency (in terms of uniform energy factor, thermal efficiency and standby loss performance). In contrast to the CWH equipment test procedure under Title 10 of the Code of Federal Regulations, Part 431, which uses fixed operating conditions in a laboratory setting, the energy use analysis for CWH equipment seeks to estimate the range of energy consumption of the equipment in the field. The U.S. Department of Energy (DOE) estimates the annual energy consumption of such equipment at specified energy efficiency levels across a range of regions and building characteristics.

For the calculation of the energy consumed by CWH equipment, DOE considers the energy use associated with providing water heating in either commercial or residential buildings. Energy use is analyzed from the approach of fulfilling the entire building's hot water load. The energy use analysis provides estimates of the distribution of annual energy consumption for CWH equipment at each efficiency standard level considered.

DOE develops energy consumption estimates for the key equipment classes listed in Table 7.1.1. The CWH equipment analyzed utilize natural gas fuel or electric power for heating water as well as the associated electric energy to power components such as an igniter, draft inducer (fan), and other auxiliary equipment.

Table 7.1.1 CWH Equipment Classes Analyzed

Equipment Class	Representative Model	
	Input Capacity	Volume *gal*
Commercial gas-fired storage water heater	199,000 Btu/h	100
Residential-duty gas-fired storage water heater	76,000 Btu/h	75
Commercial gas-fired instantaneous: tankless water heater	250,000 Btu/h	-
Commercial gas-fired instantaneous: hot water supply boiler	399,000 Btu/h	-
Commercial electric storage water heater	18 kW	119

DOE estimates the energy consumption of CWH equipment in commercial and residential buildings by developing a building sample for each of the equipment classes based on the Energy Information Administration's (EIA) 2003 Commercial Building Energy Consumption Survey (CBECS 2003) and EIA's 2009 Residential Energy Consumption Survey (RECS 2009).[1,2] These are the latest available surveys for commercial and residential buildings.[a] This sample is further described in section 7.2.

[a] EIA is currently working on the 2013 version of RECS, which is not expected to be available until some point in 2015. Additionally, EIA determined that the 2007 CBECS did not yield valid statistical estimates of building counts, energy characteristics, consumption, and expenditures and therefore did not release the majority of the data tables and public use files. Thus, CBECS 2003 data were used for this analysis.

DOE developed daily hot water loads specific to each building record sampled from CBECS 2003 and RECS 2009. For each commercial building type, DOE developed and applied gallons-per-day hot water loads on a square-foot basis to each sampled commercial building. For each residential building type, DOE applied the hot water loads model developed by the Lawrence Berkeley National Laboratory (LBNL)[3] to each sampled residential building. For multi-family building records, DOE converted the housing unit's load to a total hot water load for the building. Then, DOE converted daily volumetric hot water loads into daily British thermal unit (Btu) energy loads.

DOE developed maximum hot water loads for each building record sampled from CBECS 2003 and housing record sampled from RECS 2009. These loads determined the number and appropriateness of the CWH equipment needed to fulfill a building's maximum load over the max load duration. Using the daily Btu energy loads and number of CWH equipment units for the specific building, DOE determined the operating hours of the CWH equipment to satisfy the building. From the operating and standby hours, DOE developed energy use for equipment across efficiency levels.

7.2 BUILDING SAMPLE

DOE's determination of the annual energy use of CWH equipment relies on data from CBECS 2003 and RECS 2009. CBECS 2003 includes building characteristic data from 5,215 building records representing 4.9 million commercial buildings. RECS 2009 includes housing unit characteristic data from 12,083 housing unit records that represent more than 113.6 million households.

The subset of CBECS 2003 or RECS 2009 records used in the analysis meet all the following general criteria:

- not vacant
- use water heating equipment for hot water
- use an energy source that is natural gas fuel or electric power (matching the fuel type of the CWH equipment class).

DOE disaggregates EIA's CBECS 2003- and RECS 2009-derived subset into further subsets. The subsets are designed to isolate the buildings that are suitable for each of the different equipment classes analyzed (as shown in Table 7.2.1). To sample between the commercial and residential samples, DOE converts RECS residential housing unit records into building records (conversion factors detailed in appendix 7A). This allows for the sampling of commercial and residential buildings concurrently.

Certain CBECS building types (PBA-plus categories) were not sampled since DOE did not have enough information to assign hot water loads to them (as shown in appendix 7A). These CBECS building types amounted to the exclusion of 566 records representing 773,559 buildings. Mobile homes (RECS Type HUQ 4) were not sampled from RECS data since DOE determined this residential housing type is not suitable for CWH equipment. This amounted to the exclusion of 541 records representing 6,940,961 housing units. For housing unit records in multifamily buildings (Type HUQ 4 and 5), DOE excluded records in which the water heating equipment was not used by more than one housing unit (*i.e.*, was not shared amongst multiple housing units). This amounted to the exclusion of 1,618 records representing 15,792,940 housing units.

DOE also disaggregated the CBECS 2003- and RECS 2009-derived subsets based on the ability of each equipment class' representative model to meet a building's maximum load requirement. The baseline representative model of each equipment class has a hot water delivery performance capability (as discussed in further detail in section 7.7). If the maximum load requirement of a sampled building is lower than 90 percent of the hot water delivery performance of the baseline representative model, then the building is not sampled since its maximum load is deemed not large enough for the specific CWH equipment to be a suitable option to service the load. Due to the maximum input capacity and storage specifications of residential-duty gas-fired storage water heaters, DOE limited the buildings sample to records requiring four or fewer units to fulfill the maximum load since larger maximum load requirements were deemed more likely served by larger capacity equipment.

More than one equipment class may be suitable to fulfill the hot water requirements of the same building record due to similar cumulative hot water delivery capability. In addition, CBECS 2003 and RECS 2009 data do not report which types of CWH equipment are installed in which building records. As a result, sampled building records may have been analyzed for more than one equipment class.

The CBECS 2003 and RECS 2009 sample weights indicate how prevalent each commercial or residential building is on a national level, in 2003 and 2009, respectively. Appendix 7A provides the variables included in the analysis and their definitions, as well as further information about the derivation of the building samples and adjustments to the weights.

Table 7.2.1 Selection of CBECS 2003 Records for CWH Equipment

Equipment Class	CBECS 2003		RECS 2009	
	No. of Records	Number of Buildings	No. of Records	Number of Buildings
Commercial gas-fired storage water heater	839	213,622	334	61,450
Residential-duty gas-fired storage water heater	494	233,542	471	249,747
Commercial gas-fired instantaneous: tankless water heater	1,025	333,308	626	406,753
Commercial gas-fired instantaneous: hot water supply boiler	517	83,599	223	25,660
Commercial electric storage water heater	624	182,994	199	91,963

7.3 HOT WATER USE IN COMMERCIAL BUILDINGS

To calculate the energy use of CWH equipment in each equipment class, DOE first determines the daily hot water load demand of the sampled building. For commercial buildings, DOE used the daily hot water load schedules and square footage from the scorecards of the 2013 DOE Commercial Prototype Building Models[4] and normalized peaks from the DOE EnergyPlus Energy Simulation Software.[5] Using the daily load schedules and normalized peaks, DOE developed average gallons-per-day (GPD) load per building type (shown in appendix 7B). The commercial building's GPD load is calculated using the following equation:

$$GPD_{Bldg} = \sum_{T=1}^{24} Peak_{Day} \times Peak_{HR\_Fraction}$$

Eq. 7.1

Where:

GPD_{Bldg} = Gallons-per-day hot water demand for the commercial building type, gal
$Peak_{Day}$ = Average peak hour demand per day for the commercial building type, gal
$Peak_{HR\_Fraction}$ = Fraction of peak demand for each hour, percent
T = Hour of day, h

Once the GPD load was calculated for every commercial prototype building, DOE divided the GPD by the square footage specific to each commercial prototype building to determine GPD per square foot. DOE mapped the commercial prototype buildings to the CBECS specific principal building activity (PBA-plus) based on the similarity of building activity. Using the GPD per square foot, DOE then scaled the hot water load to the square footage of the sampled CBECS commercial building record based on specific principal building activity (shown in Table 7.3.1).

The small, medium, and large office commercial prototype buildings were differentiated based on the number of floors. Offices were considered small if having one floor, medium if having two to four floors, and large if having five floors or more. Since the commercial prototype buildings did not include nursing homes and dormitories in the collection of building types, DOE used the *2011 ASHRAE Handbook of HVAC Applications*[6] to determine their average GPD load. Dormitory GPD was based on the number of rooms in the building while nursing home GPD was based on the number of beds. Dormitory rooms were assumed to have an average of one and a half students per room.

Table 7.3.1 Commercial Building GPD-per-Thousand-Square-Feet Scalars

Commercial Prototype Building	CBECS PBA-Plus	Average GPD	Square Feet	GPD per Thousand Square Feet
Small Office	'02'='Administrative/professional office' '03'='Bank/other financial' '04'='Government office' '05'='Medical office (non-diagnostic)' '06'='Mixed-use office' '07'='Other office' '44'='Post office/postal center' '16'='Fire station/police station' '17'='Other public order and safety'	21.83	5,503	3.968
Medium Office	'02'='Administrative/professional office' '03'='Bank/other financial' '04'='Government office' '05'='Medical office (non-diagnostic)' '06'='Mixed-use office' '07'='Other office' '44'='Post office/postal center' '16'='Fire station/police station' '17'='Other public order and safety'	195.61	53,633	3.647
Large Office	'02'='Administrative/professional office' '03'='Bank/other financial' '04'='Government office' '05'='Medical office (non-diagnostic)' '06'='Mixed-use office' '07'='Other office' '44'='Post office/postal center' '16'='Fire station/police station' '17'='Other public order and safety'	1,643.88	498,637	3.297
Standalone Retail	'42'='Retail store' '12'='Convenience store' '13'='Convenience store with gas station' '14'='Grocery store/food market' '41'='Vehicle dealership/showroom' '43'='Other retail'	97.70	24,692	3.957
Strip Mall	'50'='Strip shopping mall' '51'='Enclosed mall'	9.25	22,500	0.411
Primary School	'28'='Elementary/middle school' '31'='Other classroom education' '30'='Preschool/daycare'	637.04	73,966	8.613
Secondary School	'29'='High school' '27'='College/university'	2,587.08	210,907	12.266
Outpatient Healthcare	'18'='Medical office (diagnostic)' '19'='Clinic/other outpatient health'	346.93	40,946	8.473
Hospital	'35'='Hospital/inpatient health'	3,285.67	241,413	13.610
Small Hotel	'39'='Motel or inn'	2,342.36	40,101	58.412
Large Hotel	'38'='Hotel'	4,460.34	122,115	36.526

Commercial Prototype Building	CBECS PBA-Plus	Average GPD	Square Feet	GPD per Thousand Square Feet
Warehouse	'09'='Distribution/shipping center' '10'='Non-refrigerated warehouse' '47'='Vehicle storage/maintenance' '11'='Self-storage' '20'='Refrigerated warehouse'	30.96	52,050	0.595
Quick-service Restaurant	'32'='Fast food'	564.51	2,501	225.714
Full-service Restaurant	'33'='Restaurant/cafeteria'	1,592.99	5,502	289.530
Assembly	'21'='Religious worship' '22'='Entertainment/culture' '23'='Library' '24'='Recreation' '25'='Social/meeting' '26'='Other public assembly'	173.74	10,751	16.160

Building Type	CBECS PBA-Plus	GPD per bed	GPD per room	CBECS Code
Nursing Homes	'36'='Nursing home/assisted living'	18.4	-	NRSBED8
Dormitories	'37'='Dormitory/fraternity/sorority'	-	19.05	LODRM8

7.4 HOT WATER USE IN RESIDENTIAL BUILDINGS

To calculate daily hot water loads for residential buildings, DOE used the hot water use model created by the LBNL for the 2010 “Energy Conservation Standards for Residential Water Heaters, Direct Heating Equipment, and Pool Heaters.”[7] 75 FR 20112 (April 16, 2010) This model was developed to determine hot water loads of individual housing units and was an update to a previously used LBNL model.[8] For RECS housing unit records in multi-family buildings, DOE modified the model for the analysis of whole building loads. This meant normalizing the number of housing unit occupants in each age group in the calculation of daily loads (shown in appendix 7B), which prevented units with anomalous occupancy from characterizing entire buildings. The LBNL model reflected an analysis in which each housing unit had a water heater with a specific storage tank size to serve the housing unit’s hot water load. To calibrate for this, DOE assigned storage tank sizes to housing unit records as if the load were served by an individual water heater in the apartment, as determined using a distribution based on RECS data for multifamily buildings with individual water heaters in housing units (shown in appendix 7B). Then, DOE multiplied the housing unit’s load by the number of units in the building to determine the total hot water load of the building.

7.4.1 Equation for Hot Water Use

The hot water draw model uses an equation expressed as follows.

$$vol = \{sea\_coef + (per\_coef \times per) + (age1\_coef \times age1) + (age2\_coef \times age2) + [age34\_coef \times (age3 + age4)] + (T_{tank}\_coef \times T_{tank}) + (Tank_{sz}\_coef \times Tank_{sz}) + (T_{in}\_coef \times T_{in}) + (T_{air}\_coef \times$$

T_{air}) + (home_*coef* × *athome*) − [(0.692 × *per* +1.335 × $\sqrt{per}$) × *dw_adj* −[(1.1688 × *per* + 4.7737 × $\sqrt{per}$) × *cw_adj*]} × (*senior_mf_coef* × *senior_mf*) × (*no_pay_coef* × *no_pay*)

Eq. 7.2

Where:

vol = hot water consumption, gallons per day, gal/day,
per = total number of persons in the household,
age1 = number of children, age 0–5 years,
age2 = number of children, age 6–13,
age3 = number of adults, age 14–64,
age4 = number of adults, age 65 or above,
T_{tank} = thermostat setting of water heater, degrees Fahrenheit, °F,
$Tank_{sz}$ = nominal tank size of water heater, gal,
T_{in} = temperature of water heater inlet water, °F,
T_{air} = outdoor air temperature, °F,
athome = presence of adults at home during day,
dw_adj = adjustment factor to account for the differences between the current energy conservation standard for dishwashers and the households that have no dishwasher,
cw_adj = adjustment factor to account for the differences between the current energy conservation standard for clothes washers and the households that have no clothes washer,
senior_mf = senior-only household in a multi-family building,
no_pay = household that does not pay for hot water,
sea_coef = coefficient for seasonal effects,
per_coef = coefficient for total number of persons in household (normal distribution),
age1_coef = coefficient for "age1" (normal distribution),
age2_coef = coefficient for "age2" (normal distribution),
age34_coef = coefficient for "age3" + "age4" (normal distribution),
home_coef = coefficient for "athome" (normal distribution),
$Tank_{sz}$*_coef* = coefficient for water heater tank size (normal distribution),
T_{tank}*_coef* = coefficient for thermostat set point (normal distribution),
T_{in}*_coef* = coefficient for water inlet temperature (normal distribution),
T_{air}*_coef* = coefficient for average outdoor temperature (normal distribution),
senior_mf_coef = coefficient for senior-only household in a multi-family building (normal distribution), and
no_pay_coef = coefficient for household that does not pay for hot water (normal distribution).

7.4.2 Description of Key Variables Used in Draw Model

The following is a description of the primary variables used in the hot water draw model. See appendix 7B for criteria used to determine each draw model variable.

- *Number of Persons in Household (per)*. The total number of household members.
- *Number of Preschool Children 0–5 (age1)*. The total number of infants and young children ages 0 to 5.

- *Number of School-Age Children 6–13 (age2)*. The total number of children, ages 6 to 13.
- *Number of Adults 14–64 (age3)*. The total number of adults, ages 14 to 64.
- *Number of Adults 65+ (age4)*. The total number of adults, age 65 or older.
- *Number of Thermostat Set point (T_{tank})*. The thermostat setting of the water heater.
- *Water Heater Tank Size (Tanksz)*. The nominal size of the water heater tank.
- *Outdoor Air Temperature (T_{air})*. The average annual outdoor air temperature.
- *Inlet Water Temperature (T_{in})*. The temperature of the water entering the water heater.
- *Household Member (athome)*. The presence of an adult household member at home during the day.
- *Senior Only (senior_mf)*. A senior-only (age 65 or above) household in a multi-family building.
- *No-Pay Household (no_pay)*. A household that does not pay to heat water.
- *Coefficient for Seasonal Effects (sea_coef)*. Variable that adjusts hot water use for winter, spring, summer, and fall seasons.
- *Dishwasher (dw_adj)*. Adjustment factor to account for the differences due to the current energy conservation standard for dishwashers and for the cases of households with no dishwashers.
- *Clothes Washer (cw_adj)*. Adjustment factor to account for the differences between the current energy conservation standard for clothes washers and households that have no clothes washers.

7.5 CONVERSION OF HOT WATER USE TO ENERGY USE

DOE converted daily volumetric hot water loads into daily Btu energy loads by using an equation that multiplies a building's average gallons-per-day (GPD) consumption of hot water by the density of water, specific heat of water, and the hot water temperature rise.

$$HWL_{bldg} = GPD_{bldg} \times dT_m \times Cp \times y$$

Eq. 7.3

Where:

HWL_{bldg} = Btu per day of energy use to meet the hot water load for the sampled building,
GPD_{bldg} = gallons per day hot water use for the sampled building,
dT_m = change in temperature from the equipment's set-point temperature to the average monthly inlet temperature of the sampled building for the given month (m), °F,
Cp = specific heat of water, Btu per pound per °F, and
y = specific weight of water, pounds per gallon.

DOE held specific heat of water (Cp) constant at 1.000743 BTU per pound per °F and specific weight of water (y) constant at 8.29 pounds per gallon for all sampled building energy use calculations. The temperature rise (dT_m) was specific to the sampled building and differed by month due to the variation in inlet temperature. The equipment's set point temperature was either 120 °F or 140 °F based on the residential or commercial building type, as detailed in appendix 7B.

The inlet temperature was specific to the sampled residential or commercial building. To calculate the inlet temperature, DOE developed monthly dry bulb temperature estimates for each U.S. state using typical mean year (TMY) temperature data, captured in location files provided by the DOE EnergyPlus Energy Simulation Software.[5] Then, these dry bulb temperatures were used to develop monthly average inlet temperatures using an equation and methodology developed by the National Renewable Energy Laboratory (NREL).[9]

$$T_{mains} = (T_{amb,avg} + offset) + ratio \times \left(\frac{dT_{amb,max}}{2}\right) * sin(0.986 \times (day\# - 15 - lag) - 90)$$

Eq. 7.4

Where:

T_{mains} = mains (supply) temperature to the CWH equipment (also known as the inlet temperature), °F,
$T_{amb,avg}$ = annual average ambient air temperature, °F,
$dT_{amb,max}$ = maximum difference between monthly average ambient temperatures (*e.g.,* $T_{amb,avg,july}$ - $T_{amb,avg,January}$), °F,
0.986 = degrees/day (360/365),
day# = Julian day of the year (1–365),
offset = 6 °F,
ratio = 0.4 + 0.1 × ($T_{amb,avg}$ – 44), and
lag = 35 – 1.0 × ($T_{amb,avg}$ – 44).

Dry bulb and inlet water temperature data are available in appendix 7C.

In addition, DOE used building-specific Btu load adders to account for the additional piping heat loss in building types that typically use recirculation loops to distribute hot water to end uses. These adders are the product of the pipe length, pipe heat loss rate, temperature difference between the ambient air and hot water in pipes, and recirculation loop operating hours for the building using a methodology described by Sezgen and Koomey.[10]

$$DL_{bldg} = \left(2 \times \sqrt{\frac{SqFt_{bldg}}{N_{floors}}} + Ht_{riser} \times (N_{floors} - 1)\right) \times P_{ua} \times dT \times T_{recirc}$$

Eq. 7.5

Where:

DL_{bldg} = daily Btu heat loss from recirculation loop operation, Btu,
$SqFt_{bldg}$ = square footage of the building, ft^2,
N_{floors} = number of floors,
Ht_{riser} = height of recirculation loop riser, ft,
P_{ua} = heat loss from piping, Btu/h per ft per °F,
dT = change in temperature from the recirculation loop's hot water temperature to the building ambient temperature, °F, and
T_{recirc} = hours of recirculation loop operation, h.

DOE held constant the height of the recirculation loop riser (Ht_{riser}) at 10 feet per floor, piping heat loss (P_{ua}) at 0.25 Btu/h per foot per °F (0.5 inch glass fiber insulation on 0.75 inch copper piping),[6] recirculation loop's hot water temperature at 120 °F, and building ambient temperature at 70 °F (dT).

The number of floors was specific to the RECS building record data. For CBECS, the number of floors was specific to the building record data for buildings with 1 to 14 floors. CBECS building records with 15 or more floors were classified into two categories,15-25 floors and greater than 25 floors. DOE assigned 20 floors to records in the "15-25 floors" category, and 30 floors to the records in the "greater than 25 floors" category.

Square footage was specific to the CBECS building record data. For RECS, DOE assigned recirculation loop losses to apartment buildings with five or more units (Type HUQ 5) and shared water heating equipment. Building square footage was calculated by multiplying the housing unit's square footage by the number of apartments in the building. DOE estimated the recirculation loop hours of operation (T_{recirc}) based on the expected hours of hot water activity for the building type. Details on the building types selected for recirculation loop systems and their recirculation loop operating hours are available in appendix 7B.

7.6 MAXIMUM HOT WATER LOADS FOR SIZING

The size and number of CWH equipment needed to fulfill a building's hot water demand is based on a building's maximum hot water load over the duration in which this load occurs. DOE determined the gallons-per-hour (GPH) load of sampled buildings for sizing by developing a methodology based primarily on the sizing calculators of a major CWH equipment manufacturer.[11] DOE used the default temperature settings of the sizing calculators, which resulted in a water temperature rise of 100 °F for all buildings except hospitals, nursing homes, single-family detached homes and single-family attached homes (80 °F temperature rise). Each building type, whether residential or commercial, had its calculations tailored to its hot water usage activities. These activities are categorized as main max load, laundry max load, and food service and preparation max load. The main max load is customized specifically to each building type, whereas the laundry and food service and preparation max loads are additional loads. Details on the inputs and assumptions used in the hot water load sizing calculations are shown in appendix 7B.

7.6.1 Primary Building Max Load Calculations

DOE customized the main max load to each building type as defined in each building type's subsection. The additional food service and laundry max loads have their calculations defined in section 7.6.2.

7.6.1.1 Apartment Buildings

DOE adapted a manufacturer's sizing methodology to size CWH equipment to the hot water activity in apartment buildings. The main max load, occupant showering, is depicted in the parenthetical element of the formula calculating the overall building max load.

$$Max_{apt} = \left(Apts \times\ Occ_{apt} \times T_{shower:apt} \times GPM_{shower:apt} \div D_{shower:apt}\right) + Max_{cl} + Max_{ul}$$

Eq. 7.6

Where:

Max_{apt} = maximum gallons-per-hour load for the sampled apartment building,
$Apts$ = number of apartments in the building,
Occ_{apt} = number of occupants per apartment,
$T_{shower:apt}$ = minutes per shower,
$GPM_{shower:apt}$ = gallons-per-minute of hot water flowing out of the showerhead,
$D_{shower:apt}$ = duration of the showering period for the apartment building,
Max_{cl} = max gallons-per-hour for the apartment building's communal laundry activity, and
Max_{ul} = max gallons-per-hour for the apartment building's unit laundry activity.

Apartment buildings are assumed to either have a communal laundry room of clothes washers or individual clothes washers within each apartment unit. Thus, either Max_{cl} or Max_{ul} will be zero, depending on the laundry accommodations in the building.

7.6.1.2 Hotel/Motel

DOE adapted a manufacturer's sizing methodology to size CWH equipment to the hot water activity in hotels and motels. The main max load includes occupant showering, service sinks, and public bath rooms. These hot water sub-activities are depicted in the parenthetical elements of the formula calculating the overall building max load.

$$\begin{aligned} Max_{hm} = (&Rm_{hm} \times Occ_{rm:hm} \times\ T_{shower:hm} \times GPM_{hm}\ \div D_{shower:hm}) \\ &+ (Sinks_{hm} \times GPH_{sink:hm}) + (PBR_{hm} \times GPH_{PBR:hm}) + Max_{fs:hm} \\ &+ Max_{mll:hm} \end{aligned}$$

Eq. 7.7

Where:

Max_{hm} = maximum gallons-per-hour load for the sampled hotel/motel,
Rm_{hm} = number of rooms in the hotel/motel,
$Occ_{rm:hm}$ = number of occupants per hotel/motel room,
$T_{shower:hm}$ = minutes per shower,
GPM_{hm} = gallons-per-minute of hot water flowing out of the showerhead,
$D_{shower:hm}$ = duration of the shower period for the hotel/motel, as a whole,
$Sinks_{hm}$ = number of service sinks in the hotel/motel,
$GPH_{sinks:hm}$ = gallons-per-hour of hot water flowing out of the service sinks,
PBR_{hm} = number of public bath rooms in the hotel/motel,
$GPH_{PBR:hm}$ = gallons-per-hour of hot water use per public bath room,
$Max_{fs:hm}$ = max gallons-per-hour for the hotel/motel's food service activity (if present in building), and

$Max_{mll:hm}$ = max gallons-per-hour for the hotel/motel's multi-load laundry activity (if present in building).

7.6.1.3 Dormitory

DOE adapted a manufacturer's sizing methodology to size CWH equipment to the hot water activity in dormitories. The main max load includes occupant hot water usage and service sinks. Those hot water sub-activities are depicted in the parenthetical elements of the formula calculating the overall building max load.

$$Max_d = (Rm_d \times Occ_{rm:d} \times GPH_{occ:d}) + (Sinks_d \times GPH_{sinks:d}) + Max_{fs:d} + Max_{cl:d}$$

Eq. 7.8

Where:

Max_d = maximum gallons-per-hour load for the sampled dormitory,
Rm_d = number of rooms in the dormitory,
$Occ_{rm:d}$ = number of occupants per dormitory room,
$GPH_{occ:d}$ = gallons-per-hour of hot water per dormitory occupant
$Sinks_d$ = number of service sinks in the dormitory,
$GPH_{sinks:d}$ = gallons-per-hour of hot water flowing out of the service sinks,
$Max_{fs:d}$ = max gallons-per-hour for the dormitory's food service activity (if present in building), and
$Max_{cl:d}$ = max gallons-per-hour for the dormitory's communal laundry activity (if present in building).

7.6.1.4 Single-family Home

DOE adapted a manufacturer's sizing methodology to size CWH equipment, notably residential-duty gas storage water heaters, to the hot water activity in single-family attached and detached homes. The single-family home building type (attached or detached) has only a main max load since single-family homes do not conduct commercial food preparation and service, or large-scale laundry activity. The main max load includes occupant hot water usage, bath rooms, dishwasher and clothes washer. Those hot water activities are depicted in the formula calculating the overall building max load.

$$Max_{sfh} = \left(Occ_{sfh} \times GPH_{occ:sfh}\right) + \left(BR_{sfh} \times GPH_{br:sfh}\right) + GPH_{dw:sfh} + GPH_{cw:sfh}$$

Eq. 7.9

Where:

Max_{sfh} = maximum gallons-per-hour load for the sampled single-family home,
Occ_{sfh} = number of occupants in the home,
$GPH_{occ:sfh}$ = gallons-per-hour of hot water adder per occupant,
BR_{sfh} = number of bath rooms in the single-family home,
$GPH_{br:sfh}$ = gallons-per-hour of hot water adder per bath room,
$GPH_{dw:sfh}$ = gallons-per-hour adder for the presence of a dishwasher, and

$GPH_{cw:sfh}$ = gallons-per-hour adder for the presence of a clothes washer.

7.6.1.5 Office Building

DOE adapted a manufacturer's sizing methodology to size CWH equipment to the hot water activity in office buildings. The main max load is worker general hot water usage, which is depicted in the parenthesis of the formula calculating the overall building max load.

$$Max_{off} = \left(Wker_{off} \times GPH_{off:wker}\right) + Max_{fs:off} + Max_{cl:off}$$

Eq. 7.10

Where:

Max_{off} = maximum gallons-per-hour load for the sampled office building,
$Wker_{off}$ = number of workers in the office building,
$GPH_{off:wker}$ = gallons-per-hour of hot water per worker,
$Max_{fs:off}$ = max gallons-per-hour for the food service activity (if present), and
$Max_{cl:off}$ = max gallons-per-hour for the communal laundry activity (if present).

7.6.1.6 Nursing Home

DOE adapted a manufacturer's sizing methodology to size CWH equipment to the hot water activity in nursing homes. The main max load is resident general hot water usage, which is depicted in the parenthesis in the formula calculating the overall building max load.

$$Max_{nh} = (Beds_{nh} \times GPH_{bed:nh}) + Max_{fs:nh} + Max_{mll:nh}$$

Eq. 7.11

Where:

Max_{nh} = maximum gallons-per-hour load for the sampled nursing home,
$Beds_{nh}$ = number of beds in the nursing home,
$GPH_{bed:nh}$ = gallons-per-hour of hot water per bed,
$Max_{fs:nh}$ = max gallons-per-hour for the food service activity (if present), and
$Max_{mll:nh}$ = max gallons-per-hour for the multi-load laundry activity (if present).

7.6.1.7 Full Service Restaurant

DOE adapted a manufacturer's sizing methodology to size CWH equipment to the hot water activity in full service restaurants. The main max load is hot water usage for meal preparation, which is depicted in the formula calculating the overall building max load.

$$Max_{fsr} = Seats_{fsr} \times Gal_{meal:fsr} \div T_{meal:fsr}$$

Eq. 7.12

Where:

Max_{fsr} = maximum gallons-per-hour load for the sampled full service restaurant,

$Seats_{fsr}$ = number of seats in the restaurant,
$Gal_{meal:fsr}$ = gallons of hot water per meal, and
$T_{meal:fsr}$ = hours expended per consumer per meal.

7.6.1.8 Quick Service Restaurant

DOE adapted a manufacturer's sizing methodology to size CWH equipment to the hot water activity in quick service restaurants. The main max load is hot water usage for meal preparation, which is depicted in the formula calculating the overall building max load.

$$Max_{qsr} = Seats_{qsr} \times Gal_{meal:qsr} \div T_{meal:qsr}$$

Eq. 7.13

Where:

Max_{qsr} = maximum gallons-per-hour load for the sampled quick service restaurant,
$Seats_{qsr}$ = number of seats in the restaurant,
$Gal_{meal:qsr}$ = gallons of hot water per meal, and
$T_{meal:qsr}$ = hours expended per consumer per meal.

7.6.1.9 Primary School

DOE adapted a manufacturer's sizing methodology to size CWH equipment to the hot water activity in primary schools. The main max load is student general hot water usage, which is depicted in the parenthesis of the formula calculating the overall building max load.

$$Max_{ps} = \left(Seat_{ps} \times GPH_{seat:ps}\right) + Max_{fs:ps}$$

Eq. 7.14

Where:

Max_{ps} = maximum gallons-per-hour load for the sampled primary school,
$Seats_{ps}$ = number of student seats in the primary school,
$GPH_{seat:ps}$ = gallons-per-hour per seat, and
$Max_{fs:ps}$ = max gallons-per-hour for the food service activity (if present).

7.6.1.10 Secondary School

DOE adapted a manufacturer's sizing methodology to size CWH equipment to the hot water activity in secondary schools. The main max load is student general hot water usage, which is depicted in the parenthesis of the following formula that calculates the overall building max load.

$$Max_{ss} = (Seat_{ss} \times GPH_{seat:ss}) + Max_{fs:ss}$$

Eq. 7.15

Where:

Max_{ss} = maximum gallons-per-hour load for the sampled secondary school,
$Seats_{ss}$ = number of student seats in the secondary school,
$GPH_{seat:ss}$ = gallons-per-hour per seat, and
$Max_{fs:ss}$ = max gallons-per-hour for the food service activity (if present).

7.6.1.11 Assembly

DOE adapted a sizing methodology from the 2000 Pacific Northwest National Laboratory (PNNL) Screening Analysis[12] to size CWH equipment to the hot water activity in buildings designed for assembly purposes. The main max load is patron general hot water usage, which is depicted in the parenthesis of the formula calculating the overall building max load.

$$Max_a = (Seat_a \times GPH_{seat:a}) + Max_{fs:a}$$

Eq. 7.16

Where:

Max_a = maximum gallons-per-hour load for the sampled assembly building,
$Seats_a$ = number of patron seats in the assembly building,
$GPH_{seat:a}$ = gallons-per-hour per seat, and
$Max_{fs:a}$ = max gallons-per-hour for the food service activity (if present).

7.6.1.12 Warehouse

DOE adapted a sizing methodology from the 2000 PNNL Screening Analysis to size CWH equipment to the hot water activity in warehouses. The main max load is worker general hot water usage, which is depicted in the parenthesis of the formula calculating the overall building max load.

$$Max_w = (Wker_w \times GPH_{wker:w}) + Max_{fs:w}$$

Eq. 7.17

Where:

Max_w = maximum gallons-per-hour load for the sampled warehouse,
$Wker_w$ = number of workers in the warehouse,
$GPH_{wker:w}$ = gallons-per-hour per warehouse worker, and
$Max_{fs:w}$ = max gallons-per-hour for the food service activity (if present).

7.6.1.13 Retail Stand Alone

DOE adapted a sizing methodology from the 2000 PNNL Screening Analysis to size CWH equipment to the hot water activity in standalone retail buildings. The main max load is worker general hot water usage, which is depicted in the parenthesis of the formula calculating the overall building max load.

$$Max_r = (Wker_r \times GPH_{wker:r}) + Max_{fs:r}$$

Eq. 7.18

Where:

Max_r = maximum gallons-per-hour load for the sampled retail building,
$Wker_r$ = number of workers in the retail building,
$GPH_{wker:r}$ = gallons-per-hour per retail worker, and
$Max_{fs:r}$ = max gallons-per-hour for the food service activity (if present).

7.6.1.14 Retail Strip Mall

DOE adapted a sizing methodology from the 2000 PNNL Screening Analysis to size CWH equipment to the hot water activity in strip malls. The main max load is occupant general hot water usage, which is depicted in the formula calculating the overall building max load.

$$Max_{sm} = SM_{sqft} \div Sqft_{occ\_sm} \times GPH_{occ:sm}$$

Eq. 7.19

Where:

Max_{sm} = maximum gallons-per-hour load for the sampled strip mall,
SM_{sqft} = square footage of the strip mall,
$Sqft_{occ\_sm}$ = square feet per occupant, and
$GPH_{occ:sm}$ = gallons-per-hour per strip mall occupant.

7.6.1.15 Outpatient Healthcare

DOE adapted a sizing methodology from the 2000 PNNL Screening Analysis to size CWH equipment to the hot water activity in outpatient healthcare facilities. The main max load is worker general hot water usage, which is depicted in the parenthesis of the formula calculating the overall building max load.

$$Max_o = (Wker_o \times GPH_{wker:o}) + Max_{fs:o}$$

Eq. 7.20

Where:

Max_o = maximum gallons-per-hour load for the sampled outpatient healthcare facility,
$Wker_o$ = number of workers in the outpatient healthcare facility,
$GPH_{wker:o}$ = gallons-per-hour per outpatient healthcare worker, and
$Max_{fs:o}$ = max gallons-per-hour for the food service activity (if present).

7.6.1.16 Hospital

DOE adapted a manufacturer's sizing methodology to size CWH equipment to the hot water activity in hospitals. The main max load is patient general hot water usage, which is depicted in the parenthesis of the formula calculating the overall building max load.

$$Max_h = (H_{sqft} \div Sqft_{hbed} \times GPH_{hbed}) + Max_{fs:h} + Max_{mll:h}$$

Eq. 7.21

Where:

Max_h = maximum gallons-per-hour load for the sampled hospital,
H_{sqft} = square footage of the hospital,
$Sqft_{hbed}$ = square feet per hospital bed,
GPH_{hbed} = gallons-per-hour of hot water per bed,
$Max_{fs:h}$ = max gallons-per-hour for the food service activity (if present), and
$Max_{mll:h}$ = max gallons-per-hour for the multi-load laundry activity (if present).

7.6.2 Additional Sizing Load Calculations

Certain buildings conduct laundry and/or food service and preparation activity in addition to their main hot water loads. DOE's calculations for these secondary, additional peak loads are provided in each activity's subsection.

7.6.2.1 Food Service and Preparation

In addition to buildings in which food service and preparation is the main load, such as full service and quick service restaurants, there are buildings that provide food service as a secondary, additional building activity. DOE adapted a manufacturer's sizing methodology to size CWH equipment to account for food service and preparation as an additional hot water activity. The max load associated with food service activity is based on the number of meals prepared in the building, gallons of hot water per meal, and the period in which those meals take place.

$$Max_{fs} = Meals_{occ} \times Gal_{meal} \div D_{fs}$$

Eq. 7.22

Where:

Max_{fs} = max gallons-per-hour for the building's food service activity,
$Meals_{occ}$ = number of meals per building occupant,
Gal_{meal} = gallons of hot water consumed per meal, and
D_{fs} = duration of max food service period in hours.

7.6.2.2 Multi-load Laundry/Washer Extractors for On-premise Laundry

DOE adapted a manufacturer's sizing methodology to size CWH equipment for multi-load laundry (also known as washer extractors) used in hotels, motels, nursing homes and hospitals for on-premise laundry service. The max load associated with multi-load laundry activity is based on the number of rooms or beds in the building, pounds of laundry per room or bed, gallons of hot water per pound of laundry, and hours of laundry operation.

$$Max_{mll} = SU_{mll} \times LB_{su\_mll} \times GPP_{mll} \div HR_{mll}$$

Eq. 7.23

Where:

Max_{mll} = max gallons-per-hour for the building's multi-load laundry activity,
SU_{mll} = number of service units (either rooms or beds),
LB_{su_mll} = pounds of laundry per service unit (either rooms or beds),
GPP_{mll} = gallons of hot water per pound of laundry, and
HR_{mll} = hours of laundry operation per day.

7.6.2.3 Communal Laundry for On-premise Laundry

DOE adapted a manufacturer's sizing methodology to size CWH equipment for the communal clothes washers used in offices, dormitories, and apartments for on-premise laundry service. The max load associated with communal laundry activity is based on the number of clothes washers, pound capacity per washer, gallons of hot water per pound of laundry, and cycles per hour.

$$Max_{cl} = CW_{cl} \times LB_{cl} \times GPP_{cl} \times Cycle_{hr\_cl}$$

Eq. 7.24

Where:

Max_{cl} = max gallons-per-hour for the building's communal laundry activity,
CW_{cl} = number of clothes washers,
LB_{cl} = pound capacity per clothes washer,
GPP_{cl} = gallons of hot water per pound of laundry, and
$Cycle_{hr\_cl}$ = number of cycles per hour.

7.6.2.4 Laundry in Individual Apartment Units

DOE adapted a manufacturer's sizing methodology to size CWH equipment for individual clothes washers used in each apartment for laundry service. The max load associated with individual apartment laundry activity is based on the number of clothes washers, diversity factor for clothes washers in operation, pound capacity per clothes washer, gallons of hot water per pound of laundry, and cycles per hour.

$$Max_{ul} = CW_{ul} \times Div_{ul} \times LB_{ul} \times GPP_{ul} \times Cycles_{ul} \div Dur_{ul}$$

Eq. 7.25

Where:

Max_{ul} = max gallons-per-hour for the apartment building's unit laundry activity,

CW_{ul} = number of clothes washers,
Div_{ul} = diversity factor for clothes washers in operation during peak, percent,
LB_{ul} = pound capacity per clothes washer,
GPP_{ul} = gallons of hot water per pound of laundry,
$Cycles_{ul}$ = number of cycles occurring during the max laundry duration, and
Dur_{ul} = duration of max laundry period in hours.

7.7 SIZING TO MAXIMUM LOAD

Each equipment class has a representative model characterizing the input capacity and volume of the typical model in the market falling within the equipment class' range of specifications. To determine whether the analyzed CWH equipment can meet the maximum load of a sampled building, DOE calculated the hot water delivery capability of each equipment class' representative model. DOE then divided the maximum load of a sampled building by the hot water delivery capability of each equipment class' representative model to determine the number of units needed to meet the building's hot water requirements.

$$N_{cwhe} = Max_{bldg} \div GD_{cwhe}$$

Eq. 7.26

Where:

N_{cwhe} = number of CWH equipment units of a specific equipment class needed to fulfill the building's maximum load,
Max_{bldg} = total maximum load of the building over its maximum load duration, gallons, and
GD_{cwhe} = gallons of hot water the equipment is capable of delivering over the building's maximum load duration.

For each equipment class, DOE sampled CBECS and RECS building loads in need of at least 0.9 units of CWH equipment, based on the representative model analyzed, to fulfill the maximum load requirements. Due to the maximum input capacity and storage specifications of residential-duty gas-fired storage water heaters, DOE limited the buildings sample to building loads requiring four or fewer units to fulfill the maximum load since larger maximum load requirements are more likely served by larger capacity equipment.

The hot water delivery capability of representative models was based on the period of continuous maximum load of the building type, whether 1-, 2-, or 3-hours in duration.

$$GD_{1hr} = (Vol \times Tank_u) + (Q_{in} \times E_t)/(dT \times Cp \times y)$$

Eq. 7.27

$$GD_{2hr} = (Vol \times Tank_u) + 2 \times (Q_{in} \times E_t)/(dT \times Cp \times y)$$

Eq. 7.28

$$GD_{3hr} = (Vol \times Tank_u) + 3 \times (Q_{in} \times E_t)/(dT \times Cp \times y)$$

Eq. 7.29

Where:

GD_{1hr} = gallons of hot water the equipment is capable of delivering in 1 hour,
GD_{2hr} = gallons of hot water the equipment is capable of delivering in 2 hours,
GD_{3hr} = gallons of hot water the equipment is capable of delivering in 3 hours,
Vol = volume of water in the tank in gallons,
$Tank_u$ = fraction of hot water in the tank that is usable before the dilution by cold water lowers the temperature below an acceptable level,
Q_{in} = input capacity of the equipment, Btu/h,
E_t = thermal efficiency of the equipment, percent,
dT = change in temperature from the equipment's set-point temperature to the coldest average monthly inlet temperature for the year of the sampled building, °F,
Cp = specific heat of water, Btu per pound per °F, and
y = specific weight of water, pounds per gallon.

DOE held the usable fraction of hot water in the tank ($Tank_u$) constant at 0.7, specific heat of water (Cp) constant at 1.000743 Btu per pound per °F, and specific weight of water (y) constant at 8.29 pounds per gallon for all hot water delivery capability calculations. The temperature rise (dT) was specific to the sampled building based on its location. The equipment's set point temperature was either 120 °F or 140 °F based on the residential or commercial building type, as detailed in appendix 7B. The inlet temperature was specific to the sampled residential or commercial building, selected as the coldest (i.e. minimum) average monthly inlet temperature for the year. Residential buildings sampled from RECS had a low minimum inlet of 39 °F, which was for Reportable Domain 10 (Iowa, Minnesota, North Dakota, South Dakota). The high minimum inlet for residential buildings sampled from RECS was 71 °F, which was for Reportable Domain 17 (Florida). Commercial buildings sampled from CBECS had a low minimum inlet of 43 °F, which was for the West North Central division. The high for minimum inlet for commercial buildings sampled from CBECS was 60 °F, which was for the Pacific, West South Central and South Atlantic divisions. DOE uses a temperature rise (dT) of 100 °F for purposes of demonstrating the calculations in Table 7.7.1 through Table 7.7.5.

Table 7.7.1 Commercial Gas-fired Storage Water Heater – Hot Water Delivery Capability Calculations

E_t EL	E_t	Q_{in}	Vol	$Tank_u$	dT	Cp	y	GD_{1hr}	GD_{2hr}	GD_{3hr}
0	80%	199,000	100	0.7	100	1.000743	8.29	262	454	646
1	82%	199,000	100	0.7	100	1.000743	8.29	267	463	660
2	90%	199,000	100	0.7	100	1.000743	8.29	286	502	718
3	92%	199,000	100	0.7	100	1.000743	8.29	291	511	732
4	95%	199,000	100	0.7	100	1.000743	8.29	298	526	754
5	99%	199,000	100	0.7	100	1.000743	8.29	307	545	782

Table 7.7.2 Residential-duty Gas-fired Storage Water Heater – Hot Water Delivery Capability Calculations

E_t EL	E_t	Q_{in}	Vol	$Tank_u$	dT	Cp	y	GD_{1hr}	GD_{2hr}	GD_{3hr}
0	80%	76,000	75	0.7	100	1.000743	8.29	126	199	272
1	82%	76,000	75	0.7	100	1.000743	8.29	128	203	278
2	90%	76,000	75	0.7	100	1.000743	8.29	135	217	300
3	95%	76,000	75	0.7	100	1.000743	8.29	140	227	314
4	97%	76,000	75	0.7	100	1.000743	8.29	141	230	319

DOE applied an adjustment factor to the first-hour, second-hour and third-hour capability calculations of commercial gas-fired tankless water heaters to account for the shorter time duration necessary for sizing this equipment, given its minimal volume of stored water to serve maximum load. DOE used the modified Hunter's curve[13] to develop the adjustment factors, or divisors, based on residential or commercial building type. These adjustment factors adapt the sizing methodology for water heaters with storage to a methodology suitable for sizing water heaters without storage, such as commercial gas-fired tankless water heaters.

$$ATGD = TGD \div Adj_{tankless}$$

Eq. 7.30

Where:

ATGD = adjusted gallons of hot water the commercial gas-fired tankless water heater is capable of delivering over the maximum load duration,
TGD = unadjusted gallons of hot water the commercial gas-fired tankless water heater is capable of delivering over the maximum load duration, and
$Adj_{tankless}$ = divisor developed from the modified Hunter's curve to adjust the sizing methodology for water heaters with storage to suit water heaters without storage.

Table 7.7.3 provides the unadjusted hot water delivery capability of commercial gas-fired tankless water heaters across efficiency levels, assuming a 100 °F temperature rise for demonstrating the calculations. Adjustment factors are shown in appendix 7B for each residential and commercial building type analyzed.

Table 7.7.3 Commercial Gas-fired Instantaneous Tankless Water Heater – Hot Water Delivery Capability Calculations

E_t EL	E_t	Q_{in}	Vol	$Tank_u$	dT	Cp	y	GD_{1hr}	GD_{2hr}	GD_{3hr}
0	80%	250,000	-	-	100	1.000743	8.29	241	482	723
1	82%	250,000	-	-	100	1.000743	8.29	247	494	741
2	84%	250,000	-	-	100	1.000743	8.29	253	506	759
3	92%	250,000	-	-	100	1.000743	8.29	277	554	832
4	94%	250,000	-	-	100	1.000743	8.29	283	567	850
5	96%	250,000	-	-	100	1.000743	8.29	289	579	868

Commercial gas-fired hot water supply boilers are not equipped with a storage tank upon purchase. However, they are typically installed in conjunction with an unfired storage tank for purposes of providing hot water during maximum load durations. For this reason, DOE coupled commercial gas-fired hot water supply boilers with an unfired storage tank. The size of the unfired storage tank was selected based on a Monte Carlo triangle distribution with a low of 250 gallons, high of 350 gallons, and most common selection of 300 gallons (see Figure 7.7.1). For purposes of demonstrating the first-hour, second-hour and third-hour delivery capability of commercial gas-fired hot water supply boilers in Table 7.7.4, DOE chose an unfired storage tank volume of 300 gallons.

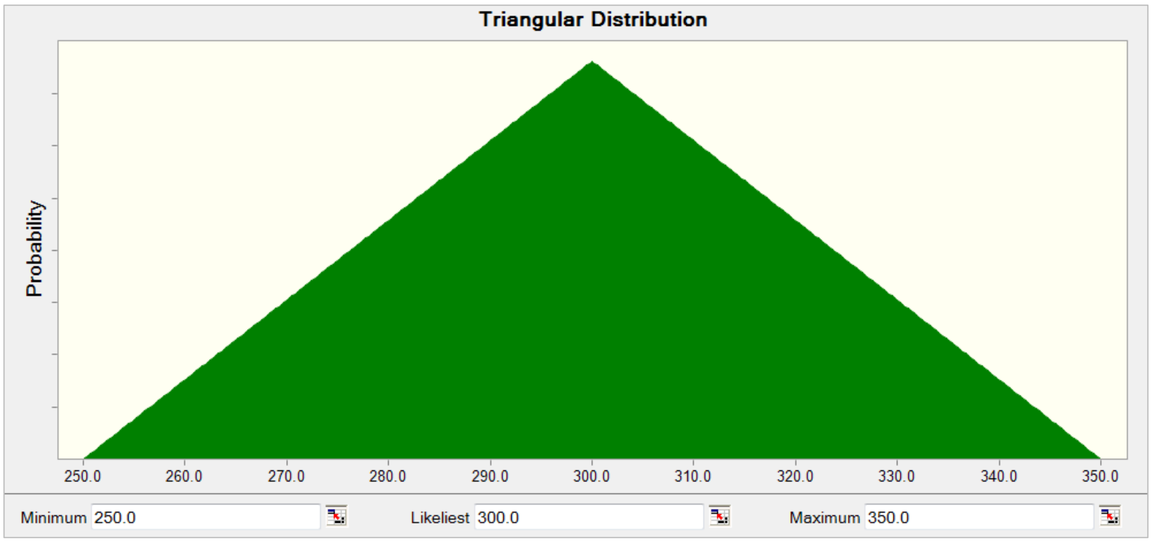

Figure 7.7.1 Distribution of Unfired Storage Tank Size for Commercial Gas-fired Instantaneous Hot Water Supply Boilers

Table 7.7.4 Commercial Gas-fired Instantaneous Hot Water Supply Boiler – Hot Water Delivery Capability Calculations

E_t EL	E_t	Q_{in}	Vol	$Tank_u$	dT	Cp	y	GD_{1hr}	GD_{2hr}	GD_{3hr}
0	80%	399,000	300	0.7	100	1.000743	8.29	595	980	1,364
1	82%	399,000	300	0.7	100	1.000743	8.29	604	999	1,393
2	84%	399,000	300	0.7	100	1.000743	8.29	614	1,018	1,422
3	92%	399,000	300	0.7	100	1.000743	8.29	652	1,095	1,537
4	94%	399,000	300	0.7	100	1.000743	8.29	662	1,114	1,566
5	96%	399,000	300	0.7	100	1.000743	8.29	672	1,133	1,595

Commercial electric storage water heaters do not have a thermal efficiency requirement under 10 CFR 431.110 and there are no options for increasing the rated thermal efficiency of this equipment. For the calculation of first-hour, second-hour and third-hour hot water delivery capability, DOE used a thermal efficiency of 98 percent as shown in Table 7.7.5.

Table 7.7.5 Commercial Electric Storage Water Heater – Hot Water Delivery Capability Calculation

E_t EL	E_t	kW	Q_{in}	Vol	$Tank_u$	dT	Cp	y	GD_{1hr}	GD_{2hr}	GD_{3hr}
0	98%	18	61,416	120	0.7	100	1.000743	8.29	157	229	302

7.8 OPERATING AND STANDBY HOURS

Given the hot water load requirements and equipment needs of the sampled buildings, DOE was able to calculate the hours of operation and standby mode for the representative model of each equipment class to service each sampled building. Since the number of equipment units allocated to a specific building was held constant at the baseline efficiency level, equipment hours of operation decreased as its thermal efficiency improved. This decrease in operation, in combination with standby performance, led to the energy savings achieved at each efficiency level above the baseline. Operating hours to meet the hot water load (including piping losses) were determined by dividing the sampled building's daily Btu load by the type and number of equipment installed, input capacity, and thermal efficiency.

$$BOH_{load} = (HWL_{bldg} + DL_{bldg}) \div (N_{cwhe} \times Q_{in} \times Et)$$

Eq. 7.31

Where:

BOH_{load} = burner operating hours per day to meet the hot water load (including piping losses),
HWL_{bldg} = daily Btu hot water load for the sampled building, Btu/day,
DL_{bldg} = daily Btu heat loss from recirculation loop operation, Btu/day,
N_{cwhe} = number of CWH equipment units of a specific equipment class (at baseline efficiency) needed to fulfill the building's maximum load,
Q_{in} = input capacity of the equipment, Btu/hour, and
E_t = thermal efficiency of the analyzed equipment, percent.

Burner operating hours decreased as thermal efficiency of the analyzed equipment (E_t) increased with each efficiency level. Once burner operating hours were determined, DOE calculated standby hours by taking the difference in the hours in a day and calculated burner operating hours.

$$Standby_{hrs} = 24 - BOH_{load}$$

Eq. 7.32

Where:

$Standby_{hrs}$ = standby mode hours per day, and
BOH_{load} = burner operating hours per day to meet the hot water load (including piping losses), h

7.9 ENERGY USE CALCULATIONS

DOE estimates the daily energy use of CWH equipment by adding the product of burning operating hours (meeting hot water load, including piping losses) and input capacity with the product of standby mode hours per day and standby loss rate.

$$ED = BOH_{load} \times Q_{in} + Standby_{hrs} \times SL$$

Eq. 7.33

Where:

ED = energy use of the CWH equipment, Btu/day,
BOH_{load} = burner operating hours per day to meet the hot water load (including piping losses),
Q_{in} = input capacity of the equipment, Btu/hour,
$Standby_{hrs}$ = standby mode hours per day, and
SL = heat loss rate while equipment is in standby, Btu/hour.

To convert average daily energy use of each month to annual energy use, DOE multiplies the average daily energy use of a particular month by the number of days in the month, and then sums the energy use of all months.

$$EA = \sum_{M=1}^{12} ED_m \times D_m$$

Eq. 7.34

Where:

EA = total annual energy use of the CWH equipment, Btu/year,
ED_m = total daily energy use of the CWH equipment for the average day within a given month (m), Btu/day, and
D_m = number of days in a given month (m).

7.9.1 Main Energy Use

The main energy use of CWH equipment is the direct heating of water (including piping losses) as well as any heat lost from the water while in standby. To calculate the main energy use, DOE subtracted the calculated daily auxiliary energy use from the total daily energy use.

$$EMain = ED - EAux$$

Eq. 7.35

Where:

$EMain$ = energy use of the CWH equipment as a result of water heating loads (including piping losses), Btu/day,
ED = energy use of the CWH equipment, Btu/day,
$EAux$ = auxiliary energy use of the CWH equipment, Btu/day.

7.9.2 Auxiliary Electric Use

CWH equipment can have auxiliary electrical use to operate electrical components such as electronic igniters, flue dampers, and fans. DOE developed methodologies to determine auxiliary energy use for each equipment class by analyzing DOE test data of models within the corresponding equipment class.

7.9.2.1 Commercial Gas-fired Storage Water Heaters

For commercial gas-fired storage water heaters, DOE analyzed test data to determine the percentage of active and standby energy use attributed to auxiliary electric components across efficiency levels (shown in appendix 7B). DOE applied these percentages to the water heating energy use of sampled buildings to determine main and auxiliary energy consumption. DOE chose this methodology since test data spanned a wide range of input capacities as this equipment class has no upper bound for input capacity. As a result of this methodology, auxiliary energy use scales with total energy use.

$$EAux_{cgs} = BOH_{load} \times Q_{in} \times P_{active:aux} + Standby_{hrs} \times SL \times P_{standby:aux}$$

Eq. 7.36

Where:

$EAux_{cgs}$ = auxiliary energy use of the CWH equipment, Btu/day,
BOH_{load} = burner operating hours per day to meet the hot water load (including piping losses),
Q_{in} = input capacity of the equipment, Btu/hour,
$P_{active:aux}$ = percentage of Btu attributed to running auxiliary electric components while the equipment is in active mode, percent,
$Standby_{hrs}$ = standby mode hours per day, and
SL = heat loss rate while equipment is in standby, Btu/hour.
$P_{standby:aux}$ = percentage of Btu attributed to running auxiliary electric components while the equipment is in standby, percent.

7.9.2.2 Residential-duty Gas-fired Storage Water Heaters

For residential-duty gas-fired storage water heaters, DOE used the electric power draw, in watts, of the auxiliary electrical components to determine auxiliary electric use across the efficiency levels for thermal efficiency and standby loss (shown in appendix 7B). DOE applied this electric power draw methodology to sampled buildings to determine main and auxiliary energy consumption. DOE chose this methodology since test data was within a limited range of input capacities, reflecting the distinct range of input capacities for this equipment class.

$$EAux_{rdgs} = BOH_{load} \times AP_{active} \times C_{w:btu} + Standby_{hrs} \times AP_{standby} \times C_{w:btu}$$

Eq. 7.37

Where:

$EAux_{rdgs}$ = auxiliary energy use of the CWH equipment, Btu/day,
BOH_{load} = burner operating hours per day to meet the hot water load (including piping losses),
AP_{active} = auxiliary power draw while the equipment is operating, watts,
$C_{w:btu}$ = conversion factor for translating watts to Btu, 3.412,
$Standby_{hrs}$ = standby mode hours per day, and
$AP_{standby}$ = auxiliary power draw while the equipment is in standby, watts.

7.9.2.3 Commercial Gas-fired Tankless Water Heaters and Commercial Gas-fired Hot Water Supply Boilers

For commercial gas-fired tankless water heaters and commercial gas-fired hot water supply boilers, DOE used a combination of the approaches for commercial gas-fired storage and residential-duty gas-fired storage water heaters. DOE analyzed test data to determine the percentage of active energy consumption attributed to auxiliary electric components. DOE chose this methodology since test data spanned a wide range of input capacities as hot water supply boilers have a high upper bound for input capacity (12.5 million Btu/hour) and tankless water heaters have no upper bound for input capacity. To determine the auxiliary electric use while the equipment is in standby mode, DOE used the electrical power draw, in watts, of the auxiliary electrical components. This methodology was chosen to reflect the on-demand operation of instantaneous equipment.

$$EAux_{instant} = BOH_{load} \times Q_{in} \times P_{active:aux} + Standby_{hrs} \times AP_{standby} \times C_{w:btu}$$

Eq. 7.38

Where:

$EAux_{instant}$ = auxiliary energy use of the CWH equipment, Btu/day,
BOH_{load} = burner operating hours per day to meet the hot water load (including piping losses),
Q_{in} = input capacity of the equipment, Btu/hour,
$P_{active:aux}$ = percentage of Btu attributed to running auxiliary electric components while the equipment is operating, percent,
$Standby_{hrs}$ = standby mode hours per day,
$AP_{standby}$ = auxiliary power draw while the equipment is in standby, watts, and
$C_{w:btu}$ = conversion factor for translating watts to Btu, 3.412.

Further details for calculating auxiliary electricity consumption appear in appendix 7B.

7.10 SUMMARY OF ENERGY USE RESULTS

Table 7.10.1 presents the average annual energy use for each considered energy efficiency level compared to the baseline energy efficiency for each CWH equipment class. The results reflect energy use in both the commercial and residential samples. The life-cycle cost (LCC) and payback period (PBP) analyses use the results calculated for each sample building.

Table 7.10.1 Average Annual Energy Consumption and Savings for Commercial Water Heating Equipment

E_t* EL	SL** EL	Design Option	Annual Fuel Use	Annual Electric Consumption of Auxiliary Components
			Total MMBtu/yr	Total kWh/yr
Commercial Gas-fired Storage Water Heaters				
0	0	80% E_t, 1.00 SL Factor	194.14	39
1	0	82% E_t, 0.98 SL Factor	189.51	38
2	0	90% E_t, 0.91 SL Factor	172.74	177
3	0	92% E_t, 0.89 SL Factor	169.06	174
4	0	95% E_t, 0.86 SL Factor	163.83	169
5	0	99% E_t, 0.83 SL Factor	157.33	162
0	1	80% E_t, 0.85 SL Factor	192.57	35
1	1	82% E_t, 0.83 SL Factor	187.98	34
2	1	90% E_t, 0.77 SL Factor	171.33	165
3	1	92% E_t, 0.76 SL Factor	167.68	162
4	1	95% E_t, 0.73 SL Factor	162.48	157
5	1	99% E_t, 0.71 SL Factor	156.03	151
0	2	80% E_t, 0.74 SL Factor	191.37	32
1	2	82% E_t, 0.72 SL Factor	186.80	31
2	2	90% E_t, 0.67 SL Factor	170.25	156
3	2	92% E_t, 0.65 SL Factor	166.61	153
4	2	95% E_t, 0.63 SL Factor	161.45	148
5	2	99% E_t, 0.61 SL Factor	155.03	143
Residential-duty Gas-fired Storage Water Heaters				
0	0	80% E_t, 1.00 SL Factor	90.18	0
1	0	82% E_t, 0.98 SL Factor	88.06	0
2	0	90% E_t, 0.60 SL Factor	77.57	149
3	0	95% E_t, 0.60 SL Factor	73.86	142
4	0	97% E_t, 0.60 SL Factor	72.48	140
0	1	80% E_t, 0.80 SL Factor	88.41	43
1	1	82% E_t, 0.78 SL Factor	86.33	42
2	1	90% E_t, 0.48 SL Factor	76.63	149
3	1	95% E_t, 0.48 SL Factor	72.91	142
4	1	97% E_t, 0.48 SL Factor	71.53	140
0	2	80% E_t, 0.77 SL Factor	88.22	43
1	2	82% E_t, 0.76 SL Factor	86.13	42
0	3	80% E_t, 0.67 SL Factor	87.42	43
1	3	82% E_t, 0.66 SL Factor	85.35	42
Commercial Gas-fired Instantaneous: Tankless Water Heaters				
0	-	80% E_t	61.89	119
1		82% E_t	60.38	117
2		84% E_t	58.94	115
3		92% E_t	53.81	107
4		94% E_t	52.66	105
5		96% E_t	51.56	104

E_t* EL	SL** EL	Design Option	Annual Fuel Use	Annual Electric Consumption of Auxiliary Components
			Total MMBtu/yr	Total kWh/yr
Commercial Gas-fired Instantaneous: Hot Water Supply Boilers				
0	-	80% E_t	374.49	744
1		82% E_t	365.48	729
2		84% E_t	356.89	714
3		92% E_t	326.23	662
4		94% E_t	319.33	650
5		96% E_t	312.68	639
Commercial Electric Storage Water Heaters				
0	0	98% E_t, 1.00 SL Factor	52.67	0
0	1	98% E_t, 0.84 SL Factor	52.23	0

* E_t = thermal efficiency
** SL Factors were rounded to the nearest hundredth.

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APPENDIX 7A. BUILDING VARIABLES

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APPENDIX 7A. BUILDING VARIABLES

7A.1 INTRODUCTION

The U.S. Department of Energy (DOE) has created a life-cycle cost (LCC) analysis model that contains a subset of the records and variables from the Energy Information Administration (EIA) Commercial Buildings Energy Consumption Survey (CBECS) and Residential Energy Consumption Survey (RECS)—CBECS 2003 and RECS 2009.[1,2] DOE uses the subsets in the LCC analysis of the commercial water heating (CWH) equipment rulemaking. This appendix explains the variable name abbreviations and provides definitions for the variable values.

For the entire CBECS 2003 dataset, refer to www.eia.gov/consumption/commercial/data/2003/index.cfm?view=microdata

For the entire RECS 2009 dataset, refer to www.eia.gov/consumption/residential/data/2009/index.cfm?view=microdata

7A.1.1 CBECS Sample Determination

Table 7A.1.1 presents the main CBECS 2003 variables used in the development of the CWH equipment data sample.

Table 7A.1.1 List of CBECS 2003 Variables Used for the Development of the CWH Equipment Sample

Variable	Description
Location Variables	
CENDIV8	Census division
REGION8	Census region
Building Characteristics Variables	
PUBID8	Building identifier
ADJWT8	Final full sample building weight
YRCON8	Year of construction category
SQFT8	Square footage
NFLOOR8	Number of floors
PBA8	Principal building activity
PBAPLUS8	Principal building activity, more specific activity
WATR8	Energy used for water heating
VACANT8	Completely vacant
RWSEAT8	Religious worship seating capacity
PBSEAT8	Assembly seating capacity
EDSEAT8	Number of classroom seats
FDSEAT8	Food service seating capacity
NRSBED8	Licensed bed capacity
LODGRM8	Number of guest rooms
LAUNDR8	Laundry onsite
FDRM8	Commercial food prep area
CAF8	Cafeteria or large restaurant
FASTFD8	Fast food or small restaurant
KITCHN8	Small kitchen area
OTFDRM8	Other food prep area
NWKER8	Number of employees during main shift
ELWATR8	Electricity used for water heating
NGWATR8	Natural gas used for water heating
FKWATR8	Fuel oil used for water heating
NGHTBTU8	Natural gas heating use (mBtu)
FKHTBTU8	Fuel oil heating use (mBtu)
ELHTBTU8	Electric heating use (mBtu)
NGWTBTU8	Natural gas water heating use (mBtu)
FKWTBTU8	Fuel oil water heating use (mBtu)
ELWTBTU8	Electric water heating use (mBtu)

7A.2 CBECS 2003 DATABASE VARIABLE RESPONSE CODES

Table 7A.2.1 provides the response codes for all CBECS 2003 variables used in the CWH equipment data sample.

Table 7A.2.1 CBECS 2003 Variable Response Codes

Variable	Response Codes	
PUBID8	Unique identifier for each respondent	
ADJWT8	Final sample weight	
REGION8	01	Northeast
	02	Midwest
	03	South
	04	West
CENDIV8	01	New England
	02	Middle Atlantic
	03	East North Central
	04	West North Central
	05	South Atlantic
	06	East South Central
	07	West South Central
	08	Mountain
	09	Pacific
YRCON8	1	Before 1920
	2	1920 to 1945
	3	1946 to 1959
	4	1960 to 1969
	5	1970 to 1979
	6	1980 to 1989
	7	1990 to 1999
	8	2000 to 2003
	9	2004
SQFT8	0-9999999996	0,000,000,009
	9999999997	Not ascertained
	9999999998	Refused
	9999999999	Don't know
NFLOOR8	0-14	009
	991	15 to 25
	992	Over 25
PBA8	01	Vacant
	02	Office
	04	Laboratory
	05	Nonrefrigerated warehouse
	06	Food sales
	07	Public order and safety
	08	Outpatient health care
	11	Refrigerated warehouse
	12	Religious worship
	13	Public assembly
	14	Education
	15	Food service
	16	Inpatient health care
	17	Nursing
	18	Lodging
	23	Strip shopping mall
	24	Enclosed mall
	25	Retail other than mall
	26	Service
	91	Other

Variable	Response Codes	
PBAPLUS8	02	Administrative/professional office
	03	Bank/other financial
	04	Government office
	05	Medical office (non-diagnostic)
	06	Mixed-use office
	07	Other office
	09	Distribution/shipping center
	10	Non-refrigerated warehouse
	11	Self-storage
	12	Convenience store
	13	Convenience store with gas station
	14	Grocery store/food market
	16	Fire station/police station
	17	Other public order and safety
	18	Medical office (diagnostic)
	19	Clinic/other outpatient health
	20	Refrigerated warehouse
	21	Religious worship
	22	Entertainment/culture
	23	Library
	24	Recreation
	25	Social/meeting
	26	Other public assembly
	27	College/university
	28	Elementary/middle school
	29	High school
	30	Preschool/daycare
	31	Other classroom education
	32	Fast food
	33	Restaurant/cafeteria
	35	Hospital/inpatient health
	36	Nursing home/assisted living
	37	Dormitory/fraternity/sorority
	38	Hotel
	39	Motel or inn
	41	Vehicle dealership/showroom
	42	Retail store
	43	Other retail
	44	Post office/postal center
	47	Vehicle storage/maintenance
	50	Strip shopping mall
	51	Enclosed mall
WATR8	1	Yes
	2	No
	7	Not ascertained
	8	Refused
	9	Don’t know
VACANT8	1	Yes
	2	No
	7	Not ascertained
	8	Refused
	9	Don’t know

Variable	Response Codes	
RWSEAT8	0-999996	000,009
	999997	Not ascertained
	999998	Refused
	999999	Don't know
PBSEAT8	0-999996	000,009
	999997	Not ascertained
	999998	Refused
	999999	Don't know
EDSEAT8	0-999996	000,009
	999997	Not ascertained
	999998	Refused
	999999	Don't know
FDSEAT8	0-999996	000,009
	999997	Not ascertained
	999998	Refused
	999999	Don't know
NRSBED8	0-999996	000,009
	999997	Not ascertained
	999998	Refused
	999999	Don't know
LODGRM8	0-999996	000,009
	999997	Not ascertained
	999998	Refused
	999999	Don't know
LAUNDR8	1	In this building
	2	In another building on-site
	3	By an offsite laundry service
FDRM8	1	Yes
	2	No
	7	Not ascertained
	8	Refused
	9	Don't know
CAF8	1	Yes
	2	No
	7	Not ascertained
	8	Refused
	9	Don't know
FASTFD8	1	Yes
	2	No
	7	Not ascertained
	8	Refused
	9	Don't know
KITCHN8	1	Yes
	2	No
	7	Not ascertained
	8	Refused
	9	Don't know
OTFDRM8	1	Yes
	2	No
	7	Not ascertained
	8	Refused
	9	Don't know

Variable	Response Codes	
NWKER8	0-999996	000,009
	999997	Not ascertained
	999998	Refused
	999999	Don't know
ELWATR8	1	Yes
	2	No
	7	Not ascertained
	8	Refused
	9	Don't know
NGWATR8	1	Yes
	2	No
	7	Not ascertained
	8	Refused
	9	Don't know
NGWTBTU8	Thousand Btu	
ELWTBTU8	Thousand Btu	

7A.3 RECS SAMPLE DETERMINATION

Table 7A.3.1 presents the main RECS 2009 variables used in the development of the CWH equipment data sample.

Table 7A.3.1 List of RECS 2009 Variables Used for the Development of the CWH Equipment Sample

Variable	Description
Location Variables	
REGIONC	Census region
DIVISION	Census division
REPORTABLE_DOMAIN	Reportable states and groups of states
Household Characteristics Variables	
NWEIGHT	Final sample weight
DOEID	Unique identifier for each respondent
TYPEHUQ	Type of housing unit
YEARMADE	Year housing unit was built
NUMAPTS	Number of apartment units in a 5+ unit apartment building
NUMFLRS	Number of floors in a 5+ unit apartment building
TOTSQFT	Total square footage (includes all attached garages, all basements, and finished/heated/cooled attics)
NCOMBATH	Number of full bath rooms
DISHWASH	Dishwasher used
CWASHER	Clothes washer used
H2OTYPE1	Type of main water heater
FUELH2O	Fuel used by main water heater
WHEATOTH	Main water heater is used by more than one housing unit
WHEATSIZ	Main water heater size (if storage tank)
NHSLDMEM	Number of household members
Age_1*	Number of household members less than 5 years old
Age_2*	Number of household members 5 to 14 years old
Age_3*	Number of household members 15 to 64 years old
Age_4*	Number of household members greater than or equal to 65 years old
ELWATER	Electricity used for water heating
UGWATER	Natural gas used for water heating
PELHOTWA	Who pays for the electricity used for water heating
PGASHTWA	Who pays for the natural gas used for water heating
MONEYPY	2009 gross household income
BTUNGWTH	Natural Gas usage for water heating, in thousand Btu, 2009
BTUELWTH	Electricity usage for water heating, in thousand Btu, 2009

* Not part of RECS 2009 variables, but developed using RECS data.

7A.4 RECS 2009 DATABASE VARIABLE RESPONSE CODES

Table 7A.4.1 provides the response codes for all RECS 2009 variables used in the CWH equipment sample.

Table 7A.4.1 Definitions of RECS 2009 Variables Used in Life-Cycle Cost Analysis

Variable	Response Codes	
DOEID	00001-12083	Unique identifier for each respondent
NWEIGHT	Final sample weight	
DIVISION	1	New England Census Division (CT, MA, ME, NH, RI, VT)
	2	Middle Atlantic Census Division (NJ, NY, PA)
	3	East North Central Census Division (IL, IN, MI, OH, WI)
	4	West North Central Census Division (IA, KS, MN, MO, ND, NE, SD)
	5	South Atlantic Census Division (DC, DE, FL, GA, MD, NC, SC, VA, WV)
	6	East South Central Census Division (AL, KY, MS, TN)
	7	West South Central Census Division (AR, LA, OK, TX)
	8	Mountain North Sub-Division (CO, ID, MT, UT, WY)
	9	Mountain South Sub-Division (AZ, NM, NV)
	10	Pacific Census Division (AK, CA, HI, OR, WA)
REGIONC	1	Northeast Census Region
	2	Midwest Census Region
	3	South Census Region
	4	West Census Region
REPORTABLE_DOMAIN	1	Connecticut, Maine, New Hampshire, Rhode Island, Vermont
	2	Massachusetts
	3	New York
	4	New Jersey
	5	Pennsylvania
	6	Illinois
	7	Indiana, Ohio
	8	Michigan
	9	Wisconsin
	10	Iowa, Minnesota, North Dakota, South Dakota
	11	Kansas, Nebraska
	12	Missouri
	13	Virginia
	14	Delaware, District of Columbia, Maryland, West Virginia
	15	Georgia
	16	North Carolina, South Carolina
	17	Florida
	18	Alabama, Kentucky, Mississippi
	19	Tennessee
	20	Arkansas, Louisiana, Oklahoma
	21	Texas
	22	Colorado
	23	Idaho, Montana, Utah, Wyoming
	24	Arizona
	25	Nevada, New Mexico
	26	California
	27	Alaska, Hawaii, Oregon, Washington

Variable	Response Codes	
TYPEHUQ	1	Mobile home
	2	Single-family detached
	3	Single-family attached
	4	Apartment in building with 2–4 units
	5	Apartment in building with 5+ units
YEARMADE	1600-2009	Year housing unit was built
NUMFLRS	1-99	Number of floors
	-2	Not applicable
NUMAPTS	5-995	Number of apartment units
	-2	Not applicable
TOTSQFT	Square feet	
NCOMBATH	0-9	Number of full bathrooms
DISHWASH	0	No
	1	Yes
CWASHER	0	No
	1	Yes
H2OTYPE1	1	Storage water heater
	2	Tankless water heater
	-2	Not applicable
FUELH2O	1	Natural gas
	2	Propane/Liquid petroleum gas (LPG)
	3	Fuel oil
	4	Kerosene
	5	Electricity
	7	Wood
	8	Solar
	21	Other fuel
	-2	Not applicable
WHEATOTH	0	No
	1	Yes
	-2	Not applicable
WHEATSIZ	1	Small (30 gallons or less)
	2	Medium (31 to 49 gallons)
	3	Large (50 gallons or more)
	-2	Not applicable
NHSLDMEM	0-15	Number of household members
Age_1*	0-7	Number of household members less than 5 years old
Age_2*	0-7	Number of household members 5 to 14 years old
Age_3*	0-11	Number of household members 15 to 64 years old
Age_4*	0-3	Number of household members greater than or equal to 65 years old

Variable	Response Codes	
MONEYPY	1	Less than $2,500
	2	$2,500 to $4,999
	3	$5,000 to $7,499
	4	$7,500 to $9,999
	5	$10,000 to $14,999
	6	$15,000 to $19,999
	7	$20,000 to $24,999
	8	$25,000 to $29,999
	9	$30,000 to $34,999
	10	$35,000 to $39,999
	11	$40,000 to $44,999
	12	$45,000 to $49,999
	13	$50,000 to $54,999
	14	$55,000 to $59,999
	15	$60,000 to $64,999
	16	$65,000 to $69,999
	17	$70,000 to $74,999
	18	$75,000 to $79,999
	19	$80,000 to $84,999
	20	$85,000 to $89,999
	21	$90,000 to $94,999
	22	$95,000 to $99,999
	23	$100,000 to $119,999
	24	$120,000 or More
BTUELWTH	Thousand Btu	
BTUNGWTH	Thousand Btu	

* Not part of RECS 2009 variables, but developed using RECS data.

7A.5 CONVERSION OF RECS WEIGHTS

To sample between the commercial and residential samples, DOE converts RECS residential housing unit records in multifamily buildings (Type HUQ 4 and 5) into building records. This allows for the sampling of commercial and residential buildings concurrently.

7A.5.1 RECS Housing Units in 2–4 Unit Multifamily Buildings (Type HUQ 4)

As shown in Table 7A.5.1, RECS housing unit records in 2–4 unit apartment buildings (Type HUQ 4) were converted to buildings records based on analysis of U.S. Census data from the 2013 American Community Survey.[3]

Table 7A.5.1 U.S. Census Data for Type HUQ 4 N-Weights Conversion Factor

Structure Type Category	Units in Structure
2 units	4,992,681
3 or 4 units	5,939,092

As shown in Table 7A.5.2, DOE calculated weights for the number of 2, 3, and 4-unit apartment buildings from the U.S. Census data, then multiplied these weights by the number of units in the building and summed the product to determine the weighted average number of units per 2–4 unit multifamily building.

Table 7A.5.2 RECS Type HUQ 4 Conversion Factor

Structure Type Category	Units in Structure	Weights	Weighted Average
2 units	4,992,681	0.4567	
3 units	2,969,546	0.2716	
4 units	2,969,546	0.2716	
Total	10,931,773	1.0000	2.81493

DOE divided the RECS n-weights for Type HUQ 4 housing records by 2.81493 to determine the number of buildings for the sample.

7A.5.2 RECS Housing Units in 5+ Unit Multifamily Buildings (Type HUQ 5)

RECS housing units in 5+ unit multifamily buildings (Type HUQ 5) were converted to buildings records based on analysis of the RECS data. DOE summed the n-weights for Type HUQ 5 housing units based on their unique number of apartments (NUMAPTS), from 5 units (lowest) to 365 units (highest). Then, DOE binned the number of units using the same bins as the U.S. Census: 5 to 9 units, 10 to 19 units, 20 to 49 units and 50+ units. Next, DOE calculated weighted average number of units for each unit bin using the RECS n-weights as shown in Table 7A.5.3.

Table 7A.5.3 RECS Type HUQ 5 Conversion Factors

Unit Bins	Weighted Average Number of Units
5 to 9 units	6.81
10 to 19 units	12.95
20 to 49 units	31.70
50+ units	148.99

DOE divided the RECS n-weights for 5+ unit multifamily housing records (Type HUQ 5) by the weighted average number of units for the bin the housing records fall in (based on its number of units).

7A.6 CBECS AND RECS BUILDINGS EXCLUDED FROM SAMPLE

DOE disaggregated EIA's CBECS 2003- and RECS 2009-derived subset into further subsets. As shown in Table 7A.6.1, certain CBECS building types (PBA-plus categories) were not sampled since there was not enough information for DOE to assign hot water loads.

Table 7A.6.1 CBECS PBA-plus Categories Excluded From Sample

PBA-plus Categories	Number of Records	Number of Buildings
'01'='Vacant'	134	182,168
'08'='Laboratory'	43	9,000
'15'='Other food sales'	6	10,267
'34'='Other food service'	43	58,001
'40'='Other lodging'	28	15,805
'45'='Repair shop'	44	76,261
'46'='Vehicle service/repair shop'	125	212,185
'48'='Other service'	79	139,489
'49'='Other'	64	70,383
Total	566	773,559

REFERENCES

1. U.S. Department of Energy–Energy Information Administration. *Commercial Buildings Energy Consumption Survey.* 2003. www.eia.doe.gov/emeu/cbecs/.

2. U.S. Department of Energy–Energy Information Administration. *Residential Energy Consumption Survey: 2009 RECS Survey Data.* 2013. www.eia.gov/consumption/residential/data/2009/.

3. U.S. Census. *2013 American Community Survey*. Table DP04, Selected Housing Characteristics. One-year estimate.

APPENDIX 7B. DETERMINATION OF COMMERCIAL WATER HEATING EQUIPMENT ENERGY USE

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APPENDIX 7B. DETERMINATION OF COMMERCIAL WATER HEATING EQUIPMENT ENERGY USE

7B.1 INTRODUCTION

The U.S. Department of Energy (DOE) developed a methodology for estimating the energy use of commercial water heating (CWH) equipment. DOE estimates the energy use of CWH equipment by adding the product of burner operating hours per day (meeting hot water load, including piping losses) and input capacity with the product of standby mode hours per day and standby loss rate.

$$ED = BOH_{load} \times Q_{in} + Standby_{hrs} \times SL$$

Eq. 7B.1

Where:

ED = energy use of the CWH equipment, Btu/day,
BOH_{load} = burner operating hours per day to meet the hot water load (including piping losses),
Q_{in} = input capacity of the equipment, Btu/hour,
$Standby_{hrs}$ = standby mode hours per day, and
SL = heat loss rate while equipment is in standby, Btu/hour.

To convert daily energy use of each month to annual energy use, DOE multiplies the average daily energy use of a particular month by the number of days in the month and sums the energy use over all months.

$$EA = \sum_{M=1}^{12} ED_m \times D_m$$

Eq. 7B.2

Where:

EA = total annual energy use of the CWH equipment, Btu/year,
ED_m = average daily energy use of the CWH equipment within a given month (m), Btu/day, and
D_m = number of days in a given month (m).

This appendix provides more detail on the construction and inputs of these calculations.

7B.2 HOT WATER USE IN COMMERCIAL BUILDINGS

This section provides an example of how DOE calculated daily hot water loads for commercial buildings. Table 7B.2.1 shows the daily load schedule and normalized peak gallons per hour (GPH) for the outpatient healthcare commercial prototype building, as provided in the DOE Commercial Prototype Building Models.[1]

Table 7B.2.1 Outpatient Healthcare Daily Load Schedule and Peak GPH

Outpatient Healthcare - Daily Hot Water Load Schedule									Normalized Peak: 60.07 GPH			
Morning												
Hour	1	2	3	4	5	6	7	8	9	10	11	12
Week	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.17	0.58	0.66	0.78	0.82
Sat	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.2	0.28	0.3	0.3
Sun/Hol	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Afternoon												
Hour	1	2	3	4	5	6	7	8	9	10	11	12
Week	0.71	0.82	0.78	0.74	0.63	0.41	0.18	0.18	0.18	0.1	0.01	0.01
Sat	0.24	0.24	0.23	0.23	0.23	0.1	0.01	0.01	0.01	0.01	0.01	0.01
Sun/Hol	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01

The commercial building's gallons per day (GPD) load is calculated using the following equation:

$$GPD_{Bldg} = \sum_{T=1}^{24} Peak_{Day} \times Peak_{HR\_Fraction}$$

Eq. 7B.3

Where:

GPD_{Bldg} = gallons-per-day hot water demand for the commercial building type, gal,
$Peak_{Day}$ = average peak demand for the commercial building type, gal,
$Peak_{HR\_Fraction}$ = fraction of peak demand for each hour, percent, and
T = hour of day, h.

The outpatient healthcare commercial prototype building had three daily load schedules based on the day of the week and holidays. DOE weighted the weekday, Saturday, Sunday/holiday daily load schedules based on the number of hours per year to determine an average GPD for the year, as shown in Table 7B.2.2.

Table 7B.2.2 Outpatient Healthcare Average GPD

Outpatient	**Hours/yr**	**Hours/yr Weights**	**Avg GPD**	**Weighted GPD**
Week Days	6,021	0.687	470.37	323.11
Sat	1,252	0.143	149.58	21.37
Sun/Hol	1,492	0.170	14.42	2.45
Total	8,765			**346.93**

The outpatient healthcare average GPD was 346.93 gallons of hot water. To scale this to the size of the outpatient healthcare building sampled from the Commercial Buildings Energy Consumption Survey (CBECS) data, DOE used square feet. The outpatient commercial prototype building was 40,946 square feet in size. By dividing the outpatient healthcare GPD by the square footage, DOE has a scalar of 8.473 GPD per thousand square feet for calculating the daily hot water loads of outpatient healthcare CBECS building records.

Table 7B.2.3 specifies the daily load schedules, normalized peaks, and square footage of the other commercial prototype buildings included in DOE's analysis, sourced from the DOE Commercial Prototype Building Models.

Table 7B.2.3 Daily Load Schedules, Normalized Peaks, and Square Footage

Fast Food Restaurant - Daily Hot Water Load Schedule						Normalized Peak: 91.28 GPH Square Feet: 2,501						
						Morning						
Hour	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Week	0	0	0	0	0	0	0.15	0.15	0.33	0.13	0.1	0.72
Sat	0	0	0	0	0	0	0.15	0.15	0.33	0.13	0.1	0.72
Sun/Hol	0	0	0	0	0	0	0.15	0.15	0.33	0.13	0.1	0.72
						Afternoon						
Hour	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Week	0.31	0.98	0.92	0.22	0.31	0.23	0.16	0.1	0.4	0.42	0.43	0.15
Sat	0.31	0.98	0.92	0.22	0.31	0.23	0.16	0.1	0.4	0.42	0.43	0.15
Sun/Hol	0.31	0.98	0.92	0.22	0.31	0.23	0.16	0.1	0.4	0.42	0.43	0

Warehouse - Daily Hot Water Load Schedule						Normalized Peak: 7.68 GPH Square Feet: 52,050						
						Morning						
Hour	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Week	0	0	0	0	0	0	0.05	0.1	0.4	0.5	0.5	0.7
Wkend	0	0	0	0	0	0	0.015	0.015	0.015	0.015	0.015	0.015
						Afternoon						
Hour	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Week	0.9	0.8	0.7	0.8	0.3	0.05	0	0	0	0	0	0
Wkend	0.015	0.015	0.015	0.015	0.015	0.015	0	0	0	0	0	0

Retail Strip Mall - Daily Hot Water Load Schedule						Normalized Peak: 1.8 GPH Square Feet: 22,500						
						Type 1						
						Morning						
Hour	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
M-Thu	0	0	0	0	0	0	0	0.04	0.04	0.15	0.23	0.32
Fri-Sat	0.13	0	0	0	0	0	0	0	0	0.2	0.23	0.32
Sun	0	0	0	0	0	0	0	0	0.1	0.14	0.29	0.31
						Afternoon						
Hour	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
M-Thu	0.41	0.62	0.6	0.55	0.45	0.5	0.46	0.47	0.34	0.33	0.23	0.13
Fri-Sat	0.41	0.65	0.6	0.55	0.45	0.5	0.46	0.47	0.34	0.33	0.23	0.13
Sun	0.36	0.36	0.34	0.35	0.37	0.34	0.25	0.27	0.21	0.16	0.16	0.1
						Type 2						
						Morning						
Hour	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Week	0	0	0	0	0	0	0	0	0.15	0.23	0.32	0.41
Sat	0	0	0	0	0	0	0	0	0.2	0.24	0.27	0.42
Sun	0	0	0	0	0	0	0	0	0	0.12	0.14	0.29
						Afternoon						
Hour	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Week	0.57	0.62	0.61	0.5	0.45	0.46	0.47	0.42	0.34	0	0	0
Sat	0.54	0.62	0.6	0.5	0.48	0.47	0.34	0	0	0	0	0
Sun	0.33	0.4	0.36	0.37	0.35	0.37	0	0	0	0	0	0
						Type 3						
						Morning						
Hour	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Week	0	0	0	0	0	0	0	0	0	0.15	0.25	0.41
Sat	0	0	0	0	0	0	0	0	0	0.2	0.27	0.42
Sun	0	0	0	0	0	0	0	0	0	0	0.12	0.29
						Afternoon						
Hour	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Week	0.57	0.62	0.61	0.5	0.45	0.46	0.47	0.42	0.34	0	0	0
Sat	0.54	0.59	0.6	0.49	0.48	0.47	0.46	0	0	0	0	0
Sun	0.31	0.36	0.36	0.34	0.35	0.37	0	0	0	0	0	0

Retail Stand Alone - Daily Hot Water Load Schedule						Normalized Peak: 17.97 GPH Square Feet: 24,692						
						Morning						
Hour	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Week	0	0	0	0	0	0	0	0.15	0.23	0.32	0.41	0.57
Sat	0	0	0	0	0	0	0	0.2	0.24	0.27	0.42	0.54
Sun/Hol	0	0	0	0	0	0	0	0	0	0.14	0.29	0.31
						Afternoon						
Hour	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Week	0.62	0.61	0.5	0.45	0.46	0.47	0.42	0.34	0.33	0	0	0
Sat	0.59	0.6	0.49	0.48	0.47	0.46	0.44	0.36	0.29	0.22	0	0
Sun/Hol	0.36	0.36	0.34	0.35	0.37	0.34	0.25	0	0	0	0	0

High-rise Apartment - Daily Hot Water Load Schedule							Normalized Peak: 274.92 GPH Square Feet: 84,360					
Morning												
Hour	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
All	0.08	0.04	0.01	0.01	0.04	0.27	0.94	1	0.96	0.84	0.76	0.61
Afternoon												
Hour	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
All	0.53	0.47	0.41	0.47	0.55	0.73	0.86	0.82	0.75	0.61	0.53	0.29

Mid-rise Apartment - Daily Hot Water Load Schedule							Normalized Peak: 107.87 GPH Square Feet: 33,744					
Morning												
Hour	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
All	0.08	0.04	0.01	0.01	0.04	0.27	0.94	1	0.96	0.84	0.76	0.61
Afternoon												
Hour	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
All	0.53	0.47	0.41	0.47	0.55	0.73	0.86	0.82	0.75	0.61	0.53	0.29

Small Office - Daily Hot Water Load Schedule							Normalized Peak: 3.85 GPH Square Feet: 5,503					
Morning												
Hour	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Week	0	0	0	0	0	0	0	0.27	0.55	0.64	0.64	0.82
Wkend	0	0	0	0	0	0	0	0	0	0	0	0
Afternoon												
Hour	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Week	1	0.91	0.55	0.55	0.73	0.37	0.37	0.18	0.27	0.09	0	0
Wkend	0	0	0	0	0	0	0	0	0	0	0	0

Medium Office - Daily Hot Water Load Schedule							Normalized Peak: 51 GPH Square Feet: 53,633					
Morning												
Hour	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Week	0	0	0	0	0	0	0.07	0.19	0.35	0.38	0.39	0.47
Sat	0	0	0	0	0	0	0.07	0.11	0.15	0.21	0.19	0.23
Sun/Hol	0	0	0	0	0	0	0.04	0.04	0.04	0.04	0.04	0.06
Afternoon												
Hour	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Week	0.57	0.54	0.34	0.33	0.44	0.26	0.21	0.15	0.17	0.08	0.05	0.05
Sat	0.2	0.19	0.15	0.13	0.14	0.07	0.07	0	0	0	0	0
Sun/Hol	0.06	0.09	0.06	0.04	0.04	0.04	0	0	0	0	0	0

Large Office - Daily Hot Water Load Schedule						Normalized Peak: 418.45 GPH Square Feet: 498,637						
Morning												
Hour	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Week	0	0	0	0	0	0	0.07	0.19	0.35	0.38	0.39	0.47
Sat	0	0	0	0	0	0	0.07	0.11	0.15	0.21	0.19	0.23
Sun/Hol	0	0	0	0	0	0	0.04	0.04	0.04	0.04	0.04	0.06
Afternoon												
Hour	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Week	0.57	0.54	0.34	0.33	0.44	0.26	0.21	0.15	0.17	0.08	0.05	0.05
Sat	0.2	0.19	0.15	0.13	0.14	0.07	0.07	0.07	0.07	0.09	0.05	0.05
Sun/Hol	0.06	0.09	0.06	0.04	0.04	0.04	0.04	0.04	0.04	0.07	0.04	0.04

Small Hotel - Daily Hot Water Load Schedule						Square Feet: 40,101						
Guest Room Normalized Peak: 171.13 GPH												
Morning												
Hour	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Week	0.2	0.15	0.15	0.15	0.2	0.35	0.6	0.8	0.55	0.4	0.3	0.2
Wkend	0.2	0.15	0.15	0.15	0.2	0.25	0.35	0.6	0.8	0.55	0.4	0.3
Afternoon												
Hour	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Week	0.2	0.2	0.2	0.2	0.2	0.3	0.55	0.4	0.4	0.6	0.45	0.25
Wkend	0.2	0.2	0.2	0.2	0.2	0.25	0.3	0.4	0.4	0.4	0.6	0.35
Laundry Normalized Peak: 123 GPH												
Morning												
Hour	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Week	0	0	0	0	0	0	0	0	1	1	1	1
Wkend	0	0	0	0	0	0	0	0	1	1	1	1
Afternoon												
Hour	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Week	1	1	1	1	0	0	0	0	0	0	0	0
Wkend	1	1	1	1	0	0	0	0	0	0	0	0

Sit-down Restaurant - Daily Hot Water Load Schedule						Square Feet: 5,502						
Main Normalized Peak: 133 GPH												
Morning												
Hour	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Week	0.2	0	0	0	0	0	0.15	0.6	0.55	0.45	0.4	0.45
Sat	0.2	0	0	0	0	0	0.15	0.15	0.15	0.5	0.45	0.5
Sun/Hol	0.25	0	0	0	0	0	0.15	0.15	0.15	0.15	0.5	0.5
Afternoon												
Hour	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Week	0.4	0.35	0.3	0.3	0.3	0.4	0.55	0.6	0.5	0.55	0.45	0.25
Sat	0.5	0.45	0.4	0.4	0.35	0.4	0.55	0.55	0.5	0.55	0.4	0.3
Sun/Hol	0.4	0.4	0.3	0.3	0.3	0.4	0.5	0.5	0.4	0.5	0.4	0.2
Dishwashing Normalized Peak: 79.8 GPH												
Morning												
Hour	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Week	0.2	0	0	0	0	0	0.15	0.6	0.55	0.45	0.4	0.45
Sat	0.2	0	0	0	0	0	0.15	0.15	0.15	0.5	0.45	0.5
Sun/Hol	0.25	0	0	0	0	0	0.15	0.15	0.15	0.15	0.5	0.5
Afternoon												
Hour	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Week	0.4	0.35	0.3	0.3	0.3	0.4	0.55	0.6	0.5	0.55	0.45	0.25
Sat	0.5	0.45	0.4	0.4	0.35	0.4	0.55	0.55	0.5	0.55	0.4	0.3
Sun/Hol	0.4	0.4	0.3	0.3	0.3	0.4	0.5	0.5	0.4	0.5	0.4	0.2

Large Hotel - Daily Hot Water Load Schedule						Square Feet: 122,115						
Main Normalized Peak: 223.69 GPH												
Morning												
Hour	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Week	0.2	0.15	0.15	0.15	0.2	0.35	0.6	0.8	0.55	0.4	0.3	0.2
Wkend	0.2	0.15	0.15	0.15	0.2	0.25	0.35	0.6	0.8	0.55	0.4	0.3
Afternoon												
Hour	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Week	0.2	0.2	0.2	0.2	0.2	0.3	0.55	0.4	0.4	0.6	0.45	0.25
Wkend	0.2	0.2	0.2	0.2	0.2	0.25	0.3	0.4	0.4	0.4	0.6	0.35
Dishwashing Normalized Peak: 79.8 GPH												
Morning												
Hour	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Week	0.2	0.15	0.15	0.15	0.2	0.25	0.5	0.6	0.55	0.45	0.4	0.45
Sat	0.2	0.15	0.15	0.15	0.2	0.25	0.4	0.5	0.5	0.5	0.45	0.5
Sun/Hol	0.25	0.2	0.2	0.2	0.2	0.3	0.5	0.5	0.5	0.55	0.5	0.5
Afternoon												
Hour	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Week	0.4	0.35	0.3	0.3	0.3	0.4	0.55	0.6	0.5	0.55	0.45	0.25
Sat	0.5	0.45	0.4	0.4	0.35	0.4	0.55	0.55	0.5	0.55	0.4	0.3
Sun/Hol	0.4	0.4	0.3	0.3	0.3	0.4	0.5	0.5	0.4	0.5	0.4	0.2
Laundry Normalized Peak: 245.4 GPH												
Morning												
Hour	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
All	0	0	0	0	0	0	0	0	0	0	0	0
Afternoon												
Hour	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
All	0	0	0	0	1	1	1	1	1	1	1	1

Secondary School - Daily Hot Water Load Schedule						Square Feet: 210,907						
Main Normalized Peak: 458.01 GPH												
Morning												
Hour	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Week	0	0	0	0	0	0	0	0	0.34	0.6	0.63	0.72
Sat	0	0	0	0	0	0	0	0	0	0	0	0
Sun/Hol	0	0	0	0	0	0	0	0	0	0	0	0
Afternoon												
Hour	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Week	0.79	0.83	0.61	0.65	0.1	0.1	0.19	0.25	0	0	0	0
Sat	0	0	0	0	0	0	0	0	0	0	0	0
Sun/Hol	0	0	0	0	0	0	0	0	0	0	0	0
Dishwashing Normalized Peak: 190.2 GPH												
Morning												
Hour	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Week	0	0	0	0	0	0	0	0	0.34	0.6	0.63	0.72
Sat	0	0	0	0	0	0	0	0	0	0	0	0
Sun/Hol	0	0	0	0	0	0	0	0	0	0	0	0
Afternoon												
Hour	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Week	0.79	0.83	0.61	0.65	0.1	0.1	0.19	0.25	0	0	0	0
Sat	0	0	0	0	0	0	0	0	0	0	0	0
Sun/Hol	0	0	0	0	0	0	0	0	0	0	0	0

Primary School - Daily Hot Water Load Schedule						Square Feet: 73,966						
Main Normalized Peak: 100.25 GPH												
Morning												
Hour	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Week	0	0	0	0	0	0	0	0	0.34	0.6	0.63	0.72
Sat	0	0	0	0	0	0	0	0	0	0	0	0
Sun/Hol	0	0	0	0	0	0	0	0	0	0	0	0
Afternoon												
Hour	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Week	0.79	0.83	0.61	0.65	0.1	0.19	0.25	0	0	0	0	0
Sat	0	0	0	0	0	0	0	0	0	0	0	0
Sun/Hol	0	0	0	0	0	0	0	0	0	0	0	0
Dishwashing Normalized Peak: 60 GPH												
Morning												
Hour	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Week	0	0	0	0	0	0	0	0	0.34	0.6	0.63	0.72
Sat	0	0	0	0	0	0	0	0	0	0	0	0
Sun/Hol	0	0	0	0	0	0	0	0	0	0	0	0
Afternoon												
Hour	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Week	0.79	0.83	0.61	0.65	0.1	0.19	0.25	0	0	0	0	0
Sat	0	0	0	0	0	0	0	0	0	0	0	0
Sun/Hol	0	0	0	0	0	0	0	0	0	0	0	0

Hospital - Daily Hot Water Load Schedule						**Square Feet: 241,413**						
Main Normalized Peak – Office, Lobby, Clinic, Operating Room: 25.07 GPH												
Morning												
Hour	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Week	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.17	0.58	0.66	0.78	0.82
Sat	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.2	0.28	0.3	0.3
Sun/Hol	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Afternoon												
Hour	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Week	0.71	0.82	0.78	0.74	0.63	0.41	0.18	0.18	0.18	0.10	0.01	0.01
Sat	0.24	0.24	0.23	0.23	0.23	0.1	0.01	0.01	0.01	0.01	0.01	0.01
Sun/Hol	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Main Normalized Peak – ER, Patient Rooms, ICU, Nurse Station, Kitchen: 161.02 GPH												
Morning												
Hour	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Week	0.3	0.3	0.3	0.3	0.3	0.301	0.3	0.5	0.58	0.66	0.78	0.82
Sat	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.5	0.6	0.6
Sun/Hol	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.5	0.6	0.6
Afternoon												
Hour	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Week	0.71	0.82	0.78	0.74	0.63	0.41	0.35	0.35	0.35	0.3	0.3	0.3
Sat	0.6	0.6	0.6	0.6	0.6	0.5	0.3	0.3	0.3	0.3	0.3	0.3
Sun/Hol	0.6	0.6	0.6	0.6	0.6	0.5	0.3	0.3	0.3	0.3	0.3	0.3
Dishwashing Normalized Peak: 34.8 GPH												
Morning												
Hour	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Week	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.17	0.58	0.66	0.78	0.82
Sat	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.2	0.28	0.3	0.3
Sun/Hol	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Afternoon												
Hour	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Week	0.71	0.82	0.78	0.74	0.63	0.41	0.18	0.18	0.18	0.10	0.01	0.01
Sat	0.24	0.24	0.23	0.23	0.23	0.1	0.01	0.01	0.01	0.01	0.01	0.01
Sun/Hol	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Laundry Normalized Peak: 168 GPH												
Morning												
Hour	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
All	0	0	0	0	0	0	0	0	1	1	1	1
Afternoon												
Hour	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
All	1	1	1	0	0	0	0	0	0	0	0	0

7B.3 HOT WATER USE IN RESIDENTIAL BUILDINGS

The Lawrence Berkeley National Laboratory (LBNL) hot water use model[2] was developed to determine hot water loads of individual housing units. For 2009 Residential Energy Consumption Survey (RECS)[3] housing unit records in multi-family buildings, DOE modified the LBNL model for the analysis of whole building loads. DOE averaged the number of housing unit occupants in each age group using RECS 2009 data on household members. The LBNL model reflected an analysis in which each housing unit had a residential water heater with a specific storage tank size to serve the housing unit's hot water load. To calibrate for this, DOE assigned storage tank sizes as if the load were served by an individual residential water heater in the apartment, as determined using a distribution based on RECS data for multifamily buildings with individual water heaters in housing units. Then, DOE multiplied the housing unit's load by the number of units in the building to determine the total hot water load of the building.

The normalized number of housing unit occupants in each age group is shown in Table 7B.3.1 and was developed using the RECS data on household members for 2–4 unit multifamily buildings (RECS Type HUQ 4) and 5+ unit multifamily buildings (RECS Type HUQ 5). By normalizing housing unit occupants, DOE prevented RECS housing unit records with anomalous occupancy levels from characterizing an entire multifamily building's GPD load.

Table 7B.3.1 Normalized Household Members by Residential Multifamily Building

Multifamily Residential Building Type	Age_1	Age_2	Age_3	Age_4	Total
	< 5	5 to 14	15 to 64	65+	
Type HUQ 4 (2–4 unit bldg)	0.196	0.316	1.628	0.180	2.32
Type HUQ 5 (5+ unit bldg)	0.135	0.196	1.360	0.242	1.93

As shown in Table 7B.3.2, DOE developed a Monte Carlo distribution to assign virtual storage tank size to the apartment unit based on the multifamily building type, fuel type, and number of bath rooms in RECS 2009 data.

Table 7B.3.2 Storage Tank Size Distribution for Individual Apartment Units by Residential Multifamily Building, Fuel Type and Number of Bathrooms

Multifamily Res Bldg	Fuel	Number of Bathrooms	Tank Size *gallons*		
			30	40	50
Type HUQ 4 (2–4 unit bldg)	Natural Gas	1	0.213	0.586	0.201
		2+	0.068	0.778	0.154
	Electricity	1	0.268	0.504	0.228
		2+	0.258	0.570	0.171
Type HUQ 5 (5+ unit bldg)	Natural Gas	1	0.236	0.617	0.147
		2+	0.183	0.552	0.265
	Electricity	1	0.407	0.476	0.117
		2+	0.236	0.624	0.141

7B.4 CONVERSION OF HOT WATER USE TO ENERGY USE

DOE developed building-specific Btu load adders to account for the heat losses of recirculation loops typically used in certain buildings to distribute hot water to end uses. DOE analysis assumes recirculation systems in sampled buildings are clocked controlled. DOE estimated the recirculation loop hours of operation (Table 7B.4.1) based on the expected hours of operation for the building type, mapped to 2003 Commercial Building Energy Consumption Survey (CBECS 2003) PBA-plus codes.[4]

Table 7B.4.1 Estimated Recirculation Loop Hours of Operation by Building Type

Building Type	CBECS PBA-Plus	Recirculation Operation Hours
Medium Office	'02'='Administrative/professional office'	12
	'03'='Bank/other financial'	
	'04'='Government office'	
	'05'='Medical office (non-diagnostic)'	
	'06'='Mixed-use office'	
	'07'='Other office'	
	'44'='Post office/postal center'	
	'16'='Fire station/police station'	
	'17'='Other public order and safety'	
Large Office	'02'='Administrative/professional office'	12
	'03'='Bank/other financial'	
	'04'='Government office'	
	'05'='Medical office (non-diagnostic)'	
	'06'='Mixed-use office'	
	'07'='Other office'	
	'44'='Post office/postal center'	
	'16'='Fire station/police station'	
	'17'='Other public order and safety'	
Primary School	'28'='Elementary/middle school'	9
	'31'='Other classroom education'	
	'30'='Preschool/daycare'	
Secondary School	'29'='High school'	16
	'27'='College/university'	
Outpatient Healthcare	'18'='Medical office (diagnostic)'	16
	'19'='Clinic/other outpatient health'	
Hospital	'35'='Hospital/inpatient health'	24
Small Hotel	'39'='Motel or inn'	24
Large Hotel	'38'='Hotel'	24
Full-service Restaurant	'33'='Restaurant/cafeteria'	12
Nursing Homes	'36'='Nursing home/assisted living'	24
Dormitories	'37'='Dormitory/fraternity/sorority'	24

Building Type	RECS Type HUQ	Recirculation Operation Hours
Apartment Buildings	5 (5+ unit apartment buildings)	24

7B.5 MAXIMUM HOT WATER LOADS

This section provides the inputs and assumptions for calculating the maximum hot water load calculations of sampled buildings.

7B.5.1 Apartment Buildings

DOE calculated the max load of a sampled apartment building using the formula:

$$Max_{apt} = \left(Apts \times Occ_{apt} \times T_{shower:apt} \times GPM_{shower:apt} \div D_{shower:apt}\right) + (CW_{cl} \times LB_{cl} \times GPP_{cl} \times Cycle_{hr\_cl}) + (CW_{ul} \times Div_{ul} \times LB_{ul} \times GPP_{ul} \times Cycles_{ul} \div Dur_{ul})$$

Eq. 7B.4

Where:

Max_{apt} = maximum gallons-per-hour load for the sampled apartment building,
$Apts$ = number of apartments in the building,
Occ_{apt} = number of occupants per apartment,
$T_{shower:apt}$ = minutes per shower,
$GPM_{shower:apt}$ = gallons-per-minute of hot water flowing out of the showerhead,
$D_{shower:apt}$ = duration of the showering period for the apartment building,
CW_{cl} = number of clothes washers in the communal laundry room,
LB_{cl} = pound capacity per clothes washer in the communal laundry room,
GPP_{cl} = gallons of hot water per pound of laundry for the communal laundry room,
$Cycle_{hr\_cl}$ = number of cycles per hour for the communal laundry room,
CW_{ul} = number of clothes washers in individual housing units,
Div_{ul} = diversity factor for clothes washers in operation during peak in individual housing units, percent,
LB_{ul} = pound capacity per clothes washer in individual housing units,
GPP_{ul} = gallons of hot water per pound of laundry for clothes washers in individual housing units,
$Cycles_{ul}$ = number of cycles occurring during the max laundry duration for clothes washers in individual housing units, and
Dur_{ul} = duration of max laundry period in hours for clothes washers in individual housing units.

DOE used the following inputs and assumptions:

- For 5+ unit apartment buildings (RECS Type HUQ 5), units per building were sourced from the RECS field NUMAPTS.
- For 2–4 unit apartment buildings (RECS Type HUQ 4), DOE assigned 2.814 units per building based on weighted U.S. Census Bureau data. (methodology, calculations, and reference are shown in appendix 7A.)
- 2.5 people occupy each apartment unit.
- The showerhead flow is 2.5 gallons-per-minute (GPM), which was the default value in the manufacturer's sizing calculator[5]
- The shower peak period is 3 hours.
- As shown in Table 7B.5.1, the minutes per shower per occupant is scaled to the number of apartments in the building to reflect diversity of the load as detailed in the manufacturer's sizing calculator.[5]

Table 7B.5.1 Apartment Building – Minutes per Shower per Occupant

Number of Apt Units		Min/Shower/occupant
Lower Bound	Upper Bound	
2	3	8.32
4	14	7.8
15	49	6.97
50	99	5.72
100	199	5.2
200	250	4.68
251	No Upper Bound	4.16

- RECS field CWASHER indicates whether the apartment unit has a clothes washer inside the unit.
  - If a clothes washer is present in the unit, all apartments units in the building were assumed to have a clothes washer in the unit.
  - If a clothes washer was not present in the unit, the apartment building was assumed to have a communal laundry room.
  - No sampled records were assumed to have both a communal laundry room and individual clothes washers in the apartment units.
- For the communal laundry room, DOE used the following:
  - The number of clothes washers per laundry room varied with the number of apartment units in the building, based on Multi-Housing Laundry Association[6] data, as depicted in **Table 7B.5.2**.
  - 15 pounds of laundry per communal clothes washer were estimated based on data from the 2014 DOE Commercial Clothes Washer rulemaking.[7]
  - 0.385 gallons of hot water per pound of laundry were estimated based on data from the 2014 DOE Commercial Clothes Washer rulemaking.
  - 1.7 cycles per hour were estimated based on data from 2014 DOE Commercial Clothes Washer rulemaking.

Table 7B.5.2 Apartment Building – Number of Communal Clothes Washers

Number of Apt Units		Number of Communal CWs
Lower Bound	**Upper Bound**	
2	14	1
15	250	NUMAPTS ÷ 15
251	No Upper Bound	NUMAPTS ÷ 15

- For laundry in individual apartment units, DOE used the following:
  - One clothes washer was assigned to each apartment in 5+ unit apartment buildings (Type HUQ 5) whereas 2.8149 clothes washers were assigned to apartment buildings with 2-4 apartment units (Type HUQ 4).
  - Max load diversity factor was based on the number of apartment units in the building, as depicted in Table 7B.5.3.
  - 12 pounds of laundry per individual residential clothes washer was estimated based on data from the 2014 DOE Commercial Clothes Washer rulemaking.
  - 0.385 gallons of hot water per pound of laundry was estimated based on data from the 2014 DOE Commercial Clothes Washer rulemaking.
  - 2 cycles per clothes washer were assumed to occur during the duration of max laundry load.
  - The max laundry period duration is 3 hours.

Table 7B.5.3 Apartment Building – Individual Unit Diversity

Number of Apt Units		Laundry Diversity
Lower Bound	Upper Bound	
2	3	80%
4	14	75%
15	49	67%
50	99	55%
100	199	50%
200	250	45%
251	No Upper Bound	40%

7B.5.2 Hotel/Motel

DOE calculated the max load of a sampled hotel/motel using the formula:

$$Max_{hm} = (Rm_{hm} \times Occ_{rm:hm} \times T_{shower:hm} \times GPM_{hm} \div D_{shower:hm}) + (Sinks_{hm} \times GPH_{sink:hm}) + (PBR_{hm} \times GPH_{PBR:hm}) + (Meals_{occ} \times Gal_{meal} \div D_{fs}) + (SU_{mll} \times LB_{su\_mll} \times GPP_{mll} \div HR_{mll})$$

Eq. 7B.5

Where:

Max_{hm} = maximum gallons-per-hour load for the sampled hotel/motel,
Rm_{hm} = number of rooms in the hotel/motel,
$Occ_{rm:hm}$ = number of occupants per hotel/motel room,
$T_{shower:hm}$ = minutes per shower,
GPM_{hm} = gallons-per-minute of hot water flowing out of the showerhead,
$D_{shower:hm}$ = duration of the shower period for the hotel/motel,
$Sinks_{hm}$ = number of service sinks in the hotel/motel,
$GPH_{sinks:hm}$ = gallons-per-hour of hot water flowing out of the service sinks,
PBR_{hm} = number of public bath rooms in the hotel/motel,
$GPH_{PBR:hm}$ = gallons-per-hour of hot water use per public bath room,
$Meals_{occ}$ = number of meals per building occupant,
Gal_{meal} = gallons of hot water consumed per meal,
D_{fs} = duration of max food service period in hours,
SU_{mll} = number of service units (rooms),
LB_{su_mll} = pounds of laundry per service unit (rooms),
GPP_{mll} = gallons of hot water per pound of laundry, and
HR_{mll} = hours of laundry operation per day.

DOE used the following inputs and assumptions:

- Rooms per hotel or motel were sourced from the CBECS field LODRM8.
- 1.5 guests occupy each room.
- Showerhead flow is 2.5 gallons-per-minute, which was the default value in the manufacturer's sizing calculator.[5]

- Duration of max shower period is 2 hours.
- Minutes per shower per guest was scaled to the number of rooms in the hotel/motel to reflect diversity of the load, sourced from the manufacturer's sizing calculator[5] and depicted in Table 7B.5.4.

Table 7B.5.4 Hotel/Motel – Minutes per Shower per Guest

Number of Hotel/Motel Rms		Min per Shower per Guest
Lower Bound	Upper Bound	
1	2	6.5
3	8	5.72
9	23	5.2
24	30	4.68
31	59	3.9
60	No Upper Bound	3.74

- Each floor is assigned one service sink. Number of floors was sourced from the CBECS field NFLOOR8.
- Each service sink is assigned 7.5 GPH of maximum hot water use, which was the default value in the manufacturer's sizing calculator[5]
- Each hotel/motel is assigned 4 public bath rooms.
- Each public bath room is assigned 2 GPH of hot water use, which was the default value in the manufacturer's sizing calculator[5]
- The presence and type of food service activity was sourced from the following CBECS fields:
  - CAF8, indicating full service restaurant or cafeteria,
  - FASTFD8, indicating a quick service restaurant,
  - KITCHN8, indicating a kitchen area, and
  - OTFDRM8, indicating other food preparation.
- The gallons per meal for the food service types are:
  - 1.5 gallons per meal for full service restaurant or cafeteria, which was the default value in the manufacturer's sizing calculator,[5]
  - 0.7 gallons per meal for quick service restaurant,[8]
  - 0.5 gallons per meal for kitchen area, and
  - 0.7 gallons per meal for other food preparation.
- If the building had multiple food service types, the gallons per meal were averaged between the food service types present in the building under the assumption that patrons were equally distributed between the food service types.
- 0.25 meals per guest during max food service duration were assumed.
- Max food service duration is 2 hours.
- CBECS field LAUNDR8 determined whether the sampled hotel/motel had on-premise laundry.
- If laundry existed in the building, multi-load laundry activity was assigned to the hotel/motel building.
  - 2 gallons of hot water per pound were assigned, which was the default value for commercial laundry operation in the manufacturer's sizing calculator.[5]
  - 8 hours of laundry operation per day were assumed.

- Pounds of laundry per room was scaled according to the number of rooms in the hotel/motel and the presence and type of food service, which was sourced from the Commercial Laundry Equipment Company[9] as depicted in Table 7B.5.5.

Table 7B.5.5 Pounds of Laundry per Hotel/Motel Room

Number of Hotel/Motel Rms		No Food Service	Full Service Restaurant	Quick Service Restaurant	Kitchen Area	Other Food Service
Lower Bound	Upper Bound	Laundry lbs/rm	Laundry lbs/rm	Laundry lbs/rm	Laundry lbs/rm	Laundry lbs/rm
1	23	8	14	12	12	12
24	59	10	14	12	12	12
60	No Upper Bound	10	14	12	12	12

7B.5.3 Dormitory

DOE calculated the max load of a sampled dormitory using the formula:

$$Max_d = (Rm_d \times Occ_{rm:d} \times GPH_{occ:d}) + (Sinks_d \times GPH_{sinks:d}) + (Meals_{occ} \times Gal_{meal} \div D_{fs}) + (CW_{cl} \times LB_{cl} \times GPP_{cl} \times Cycle_{hr\_cl})$$

Eq. 7B.6

Where:

Max_d = maximum gallons-per-hour load for the sampled dormitory,
Rm_d = number of rooms in the dormitory,
$Occ_{rm:d}$ = number of occupants per dormitory room,
$GPH_{occ:d}$ = gallons-per-hour of hot water per dormitory occupant
$Sinks_d$ = number of service sinks in the dormitory,
$GPH_{sinks:d}$ = gallons-per-hour of hot water flowing out of the service sinks,
$Meals_{occ}$ = number of meals per building occupant,
Gal_{meal} = gallons of hot water consumed per meal,
D_{fs} = duration of max food service period in hours,
CW_{cl} = number of clothes washers,
LB_{cl} = pound capacity per clothes washer,
GPP_{cl} = gallons of hot water per pound of laundry, and
$Cycle_{hr\_cl}$ = number of cycles per hour.

DOE used the following inputs and assumptions:

- Rooms per dormitory were sourced from the CBECS field LODRM8.
- Each room has 2 occupants.
- GPH per occupant was scaled to the number of occupants in the dormitory to reflect diversity of the load, sourced from the manufacturer's sizing calculator[5] and depicted in Table 7B.5.6.

Table 7B.5.6 Dormitory – GPH per occupant

Number of Occupants		GPH per Occupant
Lower Bound	Upper Bound	
1	20	12.5
21	29	11
30	39	10
40	49	8
50	69	7
70	99	5.5
100	No Upper Bound	5

- Each floor is assigned one service sink. The number of floors was sourced from the CBECS field NFLOOR8.
- Each service sink is assigned 7.5 GPH of maximum hot water use, which was the default value in the manufacturer's sizing calculator.[5]
- The presence and type of food service activity was sourced from the following CBECS fields:
  - CAF8, indicating full service restaurant or cafeteria,
  - FASTFD8, indicating a quick service restaurant,
  - KITCHN8, indicating a kitchen area, and
  - OTFDRM8, indicating other food preparation.
- The gallons per meal for the food service types are:
  - 1.5 gallons per meal for full service restaurant or cafeteria, which was the default value in the manufacturer's sizing calculator,[5]
  - 0.7 gallons per meal for quick service restaurant,[8]
  - 0.5 gallons per meal for kitchen area, and
  - 0.7 gallons per meal for other food preparation.
- If the building had multiple food service types, the gallons per meal were averaged between the food service types present in the building under the assumption that occupants were equally distributed between the food service types.
- 1 meal per occupant is assumed during max food service duration.
- Max food service duration is 1 hour.
- CBECS field LAUNDR8 determined whether the sampled dormitory had on-premise laundry.
- If laundry existed in the building, communal laundry activity was assigned to the dormitory.
  - Number of clothes washers was determined by dividing the number of occupants by 30, based on Multi-housing Laundry Association data.[6] If there were fewer than 30 occupants, then the building was assigned one communal clothes washer.
  - 15 pounds of laundry per communal clothes washer were estimated based on data from the 2014 DOE Commercial Clothes Washer rulemaking.[7]
  - 0.385 gallons of hot water per pound of laundry were estimated based on data from the 2014 DOE Commercial Clothes Washer rulemaking.[7]
  - 1.7 cycles per hour were estimated based on data from 2014 DOE Commercial Clothes Washer rulemaking.[7]

7B.5.4 Single-family Home

DOE calculated the max load of a sampled single-family home using the formula:

$$Max_{sfh} = \left(Occ_{sfh} \times GPH_{occ:sfh}\right) + \left(BR_{sfh} \times GPH_{br:sfh}\right) + GPH_{dw:sfh} + GPH_{cw:sfh}$$

Eq. 7B.7

Where:

Max_{sfh} = maximum gallons-per-hour load for the sampled single-family home,
Occ_{sfh} = number of occupants in the home,
$GPH_{occ:sfh}$ = gallons-per-hour of hot water adder per occupant,
BR_{sfh} = number of bath rooms in the single-family home,
$GPH_{br:sfh}$ = gallons-per-hour of hot water adder per bath room,
$GPH_{dw:sfh}$ = gallons-per-hour adder for the presence of a dishwasher, and
$GPH_{cw:sfh}$ = gallons-per-hour adder for the presence of a clothes washer.

DOE used the following inputs and assumptions, all of which come from the equipment manufacturer's residential sizing calculation:[10]

- Each of the first two household members receives a GPH adder of 20, each additional household member receives a GPH adder of 5.
- Number of household members was sourced from the RECS field NHSLDMEM.
- No GPH adder is assigned if household has one bathroom. Every additional bath room beyond one receives a GPH adder of 10.
- Number of bath rooms was sourced from the RECS field NCOMBATH.
- If a dishwasher is present in the household, a GPH adder of 10 is assigned.
- Presence of a dishwasher was sourced from the RECS field DISHWASH.
- If a clothes washer is present in the household, a GPH adder of 20 is assigned.
- Presence of a clothes washer was sourced from the RECS field CWASHER.

7B.5.5 Office Building

DOE calculated the max load of a sampled office building using the formula:

$$Max_{off} = \left(Wker_{off} \times GPH_{off:wker}\right) + (Meals_{occ} \times Gal_{meal} \div D_{fs}) + (CW_{cl} \times LB_{cl} \times GPP_{cl} \times Cycle_{hr\_cl})$$

Eq. 7B.8

Where:

Max_{off} = maximum gallons-per-hour load for the sampled office building,
$Wker_{off}$ = number of workers in the office building,
$GPH_{off:wker}$ = gallons-per-hour of hot water per worker,
$Meals_{occ}$ = number of meals per building occupant,
Gal_{meal} = gallons of hot water consumed per meal,
D_{fs} = duration of max food service period in hours,

CW_{cl} = number of clothes washers,
LB_{cl} = pound capacity per clothes washer,
GPP_{cl} = gallons of hot water per pound of laundry, and
$Cycle_{hr\_cl}$ = number of cycles per hour.

DOE used the following inputs and assumptions:

- Number of workers was sourced from the CBECS field NWKER8.
- Each worker is assigned a GPH of 0.4, which was the default value in the manufacturer's sizing calculator.[5]
- The presence and type of food service activity was sourced from the following CBECS fields:
  - CAF8, indicating full service restaurant or cafeteria,
  - FASTFD8, indicating a quick service restaurant,
  - KITCHN8, indicating a kitchen area, and
  - OTFDRM8, indicating other food preparation.
- The gallons per meal for the food service types are as follows:
  - 1.5 gallons per meal for full service restaurant or cafeteria, which was the default value in the manufacturer's sizing calculator,[5]
  - 0.7 gallons per meal for quick service restaurant,[8]
  - 0.5 gallons per meal for kitchen area, and
  - 0.7 gallons per meal for other food preparation.
- If the building had multiple food service types, the gallons per meal were averaged between the food service types present in the building under the assumption that workers were equally distributed between the food service types.
- 0.25 meals per worker during max food service duration were assumed.
- Max food service duration is 1 hour.
- CBECS field LAUNDR8 determined whether the sampled office building had on-premise laundry.
- If laundry existed in the building, communal laundry activity was assigned to the office building.
  - Number of clothes washers was determined by dividing the number of occupants by 30, based on Multi-housing Laundry Association data.[6] If there were fewer than 30 occupants, then the building was assigned one communal clothes washer.
  - 15 pounds of laundry per communal clothes washer were estimated based on data from the 2014 DOE Commercial Clothes Washer rulemaking.[7]
  - 0.385 gallons of hot water per pound of laundry were estimated based on data from the 2014 DOE Commercial Clothes Washer rulemaking.[7]
  - 1.7 cycles per hour were estimated based on data from 2014 DOE Commercial Clothes Washer rulemaking.[7]

7B.5.6 Nursing Home

DOE calculated the max load of a sampled nursing home using the formula:

$$Max_{nh} = (Beds_{nh} \times GPH_{bed:nh}) + (Meals_{occ} \times Gal_{meal} \div D_{fs}) + (SU_{mll} \times LB_{su\_mll} \times GPP_{mll} \div HR_{mll})$$

Eq. 7B.9

Max_{nh} = maximum gallons-per-hour load for the sampled nursing home,
$Beds_{nh}$ = number of beds in the nursing home,
$GPH_{bed:nh}$ = gallons-per-hour of hot water per bed,
$Meals_{occ}$ = number of meals per building occupant,
Gal_{meal} = gallons of hot water consumed per meal,
D_{fs} = duration of max food service period in hours,
SU_{mll} = number of service units (beds),
LB_{su_mll} = pounds of laundry per service unit (beds),
GPP_{mll} = gallons of hot water per pound of laundry, and
HR_{mll} = hours of laundry operation per day.

DOE used the following inputs and assumptions:

- Number of beds was sourced from the CBECS field NRSBED8.
- GPH of 5.7 per bed, which was the default value in the manufacturer's sizing calculator[5]
- The presence and type of food service activity was sourced from the following CBECS fields:
  - CAF8, indicating full service restaurant or cafeteria,
  - FASTFD8, indicating a quick service restaurant,
  - KITCHN8, indicating a kitchen area, and
  - OTFDRM8, indicating other food preparation.
- The gallons per meal for the food service types are as follows:
  - 1.5 gallons per meal for full service restaurant or cafeteria, which was the default value in the manufacturer's sizing calculator,[5]
  - 0.7 gallons per meal for quick service restaurant,[8]
  - 0.5 gallons per meal for kitchen area, and
  - 0.7 gallons per meal for other food preparation.
- If the building had multiple food service types present, the gallons per meal were averaged between the food service types present in the building under the assumption that patients and workers were equally distributed between the food service types.
- 1 meal per bed during max food service duration is assumed.
- 0.5 meals per worker during max food service duration are assumed.
- Number of workers was sourced from the CBECS field NWKER8.
- Max food service duration is 1 hour.
- CBECS field LAUNDR8 revealed whether the sampled nursing home building had on-premise laundry.
- If laundry existed in the building, multi-load laundry activity was assigned to the nursing home.
  - 2.7 pounds of laundry per bed were assigned, sourced from the Commercial Laundry Equipment Company[9]

- 2 gallons of hot water per pound were assigned, which was the default value for commercial laundry operation in the manufacturer's sizing calculator[5]
- 8 hours of laundry operation per day were assumed.

7B.5.7 Full Service Restaurant

DOE calculated the max load of a sampled full service restaurant using the formula:

$$Max_{fsr} = Seats_{fsr} \times Gal_{meal:fsr} \div T_{meal:fsr}$$

Eq. 7B.10

Where:

Max_{fsr} = maximum gallons-per-hour load for the sampled full service restaurant,
$Seats_{fsr}$ = number of seats in the restaurant,
$Gal_{meal:fsr}$ = gallons of hot water per meal, and
$T_{meal:fsr}$ = hours expended per consumer per meal.

DOE used the following inputs and assumptions:

- Number of restaurant seats was sourced from the CBECS field FDSEAT8.
- 1.5 gallons per meal were assigned, which was the default value in the manufacturer's sizing calculator.[5]
- 0.7 hours per meal were assumed.

7B.5.8 Quick Service Restaurant

DOE calculated the max load of a sampled quick service restaurant using the formula:

$$Max_{qsr} = Seats_{qsr} \times Gal_{meal:qsr} \div T_{meal:qsr}$$

Eq. 7B.11

Where:

Max_{qsr} = maximum gallons-per-hour load for the sampled quick service restaurant,
$Seats_{qsr}$ = number of seats in the restaurant,
$Gal_{meal:qsr}$ = gallons of hot water per meal, and
$T_{meal:qsr}$ = hours expended per consumer per meal.

DOE used the following inputs and assumptions:

- Number of restaurant seats was sourced from the CBECS field FDSEAT8.
- 0.7 gallons per meal was sourced from the 2011 ASHRAE Handbook of HVAC applications, Chapter 50: Service Water Heating.[8]
- 0.7 hours per meal were assumed.

7B.5.9 Primary School

DOE calculated the max load of a sampled primary school using the formula:

$$Max_{ps} = \left(Seat_{ps} \times GPH_{seat:ps}\right) + (Meals_{occ} \times Gal_{meal} \div D_{fs})$$

Eq. 7B.12

Where:

Max_{ps} = maximum gallons-per-hour load for the sampled primary school,
$Seats_{ps}$ = number of student seats in the primary school,
$GPH_{seat:ps}$ = gallons-per-hour per seat,
$Meals_{occ}$ = number of meals per building occupant,
Gal_{meal} = gallons of hot water consumed per meal, and
D_{fs} = duration of max food service period in hours.

DOE used the following inputs and assumptions:

- Number of student seats was sourced from the CBECS field EDSEAT8.
- Assumed each seat was occupied by a student.
- Each student was assigned a GPH of 0.6 of maximum hot water use, which was the default value in the manufacturer's sizing calculator[5]
- The presence and type of food service activity was sourced from the following CBECS fields:
    - CAF8, indicating full service restaurant or cafeteria,
    - FASTFD8, indicating a quick service restaurant,
    - KITCHN8, indicating a kitchen area, and
    - OTFDRM8, indicating other food preparation.
- The gallons per meal for the food service types are:
    - 1.5 gallons per meal for full service restaurant or cafeteria, which was the default value in the manufacturer's sizing calculator,[5]
    - 0.7 gallons per meal for quick service restaurant,[8]
    - 0.5 gallons per meal for kitchen area, and
    - 0.7 gallons per meal for other food preparation.
- If the building had multiple food service types, the gallons per meal were averaged between the food service types present in the building under the assumption that students were equally distributed between the food service types.
- 1 meal per student during max food service duration was assumed.
- Max food service duration is 1 hour.

7B.5.10 Secondary School

DOE calculated the max load of a sampled secondary school using the formula:

$$Max_{ss} = (Seat_{ss} \times GPH_{seat:ss}) + (Meals_{occ} \times Gal_{meal} \div D_{fs})$$

Eq. 7B.13

Where:

Max_{ss} = maximum gallons-per-hour load for the sampled secondary school,
$Seats_{ss}$ = number of student seats in the secondary school,
$GPH_{seat:ss}$ = gallons-per-hour per seat,
$Meals_{occ}$ = number of meals per building occupant,
Gal_{meal} = gallons of hot water consumed per meal, and
D_{fs} = duration of max food service period in hours.

DOE used the following inputs and assumptions:

- Number of student seats was sourced from the CBECS field EDSEAT8.
- Assumed each seat was occupied by a student.
- Each student was assigned a GPH of 1 for maximum hot water use, which was the default value in the manufacturer's sizing calculator.[5]
- The presence and type of food service activity was sourced from the following CBECS fields:
  - CAF8, indicating full service restaurant or cafeteria,
  - FASTFD8, indicating a quick service restaurant,
  - KITCHN8, indicating a kitchen area, and
  - OTFDRM8, indicating other food preparation.
- The gallons per meal for the food service types are:
  - 1.5 gallons per meal for full service restaurant or cafeteria, which was the default value in the manufacturer's sizing calculator,[5]
  - 0.7 gallons per meal for quick service restaurant,[8]
  - 0.5 gallons per meal for kitchen area, and
  - 0.7 gallons per meal for other food preparation.
- If the building had multiple food service types, the gallons per meal were averaged between the food service types present in the building under the assumption that students were equally distributed between the food service types.
- 1 meal per student during max food service duration was assumed.
- Max food service duration is 1.5 hours.

7B.5.11 Assembly

DOE calculated the max load of a sampled assembly building using the formula:

$$Max_a = (Seat_a \times GPH_{seat:a}) + (Meals_{occ} \times Gal_{meal} \div D_{fs})$$

Eq. 7B.14

Where:

Max_a = maximum gallons-per-hour load for the sampled assembly building,
$Seats_a$ = number of audience seats in the assembly building,
$GPH_{seat:a}$ = gallons-per-hour per seat,
$Meals_{occ}$ = number of meals per building occupant,
Gal_{meal} = gallons of hot water consumed per meal, and

D_{fs} = duration of max food service period in hours.

DOE used the following inputs and assumptions:

- Number of assembly venue seats was sourced from the CBECS field RWSEAT8 for PBA-plus 21, "Religious Worship," and PBSEAT8 for all other PBA-plus codes associated with assembly buildings.
- Assumed each seat was occupied.
- Each seat was assigned a GPH of 0.4 of maximum hot water use, sourced from the 2000 Pacific Northwest National Laboratory (PNNL) Screening Analysis.[11]
- The presence and type of food service activity was sourced from the following CBECS fields:
  - CAF8, indicating full service restaurant or cafeteria,
  - FASTFD8, indicating a quick service restaurant,
  - KITCHN8, indicating a kitchen area, and
  - OTFDRM8, indicating other food preparation.
- The gallons per meal for the food service types are:
  - 1.5 gallons per meal for full service restaurant or cafeteria, which was the default value in the manufacturer's sizing calculator,[5]
  - 0.7 gallons per meal for quick service restaurant,[8]
  - 0.5 gallons per meal for kitchen area, and
  - 0.7 gallons per meal for other food preparation.
- If the building had multiple food service types, the gallons per meal were averaged between the food service types present in the building under the assumption that occupants were equally distributed between the food service types.
- 0.5 meals per seat during max food service duration were assumed.
- Max food service duration is 1 hour.

7B.5.12 Warehouse

DOE calculated the max load of a sampled warehouse using the formula:

$$Max_w = (Wker_w \times GPH_{wker:w}) + (Meals_{occ} \times Gal_{meal} \div D_{fs})$$

Eq. 7B.15

Where:

Max_w = maximum gallons-per-hour load for the sampled warehouse,
$Wker_w$ = number of workers in the warehouse,
$GPH_{wker:w}$ = gallons-per-hour per warehouse worker,
$Meals_{occ}$ = number of meals per building occupant,
Gal_{meal} = gallons of hot water consumed per meal, and
D_{fs} = duration of max food service period in hours.

DOE used the following inputs and assumptions:

- Number of warehouse workers was sourced from the CBECS field NWKER8.

- Each worker was assigned a GPH of 0.4 of maximum hot water use, sourced from the 2000 PNNL Screening Analysis.[11]
- The presence and type of food service activity was sourced from the following CBECS fields:
  - CAF8, indicating full service restaurant or cafeteria,
  - FASTFD8, indicating a quick service restaurant,
  - KITCHN8, indicating a kitchen area, and
  - OTFDRM8, indicating other food preparation.
- The gallons per meal for the food service types are:
  - 1.5 gallons per meal for full service restaurant or cafeteria, which was the default value in the manufacturer's sizing calculator,[5]
  - 0.7 gallons per meal for quick service restaurant,[8]
  - 0.5 gallons per meal for kitchen area, and
  - 0.7 gallons per meal for other food preparation.
- If the building had multiple food service types present, the gallons per meal were averaged between the food service types present in the building under the assumption that workers were equally distributed between the food service types.
- 1 meal per worker during max food service duration was assumed.
- Max food service duration is 1 hour.

7B.5.13 Retail Stand Alone

DOE calculated the max load of a sampled warehouse using the formula:

$$Max_r = (Wker_r \times GPH_{wker:r}) + (Meals_{occ} \times Gal_{meal} \div D_{fs})$$

Eq. 7B.16

Where:

Max_r = maximum gallons-per-hour load for the sampled retail building,
$Wker_r$ = number of workers in the retail building,
$GPH_{wker:r}$ = gallons-per-hour per retail worker,
$Meals_{occ}$ = number of meals per building occupant,
Gal_{meal} = gallons of hot water consumed per meal, and
D_{fs} = duration of max food service period in hours.

DOE used the following inputs and assumptions:

- Number of retail workers was sourced from the CBECS field NWKER8.
- Each worker was assigned a GPH of 0.4 of maximum hot water use, sourced from the 2000 PNNL Screening Analysis.[11]
- The presence and type of food service activity was sourced from the following CBECS fields:
  - CAF8, indicating full service restaurant or cafeteria,
  - FASTFD8, indicating a quick service restaurant,
  - KITCHN8, indicating a kitchen area, and
  - OTFDRM8, indicating other food preparation.

- The gallons per meal for the food service types are as follows:
  - 1.5 gallons per meal for full service restaurant or cafeteria, which was the default value in the manufacturer's sizing calculator,[5]
  - 0.7 gallons per meal for quick service restaurant,[8]
  - 0.5 gallons per meal for kitchen area, and
  - 0.7 gallons per meal for other food preparation.
- If the building had multiple food service types present, the gallons per meal were averaged between the food service types present in the building under the assumption that workers were equally distributed between the food service types.
- 1 meal per worker during max food service duration was assumed.
- Max food service duration is 1 hour.

7B.5.14 Retail Strip Mall

DOE calculated the max load of a sampled warehouse using the formula:

$$Max_{sm} = SM_{sqft} \div Sqft_{occ\_sm} \times GPH_{occ:sm}$$

Eq. 7B.17

Where:

Max_{sm} = maximum gallons-per-hour load for the sampled strip mall,
SM_{sqft} = square footage of the strip mall,
$Sqft_{occ\_sm}$ = square feet per occupant, and
$GPH_{occ:sm}$ = gallons-per-hour per strip mall occupant.

DOE used the following inputs and assumptions:

- Square footage of strip mall was sourced from the CBECS field SQFT8.
- 125 feet per occupant is based on data in DOE Commercial Prototype Building Scorecard[1] for retail strip mall.
- Each occupant is assigned a GPH of 0.4 of hot water use, sourced from the 2000 PNNL Screening Analysis.[11]

7B.5.15 Outpatient Healthcare

DOE calculated the max load of a sampled outpatient healthcare facility using the formula:

$$Max_o = (Wker_o \times GPH_{wker:o}) + (Meals_{occ} \times Gal_{meal} \div D_{fs})$$

Eq. 7B.18

Where:

Max_o = maximum gallons-per-hour load for the sampled outpatient healthcare facility,
$Wker_o$ = number of workers in the outpatient healthcare facility,
$GPH_{wker:o}$ = gallons-per-hour per outpatient healthcare worker,
$Meals_{occ}$ = number of meals per building occupant,

Gal_{meal} = gallons of hot water consumed per meal, and
D_{fs} = duration of max food service period in hours.

DOE used the following inputs and assumptions:

- Number of outpatient healthcare workers was sourced from the CBECS field NWKER8.
- Each worker was assigned a GPH of 0.4 of maximum hot water use, based on similar building activities in the 2000 PNNL Screening Analysis.[11]
- The presence and type of food service activity was sourced from the following CBECS fields:
  - CAF8, indicating full service restaurant or cafeteria,
  - FASTFD8, indicating a quick service restaurant,
  - KITCHN8, indicating a kitchen area, and
  - OTFDRM8, indicating other food preparation.
- The gallons per meal for the food service types are:
  - 1.5 gallons per meal for full service restaurant or cafeteria, which was the default value in the manufacturer's sizing calculator,[5]
  - 0.7 gallons per meal for quick service restaurant,[8]
  - 0.5 gallons per meal for kitchen area, and
  - 0.7 gallons per meal for other food preparation.
- If the building had multiple food service types present, the gallons per meal were averaged between the food service types present in the building under the assumption that workers were equally distributed between the food service types.
- 0.5 meals per worker during max food service duration were assumed.
- Max food service duration is 1 hour.

7B.5.16 Hospital

DOE calculated the max load of a sampled hospital using the formula:

$$Max_h = \left(H_{sqft} \div Sqft_{hbed} \times GPH_{hbed}\right) + (Meals_{occ} \times Gal_{meal} \div D_{fs}) + (SU_{mll} \times LB_{su\_mll} \times GPP_{mll} \div HR_{mll})$$

Eq. 7B.19

Where:

Max_h = maximum gallons-per-hour load for the sampled hospital,
H_{sqft} = square footage of the hospital,
$Sqft_{hbed}$ = square feet per hospital bed,
GPH_{hbed} = gallons-per-hour of hot water per bed,
$Meals_{occ}$ = number of meals per building occupant,
Gal_{meal} = gallons of hot water consumed per meal,
D_{fs} = duration of max food service period in hours,
SU_{mll} = number of service units (beds),
LB_{su_mll} = pounds of laundry per service unit (beds),

GPP_{mll} = gallons of hot water per pound of laundry, and
HR_{mll} = hours of laundry operation per day.

DOE used the following inputs and assumptions:

- Square footage of hospital was sourced from the CBECS field SQFT8.
- 2,140 square feet per bed was sourced from CBECS 2007 analysis "Energy Characteristics and Energy Consumed in Large Hospital Buildings in the United States in 2007."[12]
- GPH of 7.6 per hospital bed was the default value in the manufacturer's sizing calculator[5]
- The presence and type of food service activity was sourced from the following CBECS fields:
  - CAF8, indicating full service restaurant or cafeteria,
  - FASTFD8, indicating a quick service restaurant,
  - KITCHN8, indicating a kitchen area, and
  - OTFDRM8, indicating other food preparation.
- The gallons per meal for the food service types are:
  - 1.5 gallons per meal for full service restaurant or cafeteria, which was the default value in the manufacturer's sizing calculator,[5]
  - 0.7 gallons per meal for quick service restaurant,[8]
  - 0.5 gallons per meal for kitchen area, and
  - 0.7 gallons per meal for other food preparation.
- If the building had multiple food service types present, the gallons per meal were averaged between the food service types present in the building under the assumption that patients and workers were equally distributed between the food service types.
- 1 meal per bed during max food service duration was assumed.
- 0.5 meals per worker during max food service duration were assumed.
- Number of workers was sourced from the CBECS field NWKER8.
- Max food service duration is 1 hour.
- CBECS field LAUNDR8 revealed whether the sampled hospital had on-premise laundry.
- If laundry existed in the building, multi-load laundry activity was assigned to the hospital.
  - 10 pounds of laundry per bed were sourced from the Commercial Laundry Equipment Company.[9]
  - 2 gallons of hot water per pound was the default value for commercial laundry operation in the manufacturer's sizing calculator.[5]
  - 8 hours of laundry operation per day were assumed.

7B.6 SIZING TO MAXIMUM LOAD

The CWH equipment's setpoint temperature was based on the residential or commercial building type. DOE used the default setpoint temperatures in the manufacturer's sizing calculator to determine the continuous maximum load duration for commercial and residential buildings (Table 7B.6.1 and Table 7B.6.2).[5]

Table 7B.6.1 Setpoint Temperature and Continuous Max Load Duration of CBECS Building Types

Building Type	CBECS PBA-Plus	Setpoint Temperature	Continuous Max Load Duration (Hours)
Small Office	'02'='Administrative/professional office' '03'='Bank/other financial' '04'='Government office' '05'='Medical office (non-diagnostic)' '06'='Mixed-use office' '07'='Other office' '44'='Post office/postal center' '16'='Fire station/police station' '17'='Other public order and safety'	140°F	1
Medium Office	'02'='Administrative/professional office' '03'='Bank/other financial' '04'='Government office' '05'='Medical office (non-diagnostic)' '06'='Mixed-use office' '07'='Other office' '44'='Post office/postal center' '16'='Fire station/police station' '17'='Other public order and safety'	140°F	1
Large Office	'02'='Administrative/professional office' '03'='Bank/other financial' '04'='Government office' '05'='Medical office (non-diagnostic)' '06'='Mixed-use office' '07'='Other office' '44'='Post office/postal center' '16'='Fire station/police station' '17'='Other public order and safety'	140°F	1
Standalone Retail	'42'='Retail store' '12'='Convenience store' '13'='Convenience store with gas station' '14'='Grocery store/food market' '41'='Vehicle dealership/showroom' '43'='Other retail'	140°F	1
Strip Mall	'50'='Strip shopping mall' '51'='Enclosed mall'	140°F	1
Primary School	'28'='Elementary/middle school' '31'='Other classroom education' '30'='Preschool/daycare'	140°F	1
Secondary School	'29'='High school' '27'='College/university'	140°F	1
Outpatient Healthcare	'18'='Medical office (diagnostic)' '19'='Clinic/other outpatient health'	140°F	1
Hospital	'35'='Hospital/inpatient health'	120°F	1
Small Hotel	'39'='Motel or inn'	140°F	2
Large Hotel	'38'='Hotel'	140°F	2
Warehouse	'09'='Distribution/shipping center' '10'='Non-refrigerated warehouse'	140°F	1

Building Type	CBECS PBA-Plus	Setpoint Temperature	Continuous Max Load Duration (Hours)
	'47'='Vehicle storage/maintenance'		
	'11'='Self-storage'		
	'20'='Refrigerated warehouse'		
Quick-service Restaurant	'32'='Fast food'	140°F	1
Full-service Restaurant	'33'='Restaurant/cafeteria'	140°F	1
Assembly	'21'='Religious worship'	140°F	1
	'22'='Entertainment/culture'		
	'23'='Library'		
	'24'='Recreation'		
	'25'='Social/meeting'		
	'26'='Other public assembly'		
Nursing Homes	'36'='Nursing home/assisted living'	120°F	1
Dormitories	'37'='Dormitory/fraternity/sorority'	140°F	1

Table 7B.6.2 Setpoint Temperature and Continuous Max Load Duration of RECS Building Types

Building Type	RECS Type HUQ	Setpoint Temperature	Continuous Max Load Duration *hours*
Single-family Detached Home	2	120°F	1
Single-family Attached Home	3	120°F	1
2–4 Unit Apartment Building	4	140°F	3
5+ Unit Apartment Building	5	140°F	3

DOE applied an adjustment factor to the first-hour, second-hour, and third-hour capability calculations of commercial gas-fired tankless water heaters to account for the shorter time duration for sizing this equipment, given its minimal volume of stored water to serve maximum load. DOE used the modified Hunter's curve[13] to develop the adjustment factors, or divisors, based on residential or commercial building type, as listed in Table 7B.6.3. These adjustment factors adapt the sizing methodology for water heaters with storage to a methodology suitable for sizing water heaters without storage, such as commercial gas-fired tankless water heaters.

Table 7B.6.3 Commercial Gas-fired Tankless Water Heater – Hot Water Delivery Capability Adjustment Factors for CBECS Building Types

Building Type	CBECS PBA-Plus	Hunter's Curve	Adjustment Factor Divisor
Small Office	'02'='Administrative/professional office'	D	1.58
	'03'='Bank/other financial'		
	'04'='Government office'		
	'05'='Medical office (non-diagnostic)'		
	'06'='Mixed-use office'		
	'07'='Other office'		
	'44'='Post office/postal center'		
	'16'='Fire station/police station'		
	'17'='Other public order and safety'		
Medium Office	'02'='Administrative/professional office'	D	1.58
	'03'='Bank/other financial'		
	'04'='Government office'		
	'05'='Medical office (non-diagnostic)'		
	'06'='Mixed-use office'		
	'07'='Other office'		
	'44'='Post office/postal center'		
	'16'='Fire station/police station'		
	'17'='Other public order and safety'		
Large Office	'02'='Administrative/professional office'	D	1.58
	'03'='Bank/other financial'		
	'04'='Government office'		
	'05'='Medical office (non-diagnostic)'		
	'06'='Mixed-use office'		
	'07'='Other office'		
	'44'='Post office/postal center'		
	'16'='Fire station/police station'		
	'17'='Other public order and safety'		
Standalone Retail	'42'='Retail store'	D	1.58
	'12'='Convenience store'		
	'13'='Convenience store with gas station'		
	'14'='Grocery store/food market'		
	'41'='Vehicle dealership/showroom'		
	'43'='Other retail'		
Strip Mall	'50'='Strip shopping mall'	D	1.58
	'51'='Enclosed mall'		
Primary School	'28'='Elementary/middle school'	D	1.58
	'31'='Other classroom education'		
	'30'='Preschool/daycare'		
Secondary School	'29'='High school'	D	1.58
	'27'='College/university'		
Outpatient Healthcare	'18'='Medical office (diagnostic)'	D	1.58
	'19'='Clinic/other outpatient health'		
Hospital	'35'='Hospital/inpatient health'	B	3.49
Small Hotel	'39'='Motel or inn'	B	3.49
Large Hotel	'38'='Hotel'	B	3.49
Warehouse	'09'='Distribution/shipping center'	D	1.58
	'10'='Non-refrigerated warehouse'		
	'47'='Vehicle storage/maintenance'		
	'11'='Self-storage'		

Building Type	CBECS PBA-Plus	Hunter's Curve	Adjustment Factor Divisor
	'20'='Refrigerated warehouse'		
Quick-service Restaurant	'32'='Fast food'	A	6.98
Full-service Restaurant	'33'='Restaurant/cafeteria'	A	6.98
Assembly	'21'='Religious worship'	D	1.58
	'22'='Entertainment/culture'		
	'23'='Library'		
	'24'='Recreation'		
	'25'='Social/meeting'		
	'26'='Other public assembly'		
Nursing Homes	'36'='Nursing home/assisted living'	B	3.49
Dormitories	'37'='Dormitory/fraternity/sorority'	B	3.49

For residential multifamily apartment buildings with greater than five units (Type HUQ 5), DOE developed adjustment factors based on the number of apartment units in the building to reflect diversity (Table 7B.6.4).

Table 7B.6.4 Commercial Gas-fired Tankless Water Heater – Hot Water Delivery Capability Adjustment Factors for RECS Building Types

Building Type	RECS Type HUQ	Hunter's Curve	Adjustment Factor Divisor
Single-family Detached Home	2	C	2.85
Single-family Attached Home	3	C	2.85
2–4 Unit Apartment Building	4	C	2.85
5+ Unit Apartment Building (Type HUQ 5)			
5 to 40 Units	5	C	3.42
41 to 60 Units	5	C	2.79
61 to 140 Units	5	C	2.25
141+ Units	5	C	1.79

7B.7 OPERATING HOURS BY EQUIPMENT CLASS AND EFFICIENCY LEVEL

Given the hot water load requirements and equipment needs of the sampled buildings, DOE was able to calculate the hours of operation and standby mode for the representative model of each equipment class to service each sampled building (Table 7B.7.1). Since the number of equipment units allocated to a specific building was held constant at the baseline efficiency level, equipment hours of operation decreased as its thermal efficiency (E_t) improved.

Table 7B.7.1 Operating Hours per Day by Equipment Class and Efficiency Level

E_t* EL	SL** EL	Design Option	Operating Hours per Day
Commercial Gas-fired Storage Water Heaters			
0	0	80% E_t, 1.00 SL Factor	2.67
1	0	82% E_t, 0.98 SL Factor	2.61
2	0	90% E_t, 0.91 SL Factor	2.38
3	0	92% E_t, 0.89 SL Factor	2.33
4	0	95% E_t, 0.86 SL Factor	2.26
5	0	99% E_t, 0.83 SL Factor	2.17
0	1	80% E_t, 0.85 SL Factor	2.65
1	1	82% E_t, 0.83 SL Factor	2.59
2	1	90% E_t, 0.77 SL Factor	2.36
3	1	92% E_t, 0.76 SL Factor	2.31
4	1	95% E_t, 0.73 SL Factor	2.24
5	1	99% E_t, 0.70 SL Factor	2.15
0	2	80% E_t, 0.74 SL Factor	2.63
1	2	82% E_t, 0.72 SL Factor	2.57
2	2	90% E_t, 0.67 SL Factor	2.34
3	2	92% E_t, 0.65 SL Factor	2.29
4	2	95% E_t, 0.63 SL Factor	2.22
5	2	99% E_t, 0.61 SL Factor	2.13
Residential-duty Gas-fired Storage Water Heaters			
0	0	80% E_t, 1.00 SL Factor	3.25
1	0	82% E_t, 0.98 SL Factor	3.17
2	0	90% E_t, 0.60 SL Factor	2.80
3	0	95% E_t, 0.60 SL Factor	2.66
4	0	97% E_t, 0.60 SL Factor	2.61
0	1	80% E_t, 0.80 SL Factor	3.19
1	1	82% E_t, 0.78 SL Factor	3.11
2	1	90% E_t, 0.48 SL Factor	2.76
3	1	95% E_t, 0.48 SL Factor	2.63
4	1	97% E_t, 0.48 SL Factor	2.58
0	2	80% E_t, 0.77 SL Factor	3.18
1	2	82% E_t, 0.76 SL Factor	3.11
0	3	80% E_t, 0.67 SL Factor	3.15
1	3	82% E_t, 0.66 SL Factor	3.08
Commercial Gas-fired Tankless Water Heaters			
0	-	80% E_t	0.68
1		82% E_t	0.66
2		84% E_t	0.65
3		92% E_t	0.59
4		94% E_t	0.58
5		96% E_t	0.57
Commercial Gas-fired Hot Water Supply Boilers			
0	-	80% E_t	2.57
1		82% E_t	2.51
2		84% E_t	2.45
3		92% E_t	2.24
4		94% E_t	2.19
5		96% E_t	2.15
Commercial Electric Storage Water Heaters			
0	0	98% E_t, 1.00 SL Factor	2.35

E_t* EL	SL** EL	Design Option	Operating Hours per Day
0	1	98% E_t, 0.84 SL Factor	2.33

* E_t = thermal efficiency
** SL factors were rounded to the nearest hundredth.

7B.8 ENERGY USE CALCULATIONS

DOE estimates the daily energy use of CWH equipment by adding the product of burner operating hours per day (meeting hot water load, including piping losses) and input capacity with the product of standby mode hours per day and standby loss rate. Then, DOE disaggregates the daily energy use of CWH equipment into main energy use and auxiliary energy use.

7B.8.1 Auxiliary Energy Use

CWH equipment can have auxiliary electrical use to operate electrical components such as electronic igniters, flue dampers and controls. DOE developed methodologies to determine auxiliary energy use based on the equipment class.

7B.8.1.1 Auxiliary Energy Use of Commercial Gas-fired Storage Water Heaters

For commercial gas-fired storage water heaters, DOE analyzed test data to determine the percentage of active and standby energy consumption attributed to auxiliary electric components across efficiency levels (shown in Table 7B.8.1).

Table 7B.8.1 Auxiliary Energy Use of Commercial Gas-fired Storage Water Heater

Efficiency Level	Auxiliary *% of active energy consumption*	Auxiliary *% of standby energy consumption*
0	0.025%	0.810%
1	0.025%	0.810%
2	0.202%	2.816%
3	0.202%	2.816%
4	0.202%	2.816%
5	0.202%	2.816%

7B.8.1.2 Auxiliary Energy Use of Residential-duty Gas-fired Storage Water Heaters

For residential-duty gas-fired storage water heaters, DOE used the electric power draw, in watts, of the auxiliary electrical components to determine auxiliary electric use across the efficiency levels for thermal efficiency and standby loss.

DOE mapped auxiliary components to the efficiency levels for residential-duty gas-fired storage water heaters based on the design and results of the Engineering Analysis (shown in Table 7B.8.2).

Table 7B.8.2 Mapping of Auxiliary Components to Efficiency Levels of Residential-duty Gas-fired Storage Water Heater

<table>
<tr><th></th><th colspan="4">Standby EL</th></tr>
<tr><th>E_t EL</th><th>0</th><th>1</th><th>2</th><th>3</th></tr>
<tr><td rowspan="2">0</td><td rowspan="2">Pilot</td><td rowspan="2">Electronic Ignition</td><td>Electronic Ignition</td><td>Electronic Ignition</td></tr>
<tr><td>Flue Damper</td><td>Flue Damper</td></tr>
<tr><td rowspan="2">1</td><td rowspan="2">Pilot</td><td rowspan="2">Electronic Ignition</td><td>Electronic Ignition</td><td>Electronic Ignition</td></tr>
<tr><td>Flue Damper</td><td>Flue Damper</td></tr>
<tr><td rowspan="2">2</td><td>Fan</td><td>Fan</td><td rowspan="6" colspan="2"></td></tr>
<tr><td>Electronic Ignition</td><td>Electronic Ignition</td></tr>
<tr><td rowspan="2">3</td><td>Fan</td><td>Fan</td></tr>
<tr><td>Electronic Ignition</td><td>Electronic Ignition</td></tr>
<tr><td rowspan="2">4</td><td>Fan</td><td>Fan</td></tr>
<tr><td>Electronic Ignition</td><td>Electronic Ignition</td></tr>
</table>

For thermal efficiency (E_t) efficiency levels 0 and 1 at standby loss efficiency level 0, the residential-duty gas-fired storage water equipment class uses a pilot light and does not have electric auxiliary components, resulting in an auxiliary electric power draw of zero watts. For all other combinations of E_t efficiency levels and standby loss efficiency levels, DOE estimated a power draw of 3 watts while the equipment is in standby mode based on an estimate from the analysis conducted for the DOE residential water heater rulemaking.[2] For active mode, DOE estimated 18 watts power draw for electronic ignition and controls, and 112 watts for the inducer fan based on test data. Residential-duty gas-fired storage water heater auxiliary active and standby electric power draw are shown in Table 7B.8.3.

Table 7B.8.3 Auxiliary Inputs for Residential-duty Gas-fired Storage Water Heater

Efficiency Level (E_t)	Efficiency Level (SL)	Active *watts*	Standby *watts*
0	0	0	0
1	0	0	0
2	0	130	3
3	0	130	3
4	0	130	3
0	1	18	3
1	1	18	3
2	1	130	3
3	1	130	3
4	1	130	3
0	2	18	3
1	2	18	3
0	3	18	3
1	3	18	3

7B.8.1.3 Auxiliary Energy Use of Commercial Gas-fired Tankless Water Heaters and Hot Water Supply Boilers

For commercial gas-fired tankless water heaters and commercial gas-fired hot water supply boilers, DOE analyzed test data to determine the percentage of active energy consumption attributed to auxiliary electric components. DOE used the electrical power draw, in watts, of the auxiliary electrical components to determine auxiliary electric use while the equipment is in standby mode. Auxiliary inputs for commercial gas-fired tankless water heaters and hot water supply boilers are shown in Table 7B.8.4.

Table 7B.8.4 Auxiliary Inputs of Commercial Gas-fired Tankless Water Heater and Commercial Gas-fired Hot Water Supply Boiler

Equipment	Auxiliary *% of active energy consumption*	Standby *watts*
Commercial gas-fired tankless water heater	0.514%	3
Commercial gas-fired hot water supply boiler	0.589%	12

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APPENDIX 7C. TEMPERATURE DATA FOR RECS AND CBECS SAMPLED BUILDINGS

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7C.1 INTRODUCTION

The Energy Information Administration's (EIA's) 2003 Commercial Building Energy Consumption Survey (CBECS 2003) and 2009 Residential Energy Consumption Survey (RECS 2009) do not provide data on inlet water temperatures.[1,2] To calculate the inlet temperature, DOE developed monthly dry bulb temperature estimates for each U.S. state using typical mean year (TMY) temperature data, captured in location files provided by the DOE EnergyPlus Energy Simulation Software.[3] Then, these dry bulb temperatures were used to develop monthly average inlet temperatures using an equation and methodology developed by the National Renewable Energy Laboratory (NREL).[4] Table 7C.2.1 through Table 7C.3.2 present the results.

7C.2 TEMPERATURE DATA FOR CBECS

Table 7C.2.1 Dry Bulb Temperature Data by CBECS Division

Census Division	Census Division Number	Monthly Average Dry Bulb Temperature *°F, Weighted*					
		Jan	Feb	Mar	Apr	May	Jun
		1	2	3	4	5	6
West South Central	7	45.88	50.64	56.36	64.99	74.71	79.74
West North Central	4	20.60	26.75	40.03	51.16	62.41	72.02
South Atlantic	5	44.60	48.98	56.93	63.63	70.57	76.87
Pacific	9	49.58	51.64	54.80	58.70	61.97	66.35
New England	1	24.77	28.82	37.01	47.05	58.02	66.03
Mountain	8	38.06	41.95	48.33	57.80	65.50	75.94
Middle Atlantic	2	30.07	30.90	41.80	51.31	61.21	70.43
East South Central	6	38.07	42.01	53.49	60.65	68.97	76.50
East North Central	3	23.45	25.71	38.32	48.97	60.36	69.43
Census Division	**Census Division Number**	**Monthly Average Dry Bulb Temperature *°F, Weighted***					
		Jul	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
		7	**8**	**9**	**10**	**11**	**12**
West South Central	7	83.62	82.27	76.33	66.67	56.10	47.39
West North Central	4	76.36	72.93	65.37	51.72	38.05	25.32
South Atlantic	5	79.56	78.41	73.85	63.56	57.51	48.26
Pacific	9	69.65	69.59	67.30	61.17	55.22	50.06
New England	1	72.51	70.00	63.26	52.23	42.27	32.78
Mountain	8	81.49	78.54	70.76	59.07	47.12	38.02
Middle Atlantic	2	75.58	74.16	65.74	54.53	45.42	35.44
East South Central	6	79.43	78.13	72.03	59.98	52.41	42.40
East North Central	3	74.06	71.07	63.62	51.08	39.90	27.79

Table 7C.2.2 Inlet Temperature Data by CBECS Division

Census Division	Census Division Number	Monthly Average Dry Bulb Temperature *°F, Weighted*					
		Jan	Feb	Mar	Apr	May	Jun
		1	2	3	4	5	6
West South Central	7	60.19	60.32	63.33	68.44	74.32	79.44
West North Central	4	45.02	43.51	45.31	49.95	56.23	62.51
South Atlantic	5	59.92	59.79	62.19	66.52	71.64	76.21
Pacific	9	60.56	60.31	61.46	63.71	66.47	69.01
New England	1	46.06	44.71	46.19	50.10	55.44	60.81
Mountain	8	53.43	52.99	55.57	60.48	66.46	71.93
Middle Atlantic	2	48.78	47.70	49.58	53.92	59.60	65.13
East South Central	6	55.37	54.99	57.57	62.43	68.31	73.68
East North Central	3	45.43	43.99	45.54	49.68	55.33	61.02
Census Division	**Census Division Number**	**Monthly Average Dry Bulb Temperature *°F, Weighted***					
		Jul	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
		7	**8**	**9**	**10**	**11**	**12**
West South Central	7	82.46	82.60	79.82	74.84	68.97	63.73
West North Central	4	67.15	68.95	67.44	63.00	56.81	50.46
South Atlantic	5	79.06	79.43	77.23	73.03	67.93	63.26
Pacific	9	70.69	71.06	70.02	67.85	65.12	62.52
New England	1	64.81	66.41	65.18	61.45	56.18	50.75
Mountain	8	75.49	76.19	73.87	69.11	63.17	57.59
Middle Atlantic	2	69.08	70.42	68.80	64.64	59.02	53.41
East South Central	6	77.13	77.77	75.44	70.74	64.89	59.41
East North Central	3	65.26	66.96	65.67	61.73	56.16	50.41

7C.3 TEMPERATURE DATA FOR RECS

Table 7C.3.1 Dry Bulb Temperature Data by RECS Reportable Domain

Reportable Domain	Reported Domain Number	Monthly Average Dry Bulb Temperature °F, Weighted					
		Jan	Feb	Mar	Apr	May	Jun
		1	2	3	4	5	6
Connecticut, Maine, New Hampshire, Rhode Island, Vermont	1	24.20	27.76	36.38	47.23	57.53	66.35
Massachusetts	2	25.43	30.08	37.76	46.83	58.60	65.65
New York	3	31.94	30.14	40.88	50.71	60.54	69.99
New Jersey	4	27.64	32.88	44.39	52.71	63.58	72.50
Pennsylvania	5	28.89	30.69	41.41	51.25	60.58	69.69
Illinois	6	23.02	26.94	39.21	50.37	60.48	70.41
Indiana, Ohio	7	26.36	27.63	40.29	50.94	61.48	70.49
Michigan	8	23.10	23.50	35.69	45.53	59.89	67.91
Wisconsin	9	15.83	20.74	34.63	45.52	57.32	66.47
Iowa, Minnesota, North Dakota, South Dakota	10	13.03	20.77	34.75	46.45	60.65	68.88
Kansas, Nebraska	11	26.40	32.48	42.97	54.56	63.51	74.16
Missouri	12	28.64	32.22	46.52	56.33	64.49	75.57
Virginia	13	34.49	37.48	48.44	56.43	65.64	73.88
Delaware, Maryland, West Virginia	14	30.56	35.58	46.27	55.02	64.30	72.47
Georgia	15	42.27	48.17	57.80	63.93	70.76	78.09
North Carolina, South Carolina	16	39.50	44.98	53.05	61.34	68.42	75.56
Florida	17	60.12	63.21	67.71	72.06	76.95	80.46
Alabama, Kentucky, Mississippi	18	38.23	43.03	53.68	61.02	69.05	76.45
Tennessee	19	37.76	40.08	53.14	59.95	68.82	76.60
Arkansas, Louisiana, Oklahoma	20	42.01	46.86	54.53	62.92	72.69	79.03
Texas	21	47.56	52.28	57.15	65.89	75.59	80.05
Colorado	22	29.87	32.60	40.99	49.78	57.53	67.15
Idaho, Montana, Utah, Wyoming	23	28.24	32.22	40.84	49.23	56.53	67.12
Arizona	24	53.04	57.94	60.58	71.28	78.73	90.34
Nevada, New Mexico	25	38.88	42.51	49.01	58.88	67.39	76.94
California	26	52.54	54.41	57.51	60.83	63.60	67.66
Alaska, Hawaii, Oregon, Washington	27	40.86	43.49	46.83	52.42	57.16	62.52

Reportable Domain	Reported Domain Number	Monthly Average Dry Bulb Temperature °F, Weighted					
		Jul	Aug	Sep	Oct	Nov	Dec
		7	8	9	10	11	12
Connecticut, Maine, New Hampshire, Rhode Island, Vermont	1	71.67	69.83	62.90	51.39	42.04	31.11
Massachusetts	2	73.50	70.20	63.69	53.22	42.54	34.76
New York	3	75.81	74.96	66.38	55.61	44.31	35.89
New Jersey	4	76.84	75.40	67.46	55.66	45.56	36.54
Pennsylvania	5	74.35	72.07	63.58	52.08	47.03	33.97
Illinois	6	75.35	71.68	64.80	51.68	40.17	25.96
Indiana, Ohio	7	74.76	71.54	64.05	52.18	41.87	30.63
Michigan	8	72.46	70.30	62.41	49.84	38.22	28.07
Wisconsin	9	71.75	69.58	61.71	48.39	35.94	22.41
Iowa, Minnesota, North Dakota, South Dakota	10	73.76	69.70	61.46	47.34	32.90	19.18

Reportable Domain	Reported Domain Number	Monthly Average Dry Bulb Temperature *°F, Weighted*					
		Jul	Aug	Sep	Oct	Nov	Dec
		7	8	9	10	11	12
Kansas, Nebraska	11	78.78	75.34	68.40	55.82	42.91	30.44
Missouri	12	78.79	76.43	69.51	55.78	42.82	31.54
Virginia	13	77.57	75.72	69.34	56.28	49.58	38.45
Delaware, Maryland, West Virginia	14	76.64	74.77	67.55	54.38	47.19	35.44
Georgia	15	80.04	79.59	74.13	62.29	56.01	46.74
North Carolina, South Carolina	16	79.26	77.51	71.80	59.61	53.27	43.64
Florida	17	81.67	81.25	79.95	74.32	69.40	62.34
Alabama, Kentucky, Mississippi	18	78.89	77.62	71.62	59.86	52.46	42.76
Tennessee	19	80.45	79.10	72.80	60.21	52.30	41.73
Arkansas, Louisiana, Oklahoma	20	82.25	80.83	74.69	64.75	53.24	43.95
Texas	21	84.21	82.89	77.04	67.50	57.33	48.88
Colorado	22	73.35	70.68	62.46	50.88	39.35	29.43
Idaho, Montana, Utah, Wyoming	23	75.54	72.46	62.80	50.29	37.99	29.94
Arizona	24	92.80	89.63	83.90	73.74	61.54	51.75
Nevada, New Mexico	25	82.36	79.59	71.86	58.97	47.37	38.80
California	26	70.26	70.27	69.13	63.72	58.19	53.21
Alaska, Hawaii, Oregon, Washington	27	67.87	67.59	61.91	53.67	46.48	40.78

Table 7C.3.2 Inlet Temperature Data by RECS Reportable Domain

Reportable Domain	Reported Domain Number	Monthly Average Dry Bulb °F, Weighted					
		Jan	Feb	Mar	Apr	May	Jun
		1	2	3	4	5	6
Connecticut, Maine, New Hampshire, Rhode Island, Vermont	1	45.76	44.39	45.79	49.60	54.82	60.09
Massachusetts	2	46.42	45.09	46.65	50.70	56.17	61.65
New York	3	48.97	47.91	49.76	54.04	59.64	65.10
New Jersey	4	49.00	47.95	50.11	54.91	61.11	67.09
Pennsylvania	5	48.34	47.21	48.93	53.04	58.48	63.83
Illinois	6	45.43	43.97	45.65	50.02	55.95	61.90
Indiana, Ohio	7	46.92	45.64	47.33	51.54	57.17	62.77
Michigan	8	44.70	43.20	44.54	48.36	53.66	59.08
Wisconsin	9	42.00	40.17	41.39	45.33	50.97	56.84
Iowa, Minnesota, North Dakota, South Dakota	10	41.10	39.11	40.42	44.67	50.76	57.11
Kansas, Nebraska	11	48.00	46.85	49.08	54.10	60.61	66.91
Missouri	12	49.20	48.19	50.49	55.49	61.90	68.04
Virginia	13	52.34	51.64	53.89	58.49	64.25	69.67
Delaware, Maryland, West Virginia	14	50.24	49.32	51.45	56.07	61.98	67.63
Georgia	15	58.52	58.46	61.22	66.10	71.81	76.87
North Carolina, South Carolina	16	55.96	55.63	58.18	62.93	68.66	73.86
Florida	17	71.12	71.67	73.99	77.46	81.20	84.22
Alabama, Kentucky, Mississippi	18	55.64	55.27	57.80	62.56	68.32	73.58
Tennessee	19	54.85	54.46	57.14	62.19	68.29	73.86
Arkansas, Louisiana, Oklahoma	20	57.84	57.72	60.56	65.65	71.64	76.98
Texas	21	61.20	61.44	64.53	69.65	75.49	80.50
Colorado	22	47.37	46.17	47.61	51.33	56.35	61.37
Idaho, Montana, Utah, Wyoming	23	46.50	45.21	46.80	50.85	56.31	61.76
Arizona	24	64.22	65.22	69.57	76.15	83.23	88.98
Nevada, New Mexico	25	53.98	53.51	56.14	61.17	67.30	72.93
California	26	62.88	62.78	63.98	66.18	68.78	71.13
Alaska, Hawaii, Oregon, Washington	27	53.73	53.06	54.05	56.46	59.65	62.79

Reportable Domain	Reported Domain Number	Monthly Average Dry Bulb Temperature °F, Weighted					
		Jul	Aug	Sep	Oct	Nov	Dec
		7	8	9	10	11	12
Connecticut, Maine, New Hampshire, Rhode Island, Vermont	1	64.05	65.66	64.50	60.88	55.73	50.40
Massachusetts	2	65.71	67.29	65.98	62.12	56.71	51.17
New York	3	68.99	70.31	68.70	64.60	59.06	53.54
New Jersey	4	71.29	72.61	70.73	66.11	59.98	53.92
Pennsylvania	5	67.70	69.07	67.60	63.66	58.28	52.86
Illinois	6	66.31	68.04	66.64	62.46	56.61	50.60
Indiana, Ohio	7	66.86	68.40	66.97	62.95	57.38	51.72
Michigan	8	63.20	64.93	63.85	60.21	54.98	49.52
Wisconsin	9	61.42	63.50	62.56	58.82	53.28	47.36
Iowa, Minnesota, North Dakota, South Dakota	10	62.06	64.32	63.31	59.28	53.29	46.90
Kansas, Nebraska	11	71.37	72.81	70.88	66.06	59.61	53.22
Missouri	12	72.32	73.63	71.61	66.80	60.46	54.22

Reportable Domain	Reported Domain Number	Monthly Average Dry Bulb Temperature *°F, Weighted*					
		Jul	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
		7	**8**	**9**	**10**	**11**	**12**
Virginia	13	73.34	74.30	72.30	67.87	62.15	56.64
Delaware, Maryland, West Virginia	14	71.56	72.75	70.88	66.44	60.58	54.85
Georgia	15	79.97	80.29	77.76	73.03	67.33	62.15
North Carolina, South Carolina	16	77.19	77.78	75.47	70.87	65.17	59.86
Florida	17	85.74	85.36	83.18	79.77	76.02	72.90
Alabama, Kentucky, Mississippi	18	76.96	77.59	75.31	70.70	64.97	59.61
Tennessee	19	77.45	78.12	75.69	70.81	64.74	59.06
Arkansas, Louisiana, Oklahoma	20	80.29	80.69	78.09	73.15	67.18	61.71
Texas	21	83.40	83.43	80.57	75.58	69.74	64.60
Colorado	22	65.08	66.51	65.30	61.75	56.79	51.72
Idaho, Montana, Utah, Wyoming	23	65.78	67.33	65.99	62.12	56.72	51.21
Arizona	24	91.90	91.22	87.13	80.69	73.58	67.64
Nevada, New Mexico	25	76.59	77.34	74.97	70.10	64.01	58.27
California	26	72.60	72.82	71.72	69.60	67.00	64.61
Alaska, Hawaii, Oregon, Washington	27	65.06	65.88	65.02	62.72	59.57	56.39

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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 ANALYSES

8.1 INTRODUCTION

The effect of amended standards on individual commercial consumers usually includes a reduction in operating cost and an increase in purchase cost. This chapter describes two metrics used in the analysis to determine the economic impact of standards on individual commercial consumers.

- **Life-cycle cost (LCC)** is the total commercial consumer cost of covered equipment, generally over the life of the equipment. The LCC calculation includes total installed cost (equipment manufacturer selling price, distribution chain markups, sales tax, and installation costs), operating costs (energy, repair, and maintenance costs), equipment lifetime, and discount rate. Future operating costs are discounted to the time of purchase and summed over the lifetime of the appliance or product.

- **Payback period (PBP)** measures the amount of time it takes commercial consumers to recover the assumed higher purchase price of more energy-efficient equipment through reduced operating costs.

The U.S. Department of Energy (DOE) conducts the LCC and PBP analysis using a spreadsheet model developed in Microsoft Excel. When combined with Crystal Ball (a commercially available software program), the LCC and PBP model generates a Monte Carlo simulation to perform the analysis by incorporating uncertainty and variability considerations in certain of the key parameters (as discussed further in section 8.1.1)

Inputs to the LCC and PBP analysis of commercial water heating (CWH) equipment are discussed in sections 8.2 and 8.3, respectively. Results for each metric are presented in section 8.4. Key variables and calculations are presented for each metric. The calculations discussed here were performed with a series of Microsoft Excel spreadsheets that are accessible over the Internet (link to be added soon).

Details of the spreadsheets and instructions for using them are discussed in appendix 8A.

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

Recognizing that each commercial building using CWH equipment is unique, DOE analyzes variability and uncertainty through LCC and PBP probability calculations that address a representative sample of individual commercial and residential buildings nationally. The results are expressed as the number of buildings experiencing economic impacts of different magnitudes. The LCC and PBP model was developed using Microsoft Excel spreadsheets combined with Crystal Ball software. The LCC and PBP analysis explicitly model both the uncertainty and variability in the model's inputs using Monte Carlo simulation and probability distributions (see appendix 8B).

The LCC analysis uses the estimated energy use for each CWH unit as described in the energy use analysis in chapter 7 of the technical support document (TSD). Energy use of CWH equipment is sensitive to inlet water temperature and therefore varies by location within the United States. Aside from energy use, other important factors influencing the LCC and PBP analysis include energy prices, installation costs, equipment distribution markups, and sales taxes.

The sampling process selects specific commercial and residential buildings for CWH equipment installation. The sampling process is predicated on a parameter called *Adjusted N-Weights*; the higher the parameter, the higher the frequency with which a building will be chosen for analysis.

DOE generates LCC and PBP results as probability distributions using a simulation based on Monte Carlo analysis methods, in which certain key inputs to the analysis consist of probability distributions rather than single-point values. Therefore, the outcomes of the Monte Carlo analysis can also be expressed as probability distributions since the Monte Carlo analysis produces a range of LCC and PBP results. A distinct advantage of this type of approach is that DOE can identify the percentage of commercial consumers achieving LCC savings or attaining certain PBP values due to an increased efficiency level (in the event that level is potentially chosen as a standard). The LCC and PBP results are developed as distributions of impacts compared to a case where no new or amended energy conservation standards are applied—the no-new-standards case.

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

The LCC is the total commercial consumer cost over the life of the equipment, including purchase price (including retail markups, sales taxes, and installation costs) and operating cost (including costs for repair, maintenance, and energy). Future operating costs are discounted to the time of purchase and summed over the lifetime of the equipment. The PBP is the increase in purchase cost of higher efficiency equipment divided by the change in annual operating cost of the equipment. It represents the number of years that it will take the commercial consumer to recover the increased purchase cost through decreased operating costs. In the PBP calculation, future costs are not discounted.

Inputs to the LCC and PBP analysis are categorized as (1) inputs for establishing the purchase cost, otherwise known as the total installed cost, and (2) inputs for calculating the operating cost (*i.e.*, energy, maintenance, and repair costs).

The primary inputs for establishing the total installed cost are the following:

- *Baseline manufacturer selling price*: The baseline manufacturer selling price (MSP) is the price charged by the manufacturer to a wholesaler for equipment meeting existing minimum energy conservation (or baseline) standards. It includes a markup that converts the cost of production (*i.e.*, the manufacturer cost) to the MSP.

- *Standard-level manufacturer selling price*: The standard-level MSP is the incremental change in MSP associated with producing equipment at each of the higher efficiency standard levels.

- *Markups and sales tax*: Markups and sales tax are the wholesaler and contractor margins and state and local retail sales taxes associated with converting the MSP to a commercial consumer price.

- *Installation cost*: Installation cost is the cost to the commercial consumer of installing the equipment. The installation cost represents all costs required to install the equipment but does not include the marked-up commercial consumer equipment price. The installation cost includes labor, overhead, and any miscellaneous materials and parts.

The primary inputs for calculating the CWH equipment operating cost for the notice of proposed rulemaking (NOPR) are the following:

- *Equipment energy consumption*: The equipment energy consumption is the site energy use associated with the use of the CWH equipment to provide hot water to the building.

- *Energy Prices*: Electricity and natural gas prices are determined using marginal monthly energy prices.

- *Electricity and natural gas price trends*: The Energy Information Administration's (EIA's) *Annual Energy Outlook 2015 (AEO2015)* is used to project energy prices into the future.

- *Maintenance costs*: The labor and material costs associated with maintaining equipment operation.

- *Repair costs*: The labor and material costs associated with repairing or replacing components that have failed.

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

- *Discount rate*: The rate at which future costs and savings are discounted to establish their present value.

Figure 8.1.1 graphically depicts the relationships between the installed cost and operating cost inputs for the calculation of the LCC and PBP.

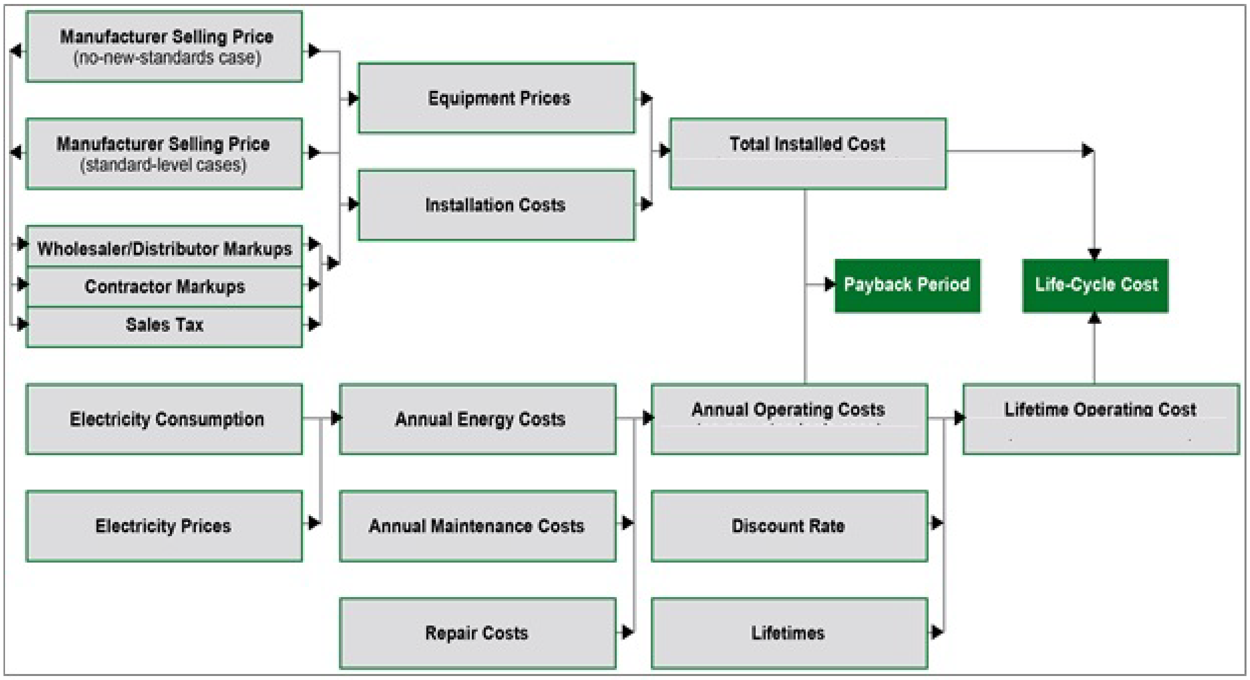

Figure 8.1.1 Flow Diagram of Inputs for the Determination of LCC and PBP

Table 8.1.1 provides descriptions of the various inputs to the calculation of the LCC and PBP. As noted earlier, most of the inputs are characterized by probability distributions that capture variability in the input variables.

Table 8.1.1 Summary of Inputs and Key Assumptions Used in the LCC and PBP Analysis

Inputs	Description
Affecting Installed Costs	
Equipment Price	Derives MSP for CWH units at different input capacities (from the engineering analysis) and multiplies by wholesaler, retailer and contractor markups, plus sales tax (from markups analysis). Applies the probability distribution for the different markups to describe their variability.
Installation Cost	Installation costs for gas-fired CWH equipment are predominately driven by the cost of venting. DOE calculated venting costs for each building in the EIA's Commercial Building Energy Consumption Survey (CBECS) and Residential Energy Consumption Survey (RECS). Primary parameters impacting venting costs include the type of installation (new construction or retrofit), draft type (atmospheric venting or power venting), CWH fuel type, building vintage, number of stories, and presence of a chimney. The analysis utilizes a logic sequence to identify when to include the primary variables, as well as a number of minor variables, to accurately determine the venting costs for each product and building within the analysis. Additionally, venting costs include removal cost (in the case of replacement) and actual vent installation labor costs. The installation costs also account for physical removal of existing equipment (in the case of a replacement) and location of the new equipment, plumbing, electrical and miscellaneous tasks. All installation costs account for overhead, taxes, and markups.
Affecting Operating Costs	
Annual Energy Use	Annual energy use includes electricity and natural gas used by CWH equipment providing hot water in either commercial or residential buildings. The energy use analysis provides estimates of the distribution of annual energy consumption for CWH equipment at different efficiency standard levels and standby loss levels considered. (Standby loss levels essentially indicate the energy loss rate when the equipment is in standby, and increasing standby loss levels indicate decreasing total standby energy losses; *i.e.*, standby loss level 2 has less total standby energy losses when compared to standby loss level 1).
Energy Efficiency	Rated thermal efficiency is the efficiency descriptor for CWH equipment. The thermal efficiency is used to determine the annual energy consumption associated with each considered efficiency level.
Standby Loss Rate	The standby loss rate is the descriptor for the amount of energy losses associated with the equipment when it is in standby mode. The standby loss rate is used to estimate standby energy losses for the equipment.
Energy Prices	Costs are calculated for CBECS 2003 buildings from marginal monthly average electricity or natural gas prices in each census division reported in CBECS 2003. Commercial prices are escalated by the *AEO2015* forecasts to estimate future electricity/gas prices. Escalation is performed at the census division level. Costs are calculated for RECS 2009 households from monthly average electricity or natural gas prices in each of 27 states and groups of states (commonly known as reportable domain) in RECS 2009. Residential prices are escalated by the *AEO2015* forecasts to estimate future electricity/gas prices. Escalation is performed at the census division level and applied to the regions used in the study.
Maintenance Cost	The cost associated with maintaining the operation of the equipment.
Repair Cost	Estimates the annualized repair cost for different efficiency levels of CWH equipment, based on costs of major repair (such as combustion systems, element, thermostat) from a variety of published sources.
Affecting Present Value of Annual Operating Cost Savings	
Equipment Lifetime	Uses the probability distribution of lifetimes developed for different equipment classes of CWH equipment.
Discount Rate	Mean real discount rates (weighted) for all buildings range from 3.6% to 5.1%, for the six income bins relevant to residential applications. For commercial applications, DOE considered mean real discount rates (weighted) from ten different commercial sectors, and the rates ranged between 3.5% and 6%.

Inputs	Description
Date Compliance is Required	2019 (generally 3 years after the "effective date," as published in the final rule)

All of the inputs depicted in Figure 8.1.1 and summarized in Table 8.1.1 are discussed in section 8.2.

8.1.3 Use of Commercial Building Energy Consumption Survey and Residential Energy Consumption Survey in Life-Cycle Cost and Payback Period Analysis

The LCC and PBP calculations detailed here are for a representative sample of individual users of CWH equipment. The CWH units are assumed to be installed both in commercial and residential buildings.

As explained in chapter 7, the EIA's 2003 Commercial Building Energy Consumption Survey (CBECS 2003) serves as the basis for determining the representative commercial sample, while EIA's 2009 Residential Energy Consumption Survey (RECS 2009) serves as the basis for determining the representative residential sample.[1,2] CBECS collects energy-related data for commercial buildings in the United States. CBECS 2003 includes data from 5,215 buildings representing 4.9 million buildings. RECS collects energy-related data for occupied primary housing units in the United States. RECS 2009 includes data from 12,083 housing units that represent almost 113.6 million households.

8.2 LIFE-CYCLE COST ANALYSIS INPUTS

Life-cycle cost is the total commercial consumer cost over the life of equipment, including purchase cost and operating costs (which are composed of costs for energy, maintenance, and repair). Future operating costs are discounted to the time of purchase and summed over the lifetime of the equipment. Life-cycle cost is defined by the following equation:

$$LCC = IC + \sum_{t=1}^{T} OC_{(t)} \Big/ (1+r)^t$$

Eq. 8.1

Where:

LCC = life-cycle cost ($),
IC = total installed cost ($),
$\sum$ = sum over the lifetime, from year 1 to year T,
T = lifetime of equipment (years),
OC = operating cost ($),
r = discount rate, and
t = year for which operating cost is being determined.

DOE expresses all the costs in $2014. Total installed cost, operating cost, lifetime, and discount rate are discussed in the following sections. In the LCC analysis, the year of equipment purchase is assumed to be 2019, the assumed effective date of energy conservation standards for CWH equipment.

8.1.1 Total Installed Cost Inputs

The total installed cost to the commercial consumer is defined by the following equation:

$$IC = EQP + INST$$

Eq. 8.2

Where:

EQP = equipment price ($) (*i.e.*, commercial consumer price for the equipment only), and
INST = installation cost ($) (*i.e.*, the cost for labor and materials).

The equipment price is based on the distribution channel through which the commercial consumer purchases the equipment. DOE defines the major distribution channels for units installed, to describe how the equipment passes from the manufacturer to the commercial consumer. DOE modeled eight different distribution channels for units, using probability distributions, and selected specific channels based on whether the water heater is used in a commercial or residential application, and whether it is a new or a replacement (CWH equipment) case (Chapter 6 of this TSD presents a more detailed account on markups). DOE constructed such channels for each equipment class. The remainder of this section provides information about the variables DOE uses to calculate the total installed cost for CWH equipment.

8.2.1.1 Manufacturer Costs

DOE develops the manufacturer costs for CWH equipment as described in the engineering analysis, chapter 5 of this TSD. The manufacturer costs at efficiency and standby loss level are shown in Table 8.2.1.

Table 8.2.1 Manufacturer Production Cost for CWH Equipment by Efficiency Level and Standby Loss Level

Equipment Class	Input Rate *Btu/h*	Thermal Efficiency *%*	Efficiency Level	Standby Loss Level	Manufacturer Production Cost *2014$*
Commercial Gas Storage	199,000	80%	0	0	$1,024
Commercial Gas Storage	199,000	82%	1	0	$1,046
Commercial Gas Storage	199,000	90%	2	0	$1,254
Commercial Gas Storage	199,000	92%	3	0	$1,264
Commercial Gas Storage	199,000	95%	4	0	$1,288

Equipment Class	**Input Rate** *Btu/h*	**Thermal Efficiency** *%*	**Efficiency Level**	**Standby Loss Level**	**Manufacturer Production Cost** *2014$*
Commercial Gas Storage	199,000	99%	5	0	$1,331
Commercial Gas Storage	199,000	80%	0	1	$1,030
Commercial Gas Storage	199,000	82%	1	1	$1,052
Commercial Gas Storage	199,000	90%	2	1	$1,260
Commercial Gas Storage	199,000	92%	3	1	$1,270
Commercial Gas Storage	199,000	95%	4	1	$1,295
Commercial Gas Storage	199,000	99%	5	1	$1,335
Commercial Gas Storage	199,000	80%	0	2	$1,051
Commercial Gas Storage	199,000	82%	1	2	$1,074
Commercial Gas Storage	199,000	90%	2	2	$1,282
Commercial Gas Storage	199,000	92%	3	2	$1,293
Commercial Gas Storage	199,000	95%	4	2	$1,317
Commercial Gas Storage	199,000	99%	5	2	$1,361
Residential-Duty Gas Storage	76,000	80%	0	0	$354
Residential-Duty Gas Storage	76,000	82%	1	0	$359
Residential-Duty Gas Storage	76,000	90%	2	0	$668
Residential-Duty Gas Storage	76,000	95%	3	0	$810
Residential-Duty Gas Storage	76,000	97%	4	0	$819
Residential-Duty Gas Storage	76,000	80%	0	1	$401
Residential-Duty Gas Storage	76,000	82%	1	1	$407

Equipment Class	**Input Rate** *Btu/h*	**Thermal Efficiency** *%*	**Efficiency Level**	**Standby Loss Level**	**Manufacturer Production Cost** ***2014$***
Residential-Duty Gas Storage	76,000	90%	2	1	$686
Residential-Duty Gas Storage	76,000	95%	3	1	$828
Residential-Duty Gas Storage	76,000	97%	4	1	$836
Residential-Duty Gas Storage	76,000	80%	0	2	$442
Residential-Duty Gas Storage	76,000	82%	1	2	$448
Residential-Duty Gas Storage	76,000	80%	0	3	$462
Residential-Duty Gas Storage	76,000	82%	1	3	$468
Commercial Gas Instantaneous - Tankless	250,000	80%	0	NA	$630
Commercial Gas Instantaneous - Tankless	250,000	82%	1	NA	$639
Commercial Gas Instantaneous - Tankless	250,000	84%	2	NA	$647
Commercial Gas Instantaneous - Tankless	250,000	92%	3	NA	$790
Commercial Gas Instantaneous - Tankless	250,000	94%	4	NA	$805
Commercial Gas Instantaneous - Tankless	250,000	96%	5	NA	$824
Commercial Gas Instantaneous – HWSB*	399,000	80%	0	NA	$1,182
Commercial Gas Instantaneous - HWSB	399,000	82%	1	NA	$1,206
Commercial Gas Instantaneous - HWSB	399,000	84%	2	NA	$1,411

Equipment Class	Input Rate *Btu/h*	Thermal Efficiency *%*	Efficiency Level	Standby Loss Level	Manufacturer Production Cost *2014$*
Commercial Gas Instantaneous - HWSB	399,000	92%	3	NA	$2,672
Commercial Gas Instantaneous - HWSB	399,000	94%	4	NA	$2,827
Commercial Gas Instantaneous - HWSB	399,000	96%	5	NA	$2,982
Commercial Electric Storage	61,416	NA	0	0	$854
Commercial Electric Storage	61,416	NA	0	1	$883

* HWSB = Hot Water Supply Boiler

8.2.1.2 Markups

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. The overall markup is multiplied times the baseline or standard-compliant manufacturer cost to arrive at the price paid by the commercial consumer. Because there are baseline and incremental markups associated with the wholesaler and mechanical contractor, the overall markup is also divided into a baseline markup (*i.e.*, a markup used to convert the baseline manufacturer price into a commercial 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 commercial consumer price). Markups can differ, depending on whether the equipment is purchased for a new construction installation or is purchased to replace existing equipment. DOE develops the overall baseline markups and incremental markups for both new construction and replacement applications as a part of the markups analysis (chapter 6 of this TSD).

Based on the percentages of the market attributed to each distribution channel, Table 8.2.2 and Table 8.2.3 display the national weighted-average baseline and incremental markups and their associated components for CWH equipment (storage and instantaneous)

Table 8.2.2 Summary of National Average Markups on CWH Equipment (Storage)

Equipment Class	Baseline Markup	Incremental Markup
Commercial Gas-Fired Storage Water Heater	3.17	2.08
Residential-Duty Gas-Fired Storage Water Heater	3.16	2.09
Commercial Electric Storage Water Heater	3.06	2.04

Table 8.2.3: Summary of National Average Markups on CWH Equipment (Instantaneous)

Equipment Class	Baseline Markup	Incremental Markup
Commercial Gas-Fired Instantaneous Water Heater	3.22	2.08
Commercial Gas-Fired Hot Water Supply Boiler	3.30	2.10

8.2.1.3 Total Commercial Consumer Price

DOE derives the commercial consumer equipment price for the baseline equipment by multiplying baseline manufacturer cost and the baseline overall markup. For each efficiency level above the baseline, DOE derives the commercial consumer equipment price by adding the baseline equipment commercial consumer price to the product of the incremental manufacturer cost and incremental overall markup for that equipment at each higher efficiency level. Markups and sales taxes can take on a variety of values, depending on location, and so the resulting total installed cost for a particular efficiency level is represented by a distribution of values.

8.2.1.4 Installation Cost

The installation cost is the cost to the commercial consumer of installing the CWH equipment. The cost of installation covers all labor and material costs associated with the installation of a CWH unit in a new building, or, in the case of an existing building with failed equipment, the removal of failed CWH equipment and the installation of a replacement unit. DOE's analysis estimates specific installation costs for each sample building based on distributions of the primary installation parameters (such as vent diameter and vent length) and building characteristics given in CBECS 2003 and RECS 2009. Additional installation costs associated with labor, minor equipment, and consumables were obtained through national reference sources, a variety of supplier websites, manufacturing literature, previous DOE reports, and information from expert consultants.

The engineering analysis identified representative product dimensions as noted in Table 8.2.4 and Table 8.2.5. DOE undertook research of the most common dimensions of doors available to determine if additional installation costs would be incurred when replacing older equipment with new high efficiency and low standby loss equipment, in the event that new equipment would by necessity have larger dimensions. DOE reviewed sources such as Lowes.com, HomeDepot.com, and Grainger.com websites to determine the average dimensions of commercially available doors. In this research, DOE analyzed metal doors, which are considered to be more representative of doors used in commercial buildings. Based upon available door dimensions, this research identified that the most common door size is 36 inches wide and 80 inches tall, with approximately 64 percent of available doors having this width or wider egress. Similarly, as these doors are available for both new construction and replacement, DOE considers this analysis to be representative of the existing stock of installed door dimensions in commercial buildings. Therefore, DOE did not include additional costs to install the new equipment in replacement installations.

Table 8.2.4 Dimensions of Representative Storage Tank Equipment Determined in Engineering Analysis

Equipment Subcategory	Height *inch*	Width *inch*
Commercial Gas-Fired Storage Water Heater	76.7	29.0
Residential-Duty Gas-Fired Storage Water Heater	68.2	24.8
Commercial Electric Storage Water Heater	64.3	32.0

Table 8.2.5 Dimensions of Instantaneous Equipment Determined in Engineering Analysis

Equipment Subcategory	Height *inch*	Width *inch*	Depth *inch*
Commercial Gas-Fired Instantaneous Tankless Water Heater	26.9	21.9	10.3
Commercial Gas-Fired Instantaneous Hot Water Supply Boiler	38.3	25.0	31.5

Labor

DOE's analysis of installation costs accounts for regional differences in labor costs. DOE estimated the installation costs at each considered efficiency level using a variety of sources, including RS Means 2013 Facilities Construction Cost Data,[3] ENR Mechanical Cost book,[4] Whitestone Facility Maintenance and Repair Cost Reference,[5] manufacturer literature, and information from expert consultants. For a detailed discussion of the development of installation costs, see appendix 8D. DOE estimates basic installation costs applicable both to replacement and new buildings. These costs, which apply to all CWH equipment, include venting costs and removal costs (in replacement cases).

Venting

For CWH equipment requiring venting, DOE calculated venting costs for each building in the CBECS and RECS data sets. A variety of installation parameters impact venting costs; among these, DOE simulated the type of installation (new construction or retrofit), draft type (atmospheric venting or power venting), fuel type, building vintage, specific number of stories, and presence of a chimney.

DOE researched the requirements of venting products in the subcategories considered in this analysis. Research sources include the National Fuel Gas Code (NFGC), equipment manufacturer's websites, and venting manufacturer's websites. DOE identified that the primary factors indicating the cost of venting are the category of venting,[a] the vent diameter,[b] and vent

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[a] The NFGC identifies venting category by the probability of condensation and vent pressure. In this analysis, DOE considers the efficiency level and vent pressure of the CWH equipment sufficient to determine the venting category.
[b] The NFGC provides data to relate the input rating of the CWH equipment to the diameter of the venting, depending upon whether the equipment is natural draft or mechanical draft.

length (which is installation dependent within the equipment's published maximum allowable vent length). Additionally, DOE simulated the type of installation (new construction or retrofit), draft type (atmospheric venting or power venting), water heater fuel type, building vintage, number of stories, and presence of a chimney. A logic sequence was applied to the identified variables in order to accurately determine the venting costs for each instance of product and building within the Monte Carlo analysis. Each of these considerations is discussed in appendix 8D along with additional information presented to describe how DOE integrated these data into the LCC modeling.

Electricity Outlet

The cost of installing an electrical outlet for products requiring electricity was modeled as the cost of an electrical receptacle ($29.50) plus the cost of 1.5 hours of one electrician's labor at the national labor rate, adjusted for the region of the installation. DOE recognizes that a considerable number of buildings already have electrical outlets accessible at the footprint of the CWH equipment. Therefore, this cost was applied to 5 percent of condensing and non-condensing installations.

Condensate Disposal

The installation cost for the condensing design includes the cost of condensate disposal. The approach reflects the currently available condensing water heater design that utilizes a power vent design. The condensate disposal includes the cost of the condensate neutralizer filter (which is required by some codes), heat tape (which is required to prevent condensate from freezing in cold climates), and condensate pump (which is required to move condensate to an appropriate disposal location). The cost of these components and the percentage of installations where these components were applied are listed in Table 8.2.6.

Table 8.2.6 Cost of Installing Various Components Required for Condensing Equipment

Component	Cost	Percentage of Condensing Installations with Each Component
Condensate Pump	$248	25%
Condensate Drain	$404	25%
Heat Tape	$65	10%
Condensate Neutralizer	$117	12.5%
Electrical Outlet	$147	50%

8.2.1.5 Total Installed Cost

The total installed cost is the sum of the equipment retail price and the installation cost. MSPs, markups, and sales taxes all can take on a variety of values, depending on location. Therefore, the resulting total installed cost for a particular efficiency and standby loss level will not be a single-point value but rather a distribution of values. Table 8.2.7 presents the average total installed cost for each CWH equipment class at efficiency and standby loss factor for the chosen trial standard levels (TSLs) examined.

Table 8.2.7 Average Total Installed Cost for CWH Equipment

Equipment*	TSL	UEF	Thermal Efficiency (Et)	Standby Loss Factor	Average Total Installed Cost *2014$*
CGSWH	0	NA	80%	1.00	4,316
CGSWH	1	NA	82%	0.72	4,581
CGSWH	2	NA	90%	0.67	5,467
CGSWH	3	NA	95%	0.63	5,537
CGSWH	4	NA	99%	0.61	5,624
RDGSWH	0	0.60	NA	NA	2,090
RDGSWH	1	0.67	NA	NA	2,528
RDGSWH	2, 3	0.77	NA	NA	3,361
RDGSWH	4	0.82	NA	NA	3,669
CGITWH	0	NA	80%	NA	4,273
CGITWH	1	NA	84%	NA	4,337
CGITWH	2	NA	92%	NA	3,819
CGITWH	3	NA	94%	NA	3,849
CGITWH	4	NA	96%	NA	3,884
CGIHWSB	0	NA	80%	NA	7,372
CGIHWSB	1	NA	84%	NA	7,961
CGIHWSB	2	NA	92%	NA	10,113
CGIHWSB	3	NA	94%	NA	10,433
CGIHWSB	4	NA	96%	NA	10,754
CESWH	0	NA	NA	1.00	3,649
CESWH	1	NA	NA	0.84	3,743

* CGSWH = commercial gas-fired storage water heater, RDGSWH = residential-duty gas-fired storage water heater, CGITWH = commercial gas-fired instantaneous tankless water heater, CGIHWSB = commercial gas-fired instantaneous hot water supply boiler, CESWH = commercial electric storage water heater

8.2.2 Operating Cost Inputs

DOE defines the operating cost by the following equation:

$$OC = EC + RC + MC \qquad \textbf{Eq. 8.3}$$

Where:

OC = operating cost ($),
EC = energy cost associated with operating the equipment ($),
RC = repair cost associated with component failure ($), and
MC = annual maintenance cost for maintaining equipment operation ($).

The remainder of this section provides information about the variables that DOE uses to calculate the operating cost for CWH equipment. The annual energy costs of the equipment are computed from energy consumption per unit for the baseline and standard-compliant cases (efficiency level 2, 3, and so on) combined with the energy prices. Equipment lifetime, discount rate, and compliance date of the standard are required for determining the operating cost and for establishing the operating cost present value.

8.2.2.1 Annual Energy Use Savings

For each equipment class, DOE calculates the annual energy use savings for each sample building at each efficiency and standby loss level, as described in chapter 7 of this TSD. Because it is unlikely that users of CWH equipment may use a higher efficiency unit more than a baseline one, DOE does not include a (direct) rebound effect in its analyses.

8.2.2.2 Average Energy Prices

DOE derives average monthly energy prices for a number of geographic areas in the United States using the latest data from EIA. The process then assigns appropriate energy prices to each building in the sample, depending on its type (commercial or residential), and its location.

EIA Data.

DOE derives 2014 annual electricity prices from EIA Form 826 database.[6] The EIA Form 826 database includes state-level energy prices. DOE calculates annual electricity prices for each CBECS region or RECS region by averaging monthly energy prices by state to get state electricity prices. For areas with more than one state, DOE weights each state's average price by its population. Table 8.2.8 and Table 8.2.9 show the electricity prices by region for commercial and residential sectors, respectively. (See appendix 8C for more details.)

Table 8.2.8 Average Commercial Electricity Prices in 2014

Census Division	Census Division Number	2014 Monthly Commercial Electricity Prices *2014¢/kWh*											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
New England	1	15.4	16.0	15.6	14.7	14.0	14.3	14.4	14.6	14.3	14.0	14.0	14.9
Middle Atlantic	2	14.1	14.6	14.2	13.1	13.0	13.8	14.0	13.8	14.0	13.2	13.0	12.7
East North Central	3	9.4	9.8	9.9	9.9	9.9	10.1	10.0	10.1	9.9	10.0	9.9	9.8
West North Central	4	8.4	8.6	8.9	8.9	9.3	9.9	10.0	10.1	9.5	9.0	8.7	8.5
South Atlantic	5	9.7	10.0	9.8	9.7	9.6	9.8	9.7	9.7	9.7	9.6	9.8	9.6
East South Central	6	10.0	10.2	10.6	10.5	10.5	10.6	10.6	10.4	10.2	10.1	10.3	10.3
West South Central	7	8.0	8.1	8.3	8.3	8.3	8.4	8.4	8.3	8.2	8.2	8.2	8.1
Mountain	8	9.0	9.2	9.3	9.5	9.8	10.3	10.3	10.1	10.2	9.8	9.4	9.1
Pacific	9	12.2	12.3	12.5	12.5	13.7	15.0	16.0	16.1	16.3	15.8	14.0	12.9

Table 8.2.9 Average Residential Electricity Prices in 2014

Reportable Domain Number	Locations	2014 Monthly Residential Electricity Prices *2014¢/kWh*											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	Connecticut, Maine, New Hampshire, Rhode Island, Vermont	17.5	17.9	17.9	18.4	18.6	18.4	17.8	18.2	18.2	18.5	18.3	18.2
2	Massachusetts	16.8	17.5	17.3	18.2	17.6	16.6	16.3	17.8	16.8	16.9	17.6	19.7
3	New York	19.5	21.7	20.9	19.6	20.6	20.9	20.3	19.5	19.4	19.4	19.5	19.3
4	New Jersey	15.3	15.7	15.9	15.7	15.5	15.9	16.5	16.0	15.9	15.6	15.6	15.6
5	Pennsylvania	12.7	13.4	13.0	13.1	13.3	13.9	14.0	13.9	13.5	13.4	13.2	13.0
6	Illinois	9.8	10.3	10.7	11.8	12.0	11.7	11.6	12.0	11.6	13.1	12.0	11.3
7	Indiana, Ohio	10.7	10.9	11.3	12.2	12.5	12.8	12.8	12.8	12.0	12.6	12.3	11.9
8	Michigan	13.9	14.0	14.1	14.6	14.9	15.0	15.1	14.9	14.8	14.7	14.4	14.0
9	Wisconsin	13.1	13.5	13.3	13.8	14.2	14.6	14.5	14.3	14.6	14.1	13.8	13.4
10	Iowa, Minnesota, North Dakota, South Dakota	10.5	10.8	11.2	11.6	11.8	12.4	12.7	12.8	12.4	11.9	11.1	10.7
11	Kansas, Nebraska	10.2	10.4	10.9	11.7	11.9	12.1	12.5	12.5	12.2	12.0	11.4	10.5
12	Missouri	8.9	9.0	9.8	10.6	11.9	12.4	12.3	12.2	11.0	10.6	10.0	9.4
13	Virginia	10.1	10.2	10.6	11.1	11.4	11.7	12.0	12.0	12.1	11.7	11.5	11.0
14	Delaware, Maryland, West Virginia	12.2	12.4	12.5	13.0	13.2	12.9	12.8	12.9	12.7	13.1	12.5	12.5
15	Georgia	10.8	10.9	11.2	11.5	11.8	12.5	12.6	12.5	12.1	11.3	10.7	10.4
16	North Carolina, South Carolina	10.7	11.3	11.4	12.1	11.8	11.7	11.7	11.8	11.9	12.1	11.2	10.9
17	Florida	11.9	11.9	11.9	11.8	11.8	12.1	12.0	12.0	12.3	12.0	12.2	11.9
18	Alabama, Kentucky, Mississippi	10.2	10.5	11.0	11.4	11.4	11.3	11.3	11.1	11.1	11.2	10.9	10.7
19	Tennessee	9.7	9.8	10.6	10.8	10.9	10.9	10.8	10.5	10.1	10.4	10.2	10.1
20	Arkansas, Louisiana, Oklahoma	8.4	8.9	9.3	10.3	10.3	10.2	10.3	10.0	10.3	10.1	9.3	9.1
21	Texas	11.2	11.2	11.7	12.0	11.9	12.1	12.0	12.0	12.0	12.0	11.9	11.8
22	Colorado	11.4	11.7	11.7	12.2	12.2	13.1	13.1	12.9	12.7	11.8	11.6	11.4
23	Idaho, Montana, Utah, Wyoming	9.7	9.8	9.8	10.0	10.4	10.9	11.2	11.1	10.8	10.4	10.4	10.0
24	Arizona	10.9	11.2	11.3	12.0	12.6	12.4	12.5	12.4	12.4	12.0	11.2	10.9
25	Nevada, New Mexico	12.0	11.8	12.6	12.8	12.7	12.9	13.1	13.0	12.8	13.0	12.8	12.4
26	California	16.6	16.2	15.9	10.1	16.5	17.0	17.7	18.1	18.0	13.4	17.1	17.1
27	Alaska, Hawaii, Oregon, Washington	12.7	12.8	12.9	13.0	13.2	13.2	13.4	13.2	13.2	13.0	12.7	12.3

DOE obtains the data for natural gas prices from EIA's Natural Gas Navigator, which includes monthly natural gas prices by state for residential and commercial sector consumers.[7] For areas with more than one state, DOE weights each state's average price by its population. Table 8.2.10 and Table 8.2.11 show the natural gas prices by region for commercial and residential sectors, respectively. (See appendix 8C for more details.)

Table 8.2.10 Average Commercial Natural Gas Prices in 2014

Census Division	Division Number	2014 Monthly Commercial Natural Gas Prices *2014$/mcf*											
		Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
New England	1	11.0	12.0	12.6	13.5	12.8	12.7	12.6	12.5	12.4	11.4	11.7	12.2
Middle Atlantic	2	9.0	9.7	9.9	9.9	10.1	9.9	9.9	9.5	9.3	8.7	8.5	8.6
East North Central	3	7.2	7.9	9.5	10.0	10.7	10.8	11.1	11.1	9.7	7.9	7.4	7.8
West North Central	4	7.6	8.1	8.2	8.9	9.3	10.6	11.0	10.7	10.2	9.4	8.5	8.3
South Atlantic	5	9.6	9.9	9.9	10.5	10.9	11.3	11.5	11.1	11.0	10.7	9.6	9.9
East South Central	6	8.9	9.3	9.5	10.3	11.3	11.6	11.7	11.4	11.4	11.0	9.6	9.4
West South Central	7	7.2	7.5	8.3	8.9	9.6	9.9	9.9	9.6	9.5	9.3	8.4	7.9
Mountain	8	7.7	8.1	8.6	8.8	8.9	9.4	9.9	9.7	9.6	9.4	8.9	8.9
Pacific	9	9.7	9.9	10.7	10.0	10.0	10.0	10.2	9.9	9.8	9.7	9.5	9.9

Table 8.2.11 Average Residential Natural Gas Prices in 2014

Reportable Domain Number	Locations	2014 Monthly Residential Natural Gas Prices *2014$/mcf*											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	Connecticut, Maine, New Hampshire, Rhode Island, Vermont	12.8	14.1	14.5	16.1	17.4	19.7	21.3	22.3	21.3	18.2	14.5	14.3
2	Massachusetts	13.4	13.7	14.9	15.7	14.7	14.8	16.1	16.2	15.4	13.1	14.4	14.8
3	New York	11.2	11.5	11.7	12.5	14.6	18.0	18.5	18.8	18.0	16.0	12.3	10.7
4	New Jersey	9.7	9.7	11.8	9.4	11.0	12.2	12.8	13.0	12.9	11.6	9.7	8.2
5	Pennsylvania	10.4	10.5	11.0	11.9	13.8	18.4	20.1	20.3	18.3	14.8	11.5	10.8
6	Illinois	7.4	8.1	11.0	13.4	14.4	17.3	18.0	18.1	15.2	9.9	7.8	8.2
7	Indiana, Ohio	8.0	8.4	8.9	10.3	14.2	20.7	21.6	21.7	19.8	12.8	9.0	8.7
8	Michigan	8.1	8.6	9.1	9.9	11.1	13.0	14.0	14.6	12.5	10.0	8.9	9.0
9	Wisconsin	8.9	9.7	14.0	11.7	14.7	12.4	14.5	13.9	12.4	9.2	9.1	9.6
10	Iowa, Minnesota, North Dakota, South Dakota	8.3	9.4	9.2	9.8	10.8	14.9	15.7	15.2	13.9	10.5	8.7	8.2
11	Kansas, Nebraska	8.3	8.9	9.4	10.7	12.7	16.7	18.8	19.4	18.3	15.4	10.3	8.9
12	Missouri	8.4	8.0	8.9	11.3	15.3	21.2	24.9	25.7	24.7	19.0	12.2	8.7
13	Virginia	10.3	10.6	11.8	12.8	15.7	20.0	21.4	21.0	21.3	19.0	12.1	11.3
14	Delaware, Maryland, West Virginia	10.4	11.1	11.5	12.6	14.6	17.8	19.8	19.9	17.9	15.1	11.4	11.3
15	Georgia	11.4	12.4	13.4	15.8	19.0	24.2	26.1	26.5	26.1	22.4	13.3	13.0
16	North Carolina, South Carolina	10.3	11.6	10.5	13.9	20.9	24.7	23.2	23.6	22.1	18.1	10.7	11.3
17	Florida	16.0	15.8	17.2	18.7	20.8	22.0	24.6	25.3	24.7	23.6	20.3	17.2
18	Alabama, Kentucky, Mississippi	10.3	10.3	10.9	12.5	16.1	19.2	20.7	20.5	20.3	17.4	11.7	11.1
19	Tennessee	8.4	9.2	9.7	11.7	14.3	17.7	19.0	18.3	18.7	16.3	10.2	9.3
20	Arkansas, Louisiana, Oklahoma	8.3	8.6	9.1	11.3	14.5	17.6	19.5	20.3	20.5	19.0	12.0	9.5
21	Texas	8.1	8.5	10.0	12.4	16.0	18.5	20.0	20.5	20.1	19.3	12.5	9.9
22	Colorado	7.6	7.8	8.2	9.3	10.2	12.8	15.4	15.4	13.5	10.0	8.1	7.3
23	Idaho, Montana, Utah, Wyoming	8.4	8.7	9.4	9.1	9.2	10.7	11.5	12.0	11.4	10.4	9.2	9.2
24	Arizona	13.1	15.6	18.2	17.7	19.1	21.7	23.4	24.2	23.9	22.1	17.6	16.7
25	Nevada, New Mexico	8.7	9.2	10.4	11.2	12.4	14.3	16.2	16.5	15.8	14.9	11.4	9.8
26	California	10.7	11.1	11.8	11.5	12.2	12.0	12.5	12.1	12.3	12.3	11.1	11.3
27	Alaska, Hawaii, Oregon, Washington	14.5	14.2	14.9	15.0	15.8	16.5	16.4	17.4	16.6	14.9	14.3	13.5

Energy Price Trends

To arrive at prices in future years, DOE multiplies the prices described in the preceding section by the forecasts of annual average price changes in EIA's *AEO2015*. Figure 8.2.1 and Figure 8.2.2 show the commercial and residential natural gas price trends. To estimate the trend after 2040, DOE uses the average rate of change during 2030–2040.

DOE estimates an index for each year that represents the price change for that fuel. For example, the index for year 2020 from a base year of 2014 is calculated using fuel price (year 2020)/fuel price (year 2014). Furthermore, this index is used in conjunction with the EIA fuel price (for year 2014) to estimate the fuel price in the year 2020. DOE applies the projected energy price for each of the nine census divisions to each building in the sample based on the building's location. Appendix 8C includes more details.

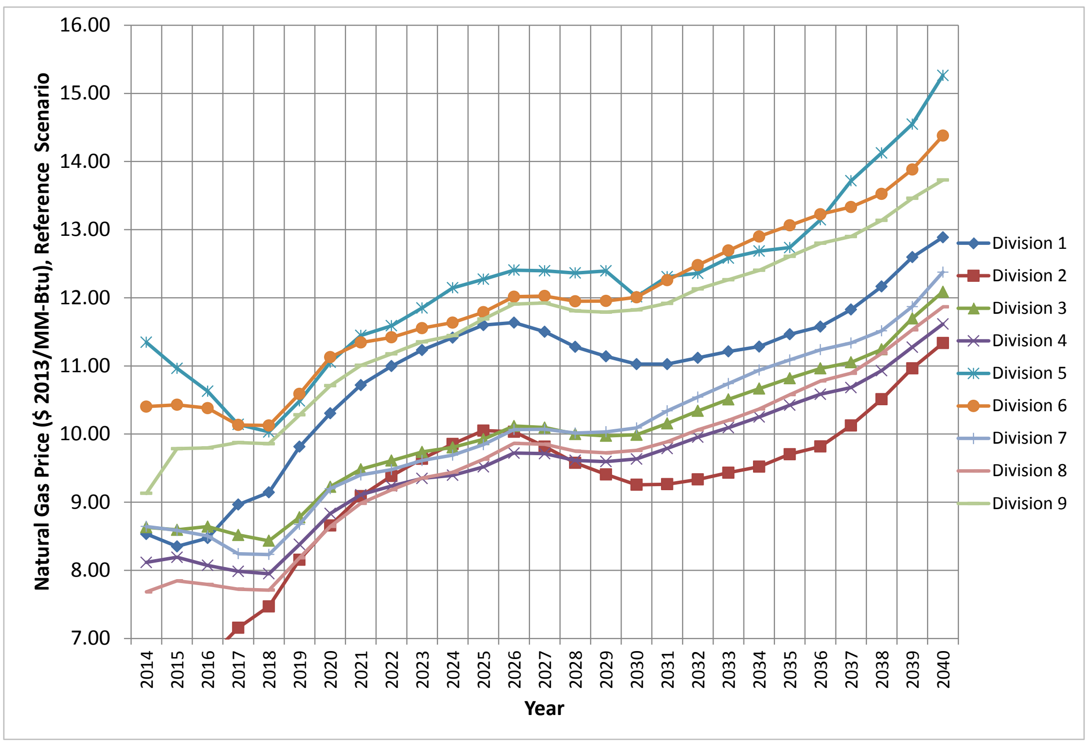

Figure 8.2.1 Projected *AEO2015* Commercial Natural Gas Prices

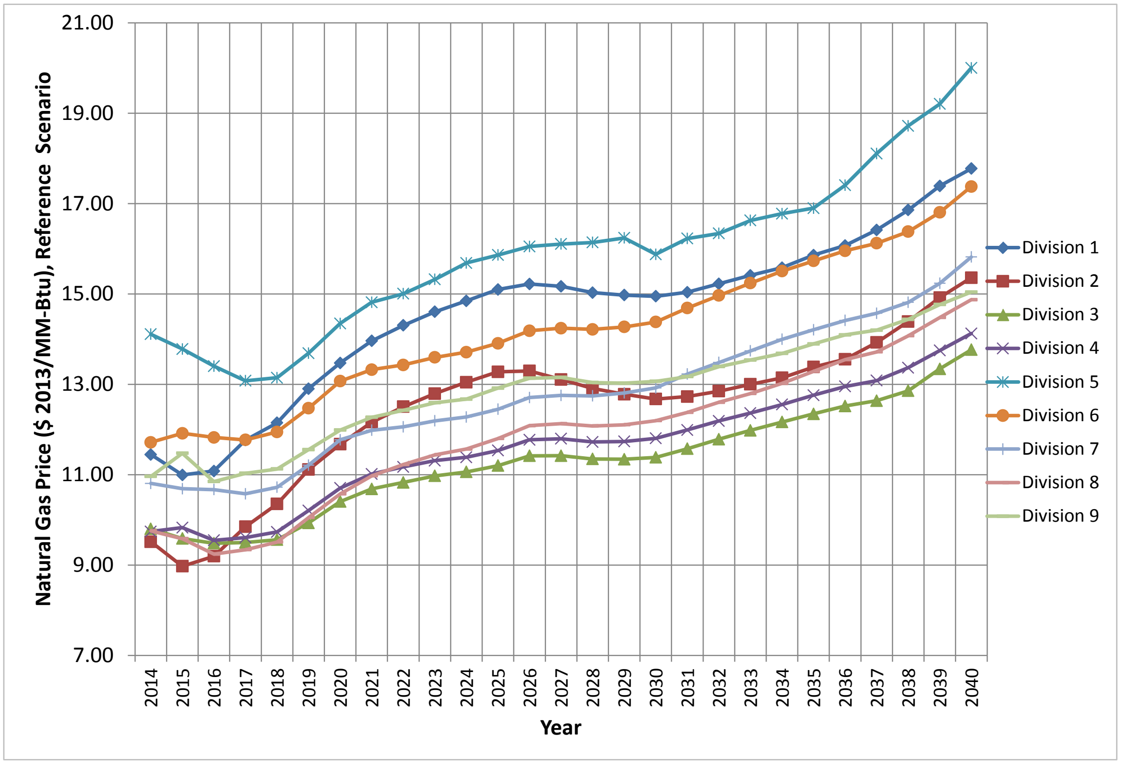

Figure 8.2.2 Projected Residential Natural Gas Prices

8.2.2.3 Repair Cost

The repair cost is the cost to the commercial consumer for replacing or repairing components in the CWH unit that have failed (such as combustion systems, controls, elements, and thermostats). DOE obtained the costs of serviceable components for each equipment class using internet research. It is noted that only the commercial gas-fired storage water heater, commercial gas-fired instantaneous hot water supply boiler, commercial gas-fired instantaneous tankless water heater, and residential-duty storage water heater repair costs were found to vary with the efficiency level. DOE calculated repair costs assuming a typical product level failure rate of 2 percent per year and assuming an average of five components that are typically replaced; this equates to a 0.4 percent failure rate for shipments each year.

The labor required to replace a component was estimated as 2 hours for combustion systems, 1 hour for combustion controls, and ¾ hour to replace an electric water heater thermostat. DOE estimates that it will require 3 hours on average to replace an electric heating element, accounting for the time required to drain a storage tank before element replacement and refilling the tank afterwards.

The annual repair cost for each equipment class is presented in Table 8.2.12. It is noted that the costs identified here are applied to 0.4 percent of the shipments in any given year. Additionally DOE accounts for markups, regional differences in labor costs, and the discount rate for repair costs continuing through the analysis period. For a detailed discussion of the development of repair costs, see appendix 8E.

Table 8.2.12 Annualized Repair Cost for CWH Equipment (2013$)

Equipment Classes	Efficiency	Cost *2013$*
Commercial Gas-Fired Storage Water Heaters and Gas-Fired Instantaneous Water Heaters	Atmospheric	$704
	Powered	$1018
	High Efficiency	$1818
Residential-Duty Gas-fired Storage Water Heaters	Atmospheric	$399
	Powered	$692
	High Efficiency	$1320
Commercial Electric Storage Water Heaters	Not Applicable	$411

8.2.2.4 Maintenance Cost

Maintenance costs are associated with maintaining the operation of the equipment. DOE referenced Whitestone maintenance schedule, costs of consumables, and labor hours for the costs relating to maintenance, as this reference presented the most complete set of data for the products categories in consideration. Whitestone presented the information in a similar manner as RS Means, identifying both labor hours and crews. For consistency, the RS Means labor rates were used to calculate the installation labor costs based upon this data.

It is noted that the Whitestone reference was from 2013 and that the cost of consumables obtained in the Whitestone reference was listed relative to costs in Washington, DC, while the RS Means data presented costs relative to the national average. To account for this, the costs of consumables were first corrected for inflation between 2013 and 2015 using the price deflator values, then corrected to the national average

Whitestone identified the labor hours and material costs for routine maintenance of each of the product classes. As the available sources presented maintenance data in non-uniform schedules,[c] the cost of maintenance was annualized to more readily fit the analysis, as shown in Table 8.2.13. It is noted that all maintenance is performed by one plumber and that the material cost identified in this analysis accounts for replacement of miscellaneous components such as gaskets and sealants. Additional detailed information about this topic is available in appendix 8E.

Table 8.2.13 Annualized Maintenance Cost for CWH Equipment

Equipment Class	Annual Cost *2013$*
Commercial Gas-Fired Storage Water Heater	$260
Residential-Duty Gas-Fired Storage Water Heater	$260
Commercial Gas-Fired Instantaneous Tankless Water Heater	$28
Commercial Gas-Fired Instantaneous Hot Water Supply Boiler	$28
Commercial Electric Storage Water Heater	$57

[c] Neither of the maintenance schedules obtained from RS Means nor Whitestone matched the manufacturers' recommendations. Similarly, the data did not consistently have annual maintenance but identified types of service on various schedules.

8.2.2.5 Lifetime

DOE defines lifetime as the age when an appliance is retired from service. DOE uses national survey data, published studies, and projections based on manufacturer shipment data to calculate the distribution of CWH equipment lifetimes. For a detailed discussion of the development of CWH equipment lifetime, see appendix 8F.

Table 8.2.14 shows the weighted average of lifetime for each equipment class. DOE assumes that the lifetime of a CWH unit is the same within an equipment class, across all efficiency and standby loss levels.

Table 8.2.14 Lifetime Parameters for CWH Equipment

Equipment Class	Average Lifetime *Years*
Commercial Gas-Fired Storage Water Heater	10
Residential-Duty Gas-Fired Storage Water Heater	12
Commercial Gas-Fired Instantaneous Tankless Water Heater	17
Commercial Gas-Fired Instantaneous Hot Water Supply Boiler	25
Commercial Electric Storage Water Heater	12

8.2.2.6 Discount Rates

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

Discount Rates for Commercial Applications

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

DOE's method views the purchase of a higher efficiency appliance as an investment that yields a stream of energy cost savings. DOE derives the discount rates for the LCC analysis by estimating the cost of capital for companies that purchase CWH equipment. The WACC is commonly used to estimate the present value of cash flows to be derived from a typical company project or investment. Most companies use both debt and equity capital to fund investments, so their cost of capital is the weighted average of the cost to the firm of equity and debt financing, as estimated from financial data for publicly traded firms in the sectors that purchase CWH equipment.[8]

Damodaran Online is a widely used source of information about company debt and equity financing for most types of firms, and it was the primary source of data for this analysis.[9]

Detailed sectors included in the Damodaran database are assigned to the aggregate categories of retail, property management, medical, industrial, lodging, office, and other.

DOE estimates the cost of equity using CAPM.[10] The CAPM assumes that the cost of equity (k_e) for a particular company is proportional to the systematic risk faced by that company, where high risk is associated with a high cost of equity and low risk is associated with a low cost of equity. The systematic risk facing a firm is determined by several variables: the risk coefficient of the firm (β), the expected return on risk-free assets (R_f), and the equity risk premium (*ERP*). The risk coefficient of the firm indicates the risk associated with that firm relative to the price variability in the stock market. The expected return on risk-free assets is defined by the yield on long-term government bonds. The *ERP* represents the difference between the expected stock market return and the risk-free rate. The cost of equity financing is estimated using the following equation, where the variables are defined as above:

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

Eq. 8.4

Where:

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

Several parameters of the cost of capital equations can vary substantially over time, and therefore the estimates can vary with the time period over which data are selected and the technical details of the data averaging method. For guidance on the time period for selecting and averaging data for key parameters and the averaging method, DOE uses Federal Reserve methodologies for calculating these parameters. In its use of the CAPM, the Federal Reserve uses a 40-year period for calculating discount rate averages, utilizes the gross domestic product price deflator for estimating inflation, and considers the best method for determining the risk free rate as one where "the time horizon of the investor is matched with the term of the risk-free security."[11]

By taking a 40-year geometric average of Federal Reserve data on annual nominal returns for 10-year Treasury bills, DOE estimates the following risk free rates for 2004–2013 (Table 8.2.15).[12] DOE also estimates the ERP by calculating the difference between risk-free rate and stock market returns for the same time period, as estimated using Damodaran Online data on the historical return to stocks.[13]

Table 8.2.15 Risk-free Rate and Equity Risk Premium (2004–2013)

Year	Risk-free Rate %	Equity Risk Premium %
2004	7.10%	3.25%
2005	7.11%	3.68%
2006	7.10%	3.49%
2007	7.08%	3.36%
2008	7.01%	2.40%
2009	6.88%	3.07%
2010	6.74%	3.23%
2011	6.61%	2.94%
2012	6.41%	3.99%
2013	6.24%	5.30%

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

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

Eq. 8.5

Where:

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

DOE estimates the WACC using the following equation:

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

Eq. 8.6

Where:

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

By adjusting for the influence of inflation, DOE estimates the real weighted average cost of capital, or discount rate, for each company. DOE then aggregates the company real weighted average costs of capital to estimate the discount rate for each of the ownership types in the CWH equipment analysis.

Table 8.2.16 shows the average WACC values for the major sectors that purchase CWH equipment. While WACC values for any sector may trend higher or lower over substantial periods of time, these values represent a cost of capital that is averaged over major business cycles.

Table 8.2.16 Weighted Average Cost of Capital for Sectors Purchasing CWH Equipment

Sector	Real Weighted Average Cost of Capital %	Standard Deviation %
Retail	5.00%	1.07%
Property	5.12%	0.90%
Medical	4.97%	0.92%
Industrial	5.23%	1.18%
Lodging	5.96%	1.65%
Food Service	4.90%	0.95%
Office	5.08%	1.28%
Other	5.04%	1.07%

Discount Rates for Residential Applications

The discount rate is the rate at which future savings and expenditures are discounted to establish their present value. DOE uses publicly available data (the Federal Reserve Board's *Survey of Consumer Finance*s) to estimate a commercial consumer's opportunity cost of funds related to appliance energy cost savings and maintenance costs. The discount rate value is applied in the LCC to future year energy cost savings and non-energy operations and maintenance costs in order to present the estimated net life-cycle cost and life-cycle cost savings. DOE notes that the discount rate used in the LCC analysis is distinct from an implicit discount rate, as it is not used to model consumer purchase decisions. The opportunity cost of funds in this case may include interest payments on debt and interest returns on assets.

DOE estimates separate discount rate distributions for six income groups, which are divided based on income percentile as reported in the Federal Reserve Board's *Survey of Consumer Finance*s (see Table 8.2.17).[14] This disaggregation reflects the fact that low- and high-income commercial consumers tend to have substantially different shares of debt and asset types, as well as facing different rates on debts and assets. Summaries of shares and rates presented in this chapter are averages across the entire population.

Table 8.2.17 Definitions of Income Groups

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

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

Shares of Debt and Asset Classes

DOE's approach involves identifying all relevant household debt or asset classes to approximate a commercial consumer's opportunity cost of funds related to appliance energy cost savings and maintenance costs. The approach assumes that in the long term, commercial consumers are likely to draw from or add to their collection of debt and asset holdings approximately in proportion to their current holdings when future expenditures are required or future savings accumulate. DOE has included several previously excluded debt types (*i.e.,* vehicle and education loans, mortgages, all forms of home equity loan) in order to better account for all of the options available to commercial 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 Federal Reserve Board's *Survey of Consumer Finances* (SCF) household (Table 8.2.18). The household-level discount rates are then aggregated to form discount rate distributions for each of the six income groups. Note that previously DOE performed aggregation of asset and debt types over households by summing the dollar value across all households and then calculating shares. Weighting by dollar value gave disproportionate influence to the asset and debt shares and rates of higher income consumers. DOE has shifted to a household-level weighting to more accurately reflect the average commercial consumer in each income group.

DOE estimates the average percentage shares of the various types of debt and equity using data from the SCFs for 1995, 1998, 2001, 2004, 2007, and 2010.[d] DOE derives the household-weighted mean percentages of each source of financing throughout the 5 years surveyed. DOE considers that these long-term averages are most appropriate to use in its analysis.

Table 8.2.18 Types of Household Debt and Equity by Percentage Shares (%)

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

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

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

Rates for Types of Debt

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

In calculating effective interest rates for home equity loans and mortgages, DOE accounted for the fact that interest on both such loans is tax deductible (Table 8.2.19). This rate corresponds to the interest rate after deduction of mortgage interest for income tax purposes and after adjusting for inflation (using the Fisher formula).[e] 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 8.2.19 Data Used to Calculate Real Effective Mortgage Rates

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

Table 8.2.20 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 2019.

Table 8.2.20 Average Real Effective Interest Rates for Household Debt

Type of Debt	Income Group					
	1	2	3	4	5	6
Mortgage	6.6%	6.2%	6.1%	5.2%	5.0%	4.0%
Home Equity Loan	7.0%	6.9%	6.7%	5.9%	5.7%	4.3%
Credit Card	15.2%	15.0%	14.5%	14.2%	14.0%	14.5%
Other Installment Loan	10.8%	10.3%	9.9%	9.4%	8.7%	8.6%
Other Residential Loan	9.8%	10.2%	8.9%	8.2%	7.7%	7.4%
Other Line of Credit	9.1%	10.9%	9.6%	8.8%	7.4%	6.1%

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

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

Rates for Types of Assets

No similar rate data are available from the SCF for classes of assets, so DOE has derived asset interest rates from various sources of national historical data (1983–2013). The interest rates associated with certificates of deposit, savings bonds, and bonds (AAA corporate bonds)[17,18,19] have been collected from Federal Reserve Board time-series data. Rates on money market accounts are from Cost of Savings Index data.[20] Rates on savings accounts have been estimated as one half of the rate for money market accounts, in view of recent differentials between the return to each of these assets. The rates for stocks are the annual returns on the Standard and Poor's. Rates for mutual funds are a weighted average of the stock rates (two-thirds weight) and the bond rates (one-third weight) in each year. DOE assumes rates on checking accounts to be zero.

DOE adjusts the nominal rates to real rates using the annual inflation rate for each year. Average nominal and real interest rates for the classes of household assets are listed in Table 8.2.21. Because the interest and return rates for each type of asset reflect economic conditions throughout numerous years, they are expected to be representative of rates that may be in effect in 2019. For each type, DOE develops a distribution of rates, as shown in appendix 8G.

Table 8.2.21 Average Nominal and Real Interest Rates for Household Equity

Type of Equity	Average Real Rate %
Savings Accounts	1.0
Money Market Accounts	1.9
Certificates of Deposit	1.9
Savings Bonds	3.4
Bonds	4.2
Stocks	9.4
Mutual Funds	7.4

Discount Rate Calculation and Summary

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

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

Eq. 8.7

Where:

DR_i = discount rate for commercial consumer *i*,
$Share_{i,j}$ = share of asset or debt type *j* for commercial consumer *i*, and
$Rate_{i,j}$ = real interest rate or rate of return of asset or debt type *j* for commercial 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 is estimated for each commercial consumer, DOE compiles the distribution of discount rates in each survey by income group by calculating the proportion of commercial consumers with discount rates in bins of 1 percent increments, ranging from 0–1 percent to greater than 30 percent. Giving equal weight to each survey, DOE compiles the six-survey distribution of discount rates.

Table 8.2.22 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 samples a rate for each RECS household from the distributions for the appropriate income group. (RECS provides household income data.) Appendix 8G presents the full probability distributions for each income group that DOE uses in the LCC and PBP analysis.

Table 8.2.22 Average Real Effective Discount

Income Group	Discount Rate %
1	4.9
2	5.1
3	4.8
4	4.0
5	3.8
6	3.6
Overall Average	4.4

8.2.2.7 Compliance Date of Standard

For any NOPR published pursuant to 42 U.S.C. 6313(a)(6)(C), the final rule would apply on the date that is the later of (1) the date 3 years after publication of the final rule establishing a new standard or (2) the date 6 years after the effective date of the current standard for a covered product. (42 U.S.C. 6313(a)(6)(C)(iv)) For CWH equipment, the date 3 years after the publication of the final rule would be later than the date 6 years after the effective date of the current standard. As a result, compliance with any amended energy conservation standards if adopted by a final rule of this rulemaking would be required beginning on the date 3 years after the publication of the final rule.

DOE calculates the LCC and PBP for all commercial consumers as if they each would purchase a new CWH unit in 2019.

8.2.2.8 Distribution of Efficiency Levels for the No-New-Standards Case

To estimate the market shares of the different efficiency levels in each CWH equipment class beginning in 2019, DOE analyzes the equipment directories from 2007 to 2014 (Table 8.2.23), and for a detailed discussion of the development of distributions for the no-new standards case, see appendix 8H.

Table 8.2.23 Market Shares for the No-New-Standards Case in 2019 by Efficiency Level for Commercial Water Heaters

SL*	EL	CGSWH		RDGSWH		CGITWH		CGIHWSB		CESWH	
		Option	Market Share	Option	Market Share	Option	Market Share	Option	Market Share	Option	Market Share
0	0	1	43.0%	1	53.7%	1	16.0%	1	40.2%	1	97.2%
0	1	2	10.7%	2	1.5%	2	40.0%	2	23.8%	2	0.0%
0	2	3	0.0%	3	0.0%	3	28.0%	3	13.8%	3	0.0%
0	3	4	4.3%	4	0.0%	4	4.0%	4	1.7%	4	0.0%
0	4	5	7.6%	5	0.0%	5	4.0%	5	7.1%	5	0.0%
0	5	6	0.9%	6	0.0%	6	8.0%	6	13.4%	6	0.0%
0	6	7	0.0%	7	0.0%	7	0.0%	7	0.0%	7	0.0%
1	0	8	11.3%	8	7.5%					8	2.8%
1	1	9	0.0%	9	0.0%					9	0.0%
1	2	10	0.0%	10	3.0%					10	0.0%
1	3	11	1.2%	11	16.4%					11	0.0%
1	4	12	3.4%	12	6.0%					12	0.0%
1	5	13	0.3%	13	0.0%					13	0.0%
1	6	14	0.0%	14	0.0%					14	0.0%
2	0	15	2.4%	15	3.0%						
2	1	16	1.5%	16	1.5%						
2	2	17	0.3%	17	0.0%						
2	3	18	0.9%	18	0.0%						
2	4	19	12.2%	19	0.0%						
2	5	20	0.0%	20	0.0%						
2	6	21	0.0%	21	0.0%						
3	0			22	1.5%						
3	1			23	6.0%						
3	2			24	0.0%						
3	3			25	0.0%						
3	4			26	0.0%						
3	5			27	0.0%						
3	6			28	0.0%						

* SL = standby loss, EL = efficiency level, CGSWH = commercial gas-fired storage water heater, RDGSWH = residential-duty gas-fired storage water heater, CGITWH = commercial gas-fired instantaneous tankless water heater, CGIHWSB = commercial gas-fired instantaneous hot water supply boiler, CESWH = commercial electric storage water heater

8.2.2.9 Marginal Factors

DOE calculates marginal electrical and gas prices by multiplying annual average prices by a marginal price factor, at the census division scale (for commercial applications), and at the reportable domain scale (for residential applications). The marginal price factor is the fraction of expenditures (due to actual energy consumption) to total expenditures (this includes for example, fixed costs, connection fee and surcharges, in addition to usage related expenditures).
Table 8.2.24 and Table 8.2.25 present the marginal factors for gas and electricity, at the different spatial scales used for residential and commercial applications.

Table 8.2.24: Residential Marginal Price Factors for Natural Gas and Electricity (at the Reportable Domain Scale)

Marginal Price Factors	Natural Gas	Natural Gas	Electricity	Electricity
REPORTABLE_DOMAIN	Non-Winter	Winter	Non-Winter	Winter
1	0.82	0.91	0.95	1.00
2	0.89	1.03	0.96	1.04
3	0.75	0.89	1.13	0.87
4	0.84	0.95	1.21	0.98
5	0.73	0.93	1.08	0.83
6	0.68	0.97	0.98	0.72
7	0.73	0.92	1.00	0.75
8	0.78	0.93	1.14	0.97
9	0.79	0.98	1.01	0.89
10	0.72	0.97	1.07	0.84
11	0.69	0.93	1.16	0.74
12	0.60	0.82	1.21	0.76
13	0.68	0.93	1.08	0.85
14	0.72	0.93	1.11	0.89
15	0.56	0.87	1.16	0.84
16	0.66	0.89	0.97	0.83
17	0.64	0.82	1.01	0.93
18	0.75	0.87	1.00	0.82
19	0.74	0.94	0.93	0.84
20	0.65	0.84	1.04	0.74
21	0.59	0.85	1.05	0.90
22	0.69	0.91	1.08	0.79
23	0.84	0.96	1.11	0.94
24	0.64	0.85	1.05	0.84
25	0.72	0.89	1.04	0.88
26	0.85	1.08	1.21	1.13
27	0.83	0.94	0.94	0.94

Table 8.2.25: Commercial Marginal Price Factors for Natural Gas and Electricity (at the Census Division Scale)

Marginal Price Factors	Natural Gas	Natural Gas	Electricity	Electricity
CENSUS_DIVISION	Non-Winter	Winter	Non-Winter	Winter
1	1.04	0.99	1.14	0.88
2	1.02	0.98	1.44	0.86
3	0.82	0.97	1.10	0.73
4	0.85	0.97	1.57	0.66
5	0.93	0.96	1.09	0.89
6	0.93	0.95	1.03	0.76
7	0.78	0.91	1.16	0.72
8	0.90	0.96	1.14	1.07
9	0.96	1.17	1.57	0.85

8.3 PAYBACK PERIOD INPUTS

The PBP is the amount of time it takes the commercial consumer to recover the assumed higher purchase cost of more energy-efficient equipment as a result of lower operating costs. Numerically, the PBP is the ratio of the increase in purchase cost (*i.e.*, from a less efficient design to a more efficient design) to the decrease in first year annual operating expenditures.

The equation for PBP is the following:

$$PBP = \Delta IC / \Delta OC$$

Eq. 8.8

Where:

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

The PBPs are expressed in years. The PBPs can be greater than the life of the equipment if the increased total installed cost of the more-efficient equipment is not recovered fast enough through reduced operating costs.

DOE also calculates a rebuttable PBP, which is the time it takes the commercial consumer to recover the assumed higher purchase cost of more energy-efficient equipment as a result of lower energy costs. Numerically, the rebuttable PBP is the ratio of the increase in purchase cost (*i.e.*, from a less efficient design to a more efficient design) to the decrease in annual energy expenditures; that is, the difference in first year annual energy cost. This calculation excludes repair costs and maintenance costs.

The data inputs to PBP are the total installed cost of the equipment to the commercial consumer at each efficiency/standby loss level and the annual (first year) operating costs at each efficiency/standby loss level. The inputs to the total installed cost are the equipment price and the installation cost. The inputs to the operating costs are the annual energy cost, the annual repair cost, and the annual maintenance cost (or, in the case of rebuttable PBP, only the annual energy cost). The PBP uses the same inputs as the LCC analysis, except that electricity price trends are not required. Since the PBP is a "simple" payback, the required electricity cost is only for the year in which a new efficient standard is to take effect—in this case, 2019.

8.4 LIFE-CYCLE COST AND PAYBACK PERIOD RESULTS

As discussed previously, DOE's approach for conducting the LCC and PBP analysis relies on developing samples of buildings that use each of the considered equipment. DOE also uses probability distributions to characterize the uncertainty in many of the inputs to the analysis. DOE used a Monte Carlo simulation technique to perform the LCC and PBP calculations on the buildings in the sample.

LCC and PBP calculations are performed 10,000 times on the sample of buildings established for all of the five CWH equipment classes. Each LCC and PBP calculation is performed on a single building that is selected from the sample of the commercial consumers. The selection of a building is based on its sample weight (*i.e.*, how representative a particular building is of other buildings in the distribution—either regionally or nationally), as described in the energy use analysis (chapter 7). Each LCC and PBP calculation is also sampled from the probability distributions that DOE develops to characterize many of the inputs to the analysis.

To evaluate the net economic impact of potential amended energy conservation standards on commercial consumers of CWH equipment, DOE conducts LCC and PBP analyses for each TSL. In general, higher-efficiency equipment would potentially affect commercial consumers in two ways: (1) purchase price would increase, and (2) annual operating costs would decrease. Inputs used for calculating the LCC and PBP include total installed costs (*i.e.*, equipment price plus installation costs) and operating costs (*i.e.,* annual energy savings, energy prices, energy price trends, repair costs, and maintenance costs). The LCC calculation also uses equipment lifetime and a discount rate.

National LCC and PBP results are presented for each CWH equipment class in the following subsections.

8.4.1 Commercial Gas-Fired Storage Water Heaters

Table 8.4.1 and Table 8.4.2 show the LCC and PBP results for efficiency/standby loss levels (associated with each TSL chosen) considered for commercial gas-fired storage water heaters. In Table 8.4.1, the simple payback is measured relative to the baseline equipment. In Table 8.4.2, the LCC savings are measured relative to the no-new-standards case efficiency distribution in the compliance year (2019).

Table 8.4.1: Average LCC and PBP Results by Efficiency Level for Commercial Gas-Fired Storage Water Heaters

TSL*	Thermal Efficiency (E_t)	Standby Loss Factor	Average Costs *2014$*				Simple Payback Period *years*
			Installed Cost	First Year's Operating Cost	Lifetime Operating Cost	LCC	
0	80%	1.00	4,316	2,225	20,011	24,327	--
1	82%	0.72	4,581	2,156	19,378	23,959	3.8
2	90%	0.67	5,467	2,023	18,149	23,615	5.7
3	95%	0.63	5,537	1,944	17,415	22,952	4.3
4	99%	0.61	5,624	1,883	16,863	22,488	3.8

* The results for each TSL are calculated assuming that all commercial consumers use equipment with that efficiency level. The PBP is measured relative to the baseline equipment.
Note: TSL 0 represents the baseline.

Table 8.4.2 Average LCC Savings Relative to the No-New-Standards Case Efficiency Distribution for Commercial Gas-Fired Storage Water Heaters

TSL	Thermal Efficiency (E_t)	Standby Loss Factor	Life-Cycle Cost Savings	
			% of Commercial Consumers That Experience a Net Cost	Average Life-Cycle Cost Savings* *2014$*
0	80%	1.00	0%	--
1	82%	0.72	8%	219
2	90%	0.67	30%	317
3	95%	0.63	24%	794
4	99%	0.61	21%	1,252

* The calculation includes commercial consumers with zero LCC savings (no impact).
Note: TSL 0 represents the baseline.

8.4.2 Residential-Duty Gas-Fired Storage Water Heaters

Table 8.4.3 and Table 8.4.4 show the LCC and PBP results for efficiency/standby loss levels (associated with each TSL chosen) considered for residential duty gas-fired storage water heaters. In Table 8.4.3, the simple payback is measured relative to the baseline equipment. In Table 8.4.4, the LCC savings are measured relative to the no-new-standards case efficiency distribution in the compliance year (2019).

Table 8.4.3 Average LCC and PBP Results by Efficiency Level for Residential-Duty Gas-Fired Storage Water Heaters

TSL*	UEF	Average Costs *2014$*				Simple Payback Period *years*
		Installed Cost	First Year's Operating Cost	Lifetime Operating Cost	LCC	
0	0.60	2,090	1,252	13,066	15,156	--
1	0.67	2,528	1,210	12,609	15,136	10.5
2, 3	0.77	3,361	1,145	11,886	15,248	11.9
4	0.82	3,669	1,096	11,361	15,030	10.2

* The results for each TSL are calculated assuming all commercial consumers use equipment with that efficiency level. The PBP is measured relative to the baseline equipment. UEF values are for the representative model.
Note: TSL 0 represents the baseline.

Table 8.4.4 Average LCC Savings Relative to the No-New-Standards Case Efficiency Distribution Residential-Duty Gas-Fired Storage Water Heaters

TSL	UEF	Life-Cycle Cost Savings*	
		% of Commercial Consumers That Experience a Net Cost	Average Life-Cycle Cost Savings** *2014$*
0	0.60	0%	--
1	0.67	32%	537
2, 3	0.77	42%	14
4	0.82	36%	241

* A value in parentheses is a negative number.
** The calculation includes commercial consumers with zero LCC savings (no impact).
Note: UEF values are for the representative model.
TSL 0 represents the baseline.

8.4.3 Commercial Gas-Fired Instantaneous Tankless Water Heaters

Table 8.4.5 and Table 8.4.6 show the LCC and PBP results for efficiency/standby loss levels (associated with each TSL chosen) considered for commercial gas instantaneous tankless water heaters. In Table 8.4.5, the simple payback is measured relative to the baseline equipment. In Table 8.4.6, the LCC savings are measured relative to the no-new-standards case efficiency distribution in the compliance year (2019).

Table 8.4.5 Average LCC and PBP Results by Efficiency Level for Commercial Gas-Fired Instantaneous Tankless Water Heaters

TSL*	Thermal Efficiency (E_t)	Average Costs *2014$*				Simple Payback Period *years*
		Installed Cost	First Year's Operating Cost	Lifetime Operating Cost	LCC	
0	80%	4,273	690	9,607	13,880	--
1	84%	4,337	668	9,283	13,620	2.9
2	92%	3,819	622	8,628	12,447	Immediate
3	94%	3,849	611	8,474	12,322	Immediate
4	96%	3,884	600	8,325	12,209	Immediate

* The results for each TSL are calculated assuming that all commercial consumers use equipment with that efficiency level. The PBP is measured relative to the baseline equipment.
Note: Immediate payback can result from a decrease in installation cost that is greater than the incremental increase in equipment cost.
TSL 0 represents the baseline.

Table 8.4.6 Average LCC Savings Relative to the Base Case Efficiency Distribution for Commercial Gas-Fired Instantaneous Tankless Water Heaters

TSL	Thermal Efficiency (E_t)	Life-Cycle Cost Savings	
		% of Commercial Consumers that Experience a Net Cost	Average Life-Cycle Cost Savings* *2014$*
0	80%	0%	--
1	84%	11%	86
2	92%	38%	1,009
3	94%	35%	1,119
4	96%	33%	1,224

* The calculation includes commercial consumers with zero LCC savings (no impact).
Note: TSL 0 represents the baseline.

8.4.4 Commercial Gas-Fired Instantaneous Hot Water Supply Boilers

Table 8.4.7 and Table 8.4.8 show the LCC and PBP results for efficiency/standby levels considered (associated with each TSL chosen) for commercial gas-fired instantaneous hot water supply boilers. In Table 8.4.7, the simple payback is measured relative to the baseline product. In Table 8.4.8, the LCC savings are measured relative to the no-new-standards case efficiency distribution in the compliance year (2019).

Table 8.4.7 Average LCC and PBP Results by Efficiency Level for Commercial Gas-Fired Hot Water Supply Boilers

TSL*	Thermal Efficiency (E_t)	Average Costs *2014$*				Simple Payback Period *years*
		Installed Cost	First Year's Operating Cost	Lifetime Operating Cost	LCC	
0	80%	7,372	3,990	74,284	81,656	--
1	84%	7,961	3,828	71,216	79,178	3.6
2	92%	10,113	3,579	65,754	75,867	6.7
3	94%	10,433	3,514	64,516	74,949	6.4
4	96%	10,754	3,452	63,325	74,079	6.3

* The results for each TSL are calculated assuming that all commercial consumers use equipment with that efficiency level. The PBP is measured relative to the baseline equipment.
Note: TSL 0 represents the baseline.

Table 8.4.8 Average LCC Savings Relative to the No-New-Standards Case Efficiency Distribution for Commercial Gas-Fired Hot Water Supply Boilers

TSL	Thermal Efficiency (E_t)	Life-Cycle Cost Savings	
		% of Commercial Consumers that Experience a Net Cost	Average Life-Cycle Cost Savings* *2014$*
0	80%	0%	--
1	84%	15%	1,245
2	92%	22%	3,794
3	94%	22%	4,528
4	96%	24%	5,285

* The calculation includes commercial consumers with zero LCC savings (no impact).
Note: TSL 0 represents the baseline.

8.4.5 Commercial Gas-Fired Instantaneous Water Heaters and Hot Water Supply Boilers Water Heaters

Table 8.4.9 and Table 8.4.10 show the LCC and PBP results for efficiency/standby levels considered (associated with each TSL chosen) for commercial gas-fired instantaneous tankless heater and hot water supply boilers. In Table 8.4.9, the simple payback is measured relative to the baseline product. In Table 8.4.10, the LCC savings are measured relative to the no-new-standards case efficiency distribution in the compliance year (2019).

Table 8.4.9 Average LCC and PBP Results by Efficiency Level for Commercial Gas-Fired Instantaneous Water Heaters and Hot Water Supply Boilers

TSL*	Thermal Efficiency (E_t)	Average Costs *2014$*				Simple Payback Period *years*
		Installed Cost	First Year's Operating Cost	Lifetime Operating Cost	LCC	
0	80%	6,427	2,984	54,556	60,983	--
1	84%	6,856	2,864	52,325	59,181	3.6
2	92%	8,193	2,677	48,330	56,523	5.8
3	94%	8,425	2,629	47,422	55,846	5.6
4	96%	8,658	2,582	46,549	55,207	5.6

* The results for each TSL are calculated assuming that all commercial consumers use equipment with that efficiency level. The PBP is measured relative to the baseline equipment.
Note: TSL 0 represents the baseline.

Table 8.4.10 Average LCC Savings Relative to the No-New-Standards Case Efficiency Distribution for Commercial Gas-Fired Instantaneous Water Heaters and Hot Water Supply Boilers

TSL	Thermal Efficiency (E_t)	Life-Cycle Cost Savings	
		% of Commercial Consumers that Experience a Net Cost	Average Life-Cycle Cost Savings* *2014$*
0	80%	0%	--
1	84%	14%	891
2	92%	27%	2,944
3	94%	26%	3,488
4	96%	27%	4,046

* The calculation includes commercial consumers with zero LCC savings (no impact).
Note: TSL 0 represents the baseline.

8.4.6 Commercial Electric Storage Water Heaters

Table 8.4.11 and Table 8.4.12 show the LCC and PBP results for efficiency/standby levels (associated with each TSL chosen) considered for commercial electric storage water heaters. In Table 8.4.11, the simple payback is measured relative to the baseline product. In Table 8.4.12, the LCC savings are measured relative to the no-new-standards case efficiency distribution in the compliance year (2019).

Table 8.4.11 Average LCC and PBP Results by Efficiency Level for Commercial Electric Storage Water Heaters

TSL*	Standby LossFactor	Average Costs *2014$*				Simple Payback Period *years*
		Installed Cost	First Year's Operating Cost	Lifetime Operating Cost	LCC	
0	1.00	3,649	1,743	17,094	20,743	--
1, 2, 3, 4	0.84	3,743	1,728	16,952	20,694	6.5

* The results for each TSL are calculated assuming that all commercial consumers use equipment with that efficiency level. The PBP is measured relative to the baseline equipment.
Note: TSL 0 represents the baseline.

Table 8.4.12 Average LCC Savings Relative to the No-New-Standards Case Efficiency Distribution for Commercial Electric Storage Water Heater

TSL	Standby Loss Factor	Life-Cycle Cost Savings	
		% of Commercial Consumers that Experience a Net Cost	Average Life-Cycle Cost Savings* *2014$*
0	1.00	0%	--
1, 2, 3, 4	0.84	14%	47

* The calculation includes commercial consumers with zero LCC savings (no impact).
Note: TSL 0 represents the baseline.

8.5 REBUTTABLE PAYBACK PERIOD

DOE presents rebuttable PBPs to provide the legally established rebuttable presumption that an energy efficiency standard is economically justified if the additional equipment 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 8.3. Unlike the analyses described in section 8.3, however, the rebuttable PBP is not based on probability distributions but on discrete single-point values. For example, whereas DOE uses a probability distribution of energy prices in the distributional PBP analysis, it uses only the national average energy price to determine the rebuttable PBP.

8.5.1 Inputs

Inputs for the rebuttable PBP differ from the distribution PBP in that the calculation uses discrete values, rather than distributions. Note that for the calculation of distribution PBP, because inputs for the determination of total installed cost were based on single-point values, only the variability and/or uncertainty in the inputs for determining operating cost contributed to variability in the distribution 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 all 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 will take effect.
- An average discount rate or lifetime is not required in the rebuttable PBP calculation.
- The effective date of the standard is assumed to be 2019.

8.5.2 Results

DOE calculated rebuttable PBPs for the equipment classes at each TSL. Table 8.5.1 presents the rebuttable PBPs for CWH Equipment, and Table 8.5.2 presents the various TSLs chosen for the different equipment classes.

Table 8.5.1 Rebuttable Payback Period at Each TSL for the Five Equipment Classes

Equipment Class	Rebuttable Presumption Payback *years*			
	TSL 1	TSL 2	TSL 3	TSL 4
Gas-Fired Storage Water Heaters and Storage-Type Instantaneous Water Heaters	3.8	5.6	4.2	3.7
Residential-Duty Gas-Fired Storage Water Heaters	10.5	11.3	11.3	9.6
Gas-Fired Instantaneous Water Heaters and Hot Water Supply Boilers	3.4	5.1	5.0	5.0
Tankless Water Heaters	2.3	Immediate	Immediate	Immediate
Hot Water Supply Boilers	3.5	5.9	5.8	5.7
Electric Storage Water Heaters	6.5	6.5	6.5	6.5

Table 8.5.2 TSLs Chosen for the Different Equipment Classes

Equipment Class		Trial Standard Level*,**							
		1		2		3		4	
		E_t	SL	E_t	SL	E_t	SL	E_t	SL
Commercial Gas-Fired Storage Water Heaters and Storage-Type Instantaneous Water Heaters		1	2	2	2	4	2	5	2
Residential-Duty Gas-Fired Storage Water Heaters		1	3	2	1	2	1	4	1
Gas-Fired Instantaneous Water Heaters and Hot Water Supply Boilers	Tankless Water Heaters	2	-	3	-	4	-	5	-
	Hot Water Supply Boilers	2	-	3	-	4	-	5	-
Electric Storage Water Heaters		-	1	-	1	-	1	-	1

* E_t stands for thermal efficiency, and SL stands for standby loss.
** DOE did not analyze amended energy conservation standards for standby loss of instantaneous water heaters and hot water supply boilers or for thermal efficiency of electric storage water heaters.

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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 USER INSTRUCTIONS

The results obtained in this analysis can be examined and reproduced using the Microsoft Excel spreadsheets available on the U.S. Department of Energy's (DOE's) commercial water heating equipment rulemaking web page: https://www1.eere.energy.gov/buildings/appliance_standards/standards.aspx?productid=36.

8A.2 STARTUP

DOE's spreadsheets enable users to perform life-cycle cost (LCC) and payback period (PBP) analyses for each equipment class. A single spreadsheet exists that contains input data, analysis, and results. The purpose of the LCC is (1) to input raw data for the analysis[1,2,3] and (2) inform the public about how DOE processes the data and derives the LCC.

The LCC spreadsheet can be downloaded and run separately. Existing data can be changed by copying and pasting newer data (if needed) in the cells, in various sheets. To examine the spreadsheets, DOE assumes that the user has access to a personal computer with a hardware configuration capable of running Windows XP or later. All LCC spreadsheets require Microsoft Excel 2003 or a later version installed under the Windows operating system. Because certain variables inside the spreadsheets are defined as distributions, a copy of Crystal Ball (a commercially available add-on simulation program) is required to view them.[a]

8A.3 DESCRIPTION OF LIFE-CYCLE COST WORKSHEETS

8A.3.1 Main LCC Worksheet

For all of the water heater equipment classes, DOE creates a single LCC spreadsheet containing a collection of worksheets. Each worksheet represents a conceptual component within the LCC calculation. The results in different worksheets (other than the final summary of results) are for one building sample, and not for the entire population. The LCC spreadsheet contains the following worksheets (Table 8A.3.1):

[a] See www.oracle.com/us/products/applications/crystalball/overview/index.html

Table 8A.3.1 Worksheet List and Corresponding Description

Worksheet Name	Brief Description
Introduction	Contains a brief summary of each "worksheet," and the overarching framework of the model
User.Input. Summary	Contains a user interface where the end user can choose options and execute the model. The results of the simulation can be seen here as well.
VersionLog	Contains a log of changes made in the model with time
NIA Output	Contains NIA output for the most recent simulation run
LCC Output	Contains LCC output for the most recent simulation run
Inst.Rep.Main	Contains information on installation costs
Venting Costs	Contains information on costs associated with venting for each equipment class
Cost Database	Underlying database—reporting costs that are associated with venting
Labor Costs	Underlying database—reporting costs that are associated with venting
Labels and Flags	Underlying database—as a part of the venting calculations
LCC.PBP	Provides life cycle cost and payback period results
Maint and Repair Costs	Contains costs associated with maintenance and repair for each equipment class. Information on component failure rates can also be found here
Forecast Cells	Contains output for each forecast cell based on most recent simulation run
Labels	Provides information on the different options that are available for the user to conduct simulation runs
Auxiliary Power	Contains information on auxiliary power demand for each equipment class
Energy Price	Consolidates commercial and residential energy (natural gas and electricity) prices at the relevant geographic scale
Energy Price Trends	Contains price forecasts (natural gas and electricity) based on AEO 2015
Bldg.Sample	An intermediate engine whose primary purpose is to gather relevant data for "each" n-th simulation run based on the Commercial Building Energy Consumption Survey (CBECS)/Residential Energy Consumption Survey (RECS) sample selected
Water Draw	Calculates the water draw load based on commercial/residential building selected
Engineering Table	Contains information on thermal efficiency, standby loss rate, and shipping costs for each equipment class (provided by Navigant). Other engineering characteristics such as "First Hour Rating" are also calculated in this sheet.
RECS.WH	Contains RECS information and RECS based calculations. The actual RECS sample for each simulation run is selected here (for all equipment classes) based on underlying probability distribution
CBECS.WH	Contains CBECS information and CBECS based calculations. The actual CBECS sample for each simulation run is selected here (for all equipment classes) based on underlying probability distribution
Sizing Table	Contains mathematical algorithms for calculated peak load for various types of commercial and residential buildings.
Loads Table CBECS	Provides load factors for different types of commercial buildings

Worksheet Name	Brief Description
Temperature Reportable Domain	Contains temperature estimates (dry bulb and mains) aggregated to the different reportable domains applicable to residential buildings
Temperature Census Division	Contains temperature estimates (dry bulb and mains) aggregated to the different census divisions applicable to commercial buildings
Electricity Price RD	EIA 826 electricity price data aggregated to the different reportable domains applicable to residential buildings
NG Price RD	NG Navigator natural gas data aggregated to the different reportable domains applicable to residential buildings
NG Price CD	NG Navigator natural gas data aggregated to the different census divisions applicable to commercial buildings
Electricity Price CD	EIA 826 electricity price data aggregated to the different census divisions applicable to commercial buildings
Discount Rates	Contains information on discount rates used for both commercial and residential applications
Base Case Efficiency	Provides information on existing market data regarding the fraction of equipment at each thermal efficiency and standby loss level (for all equipment classes)
Sampling Distribution	Contains mathematical algorithms that govern the probability of the different commercial/residential buildings selected for each equipment class. Commercial and residential subgroups sampling distributions are built into the skeletal framework as well.
Lifetime Distribution	Contains the probability distribution of equipment lifetime (for all equipment classes)
Markups	Contains information on the probability distribution of markups (and the specific markup factor chosen, for n-th simulation run)
Control Panel	A dashboard that allows the user to choose different parameters for the impending simulation run. Subgroups analysis can also be conducted using this sheet. The user however, runs the model from "User Input Summary".

Figure 8A.3.1 illustrates the skeletal framework of the LCC model.

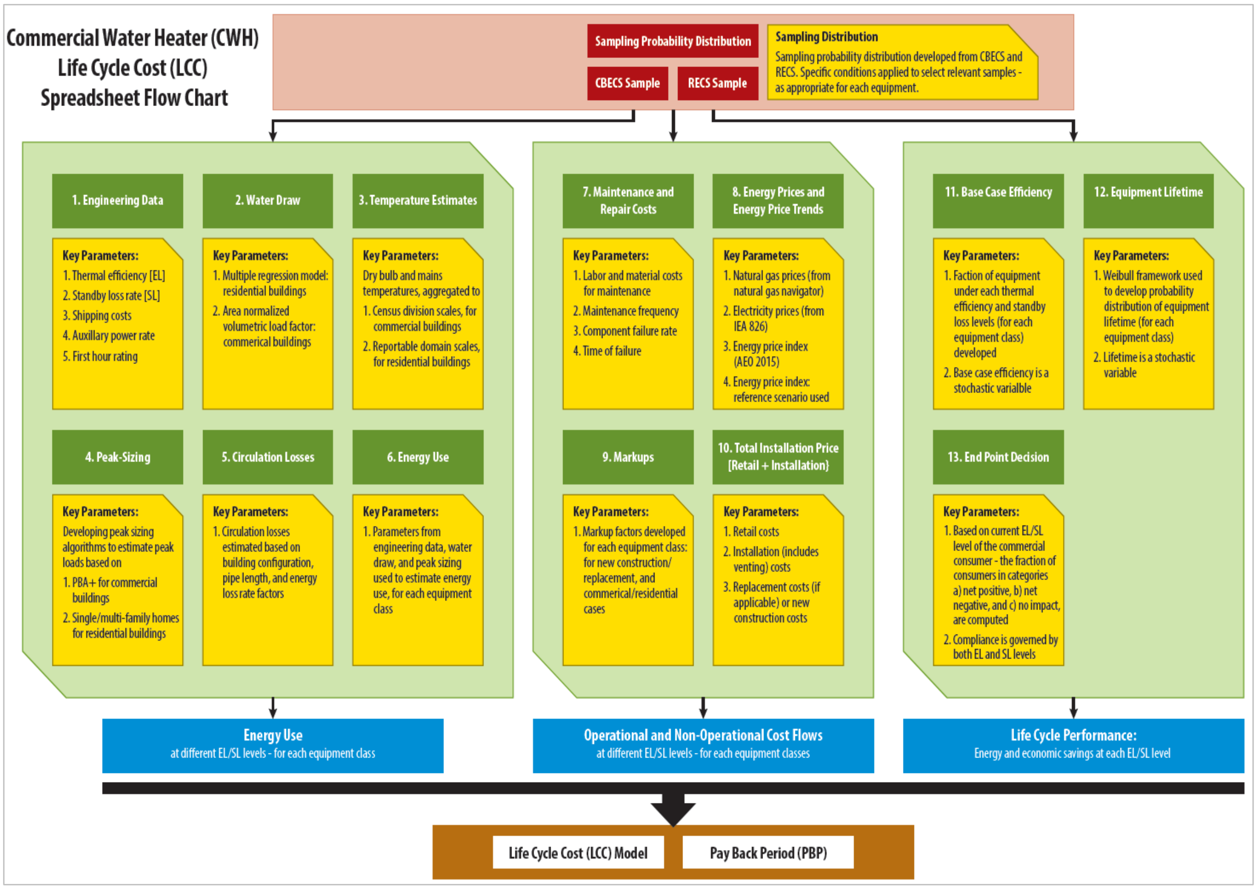

Figure 8A.3.1 LCC and Payback Calculation Process

8A.4 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 "Use Crystal Ball" when prompted and then click on the tab for the *User.Input.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) Change the parameters listed under USER INPUTS on the *User.Input.Summary* worksheet. There are five drop-down boxes, which represent the choices the user can make for the simulation:

   a) Number of Simulations
   b) Running Residential or Commercial (Separately), or Run Combination, which is a combination of both

c) If deciding to run "Separately," select which one: Residential or Commercial
d) Make further choices on whether to run subgroups.

To run the Crystal Ball simulation, click the "Run LCC" tab below the user choices. The program will open up a dialog box with a summary of the parameters the user has chosen to run the model. Then, clicking "OK" will start the simulation, and the spreadsheet will then be minimized. Monitor the progress of the simulation by watching the count of iterations at the left bottom corner. When the simulation is finished, the worksheet will reappear with the results (the results can be found to the right, in the User.Input.Summary sheet).

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APPENDIX 8B. UNCERTAINTY AND VARIABILITY IN LIFE-CYCLE COST ANALYSIS

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APPENDIX 8B. UNCERTAINTY AND VARIABILITY IN LIFE-CYCLE COST ANALYSIS

8B.1 INTRODUCTION

Analysis of energy conservation standards involves calculations of impacts, such as the impact of a standard on commercial consumer life-cycle cost (LCC). To perform the calculation, the analyst must: (1) specify the equation or model that will be used, (2) define the quantities in the equation, and (3) provide numerical values for each quantity. In the simplest case, the equation is unambiguous (contains all relevant quantities and no others), each quantity has a single numerical value, and the calculation results in a single value. However, unambiguity and precision are rarely the case. In almost all cases, the model and/or the numerical values for each quantity in the model are not completely known (*i.e.*, there is uncertainty), or the model and/or the numerical values for each quantity in the model depend upon other conditions (*i.e.*, there is variability).

Thorough analysis involves accounting for uncertainty and variability. While the simplest analysis involves a single numerical value for each quantity in a calculation, arguments can arise about what the appropriate value is for each quantity. Explicit analysis of uncertainty and variability is intended to provide more complete information to the decision-making process.

8B.2 UNCERTAINTY

When making observations of past events or speculating about the future, imperfect knowledge is the rule rather than the exception. For example, the energy actually consumed by a particular appliance type (such as the average U.S. water heater, or refrigerator) is not directly recorded, but rather estimated based upon available information. Even direct laboratory measurements have some margin of error. When estimating numerical values expected for quantities at some future date, the exact outcome is rarely known in advance.

8B.3 VARIABILITY

Variability results when different applications or situations produce different numerical values when calculating a quantity. Specifying an exact value for a quantity may be difficult because the value depends on something else. For example, commercial water heating equipment energy consumption depends upon the specific circumstances and behaviors of the occupants (*e.g.*, number of persons, length, and temperature of showers, *etc*.). Variability makes specifying an appropriate population value more difficult inasmuch as any one value may not be representative of the entire population. Surveys can be helpful here, and analysis of surveys can relate the variable of interest (*e.g.*, hours of use) to other variables that are better known or easier to forecast (*e.g.*, persons per household).

8B.4 APPROACHES TO UNCERTAINTY AND VARIABILITY

This section describes two approaches to uncertainty and variability:

- scenario analysis, and
- probability analysis.

Scenario analysis uses a single numerical value for each quantity in a calculation, then changes one (or more) of the numerical values and repeats the calculation. A number of calculations are performed to provide some indication of the extent to which the result depends upon the assumptions. For example, the LCC of an appliance could be calculated for energy rates of 2, 8, and 14¢ per kWh.

The advantages of scenario analysis are that each calculation is simple, a range of estimates is used, and crossover points can be identified. An example of a crossover point is the energy rates at which the initial investment becomes economically justified (i.e. the initial investment pays back for itself over equipment lifetime). That is, the crossover point is the energy rate at which the commercial consumer achieves savings in operating expense that more than compensates for the increased purchase expense. The disadvantage of scenario analysis is that there is no information about the likelihood of each scenario.

Probability analysis considers the probabilities within a range of values. For quantities with variability (*e.g.*, electricity rates in different households), surveys can be used to generate a frequency distribution of numerical values (*e.g.*, the number of households with electricity rates at particular levels) to estimate the probability of each value. For quantities with uncertainty, statistical or subjective measures can be used to provide probabilities (*e.g.*, manufacturing cost to improve energy efficiency to some level may be estimated to be $10 ± $3).

The major disadvantage of the probability approach is that it requires more information, namely information about the shapes and magnitudes of the variability and uncertainty of each quantity. The advantage of the probability approach is that it provides greater information about the outcome of the calculations; that is, it provides the probability that the outcome will be in a particular range.

Scenario and probability analysis provide some indication of the robustness of the policy given the uncertainties and variability. A policy is robust when the impacts are acceptable over a wide range of possible conditions.

8B.5 PROBABILITY ANALYSIS AND THE USE OF CRYSTAL BALL

To quantify the uncertainty and variability that exist in inputs to the engineering, LCC, and payback period (PBP) analyses, the U.S. Department of Energy (DOE) uses Microsoft Excel spreadsheets combined with Crystal Ball, a commercially-available simulation software add-in, to conduct probability analyses. The probability analyses use Monte Carlo simulation and probability distributions.

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 spreadsheet model will only reveal a single outcome, generally the most likely or average scenario. Spreadsheet risk analysis uses both a spreadsheet model and simulation to automatically analyze the effect of varying inputs on outputs of the modeled system. One type of spreadsheet simulation is Monte Carlo simulation, which randomly generates values for uncertain variables again and again to simulate a model. Monte Carlo simulation was named for Monte Carlo, Monaco, where the primary attractions are casinos containing games of chance. Games of chance, such as roulette wheels, dice, and slot machines, exhibit random behavior. The random behavior in games of chance is similar to how Monte Carlo simulation selects variable values at random to simulate a model. When you roll a die, you know that a 1, 2, 3, 4, 5, or 6 will come up, but you do not know which for any particular roll. The same applies to the variables that have a known range of values but an uncertain value for any particular time or event (*e.g.*, equipment lifetime, discount rate, and installation cost).

For each uncertain variable (one that has a range of possible values), possible values are defined with a probability distribution. The type of distribution selected is based on the conditions surrounding that variable. Probability distribution types are shown in Figure 8B.5.1.

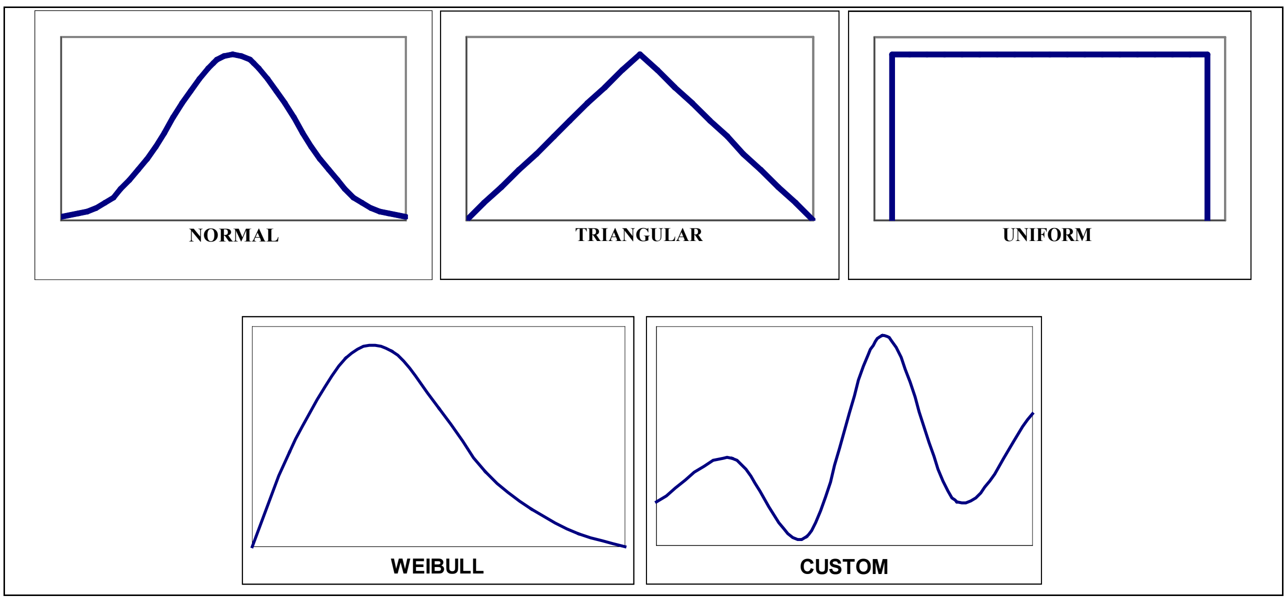

Figure 8B.5.1 Normal, Triangular, Uniform, Weibull, and Custom Probability Distributions

During a simulation, multiple scenarios of a model are calculated by repeatedly sampling values from the probability distributions for the uncertain variables and using those values for the cell. Crystal Ball simulations can consist of as many trials as desired—hundreds or even thousands. During a single trial, Crystal Ball randomly selects a value from the defined possibilities (the range and shape of the probability distribution) for each uncertain variable and then recalculates the spreadsheet.

APPENDIX 8C. ENERGY PRICE CALCULATIONS

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APPENDIX 8C. ENERGY PRICE CALCULATIONS

8C.1 INTRODUCTION

Figure 8C.1.1 depicts the energy price calculation process, which also encompasses average and marginal energy price on a monthly scale for the different fuels relevant to the analysis.

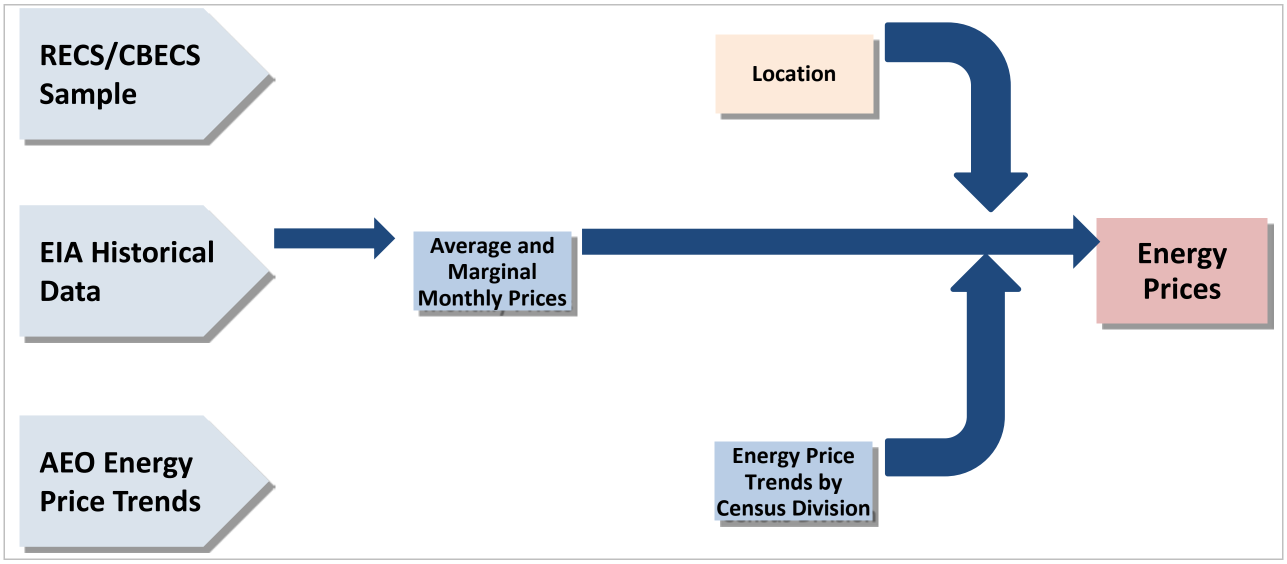

Figure 8C.1.1 Energy Price Calculation Process

8C.2 COMMERCIAL BUILDING ENERGY CONSUMPTION SURVEY/RESIDENTIAL ENERGY CONSUMPTION SURVEY SAMPLE MAPPING PROCESS

The Commercial Building Energy Consumption Survey (CBECS) building and Residential Energy Consumption Survey (RECS) household samples disaggregate the United States into nine census divisions and 27 reportable domains respectively. So, during a simulation run, when a specific sample is chosen, the corresponding census divison (in the case of CBECS) or reportable domain (in the case of RECS) is extracted from the database for the specific sample. Subsequently, the appropriate energy prices are used based on the geographic location (as identified by the census division or reportable domain) for each sample.

8C.2.1 Average Annual and marginal Prices Determination

8C.2.1.1 Annual Electrical Prices

DOE derives 2014 annual electricity prices from Energy Information Administration (EIA) Form 826 data.[1] The EIA Form 826 data include energy prices by state. DOE calculates both commercial and residential annual electricity prices for each geographical area by averaging monthly energy prices by state to get state electricity prices. For areas with more than one state, DOE weights each state's average price by its population. Table 8C.2.1and Table 8C.2.2 present monthly electricity prices for residential and commercial sectors respectively. Table 8C.2.3 shows the monthly commercial electricity prices for each census division. Table 8C.2.4 shows the monthly residential electricity prices for each reportable domain. DOE reports all energy prices in $ 2014 values.

8C.2.1.2 Marginal Electrical Prices

DOE calculates marginal electrical prices by multiplying annual average electricity prices by a marginal price factor, at the census division scale (for commercial applications), and at the reportable domain scale (for residential applications). The marginal price factor is the fraction of expenditures (due to actual energy consumption) to total expenditures (this includes for example, fixed costs, connection fee and surcharges, in addition to usage related expenditures).
Table 8C.2.9 and Table 8C.2.10 present the marginal factors for gas and electricity, at the different spatial scales used for residential and commercial applications.

Table 8C.2.1 2014 Monthly Residential Electrical Prices by State

State	2014 Monthly Residential Electrical Prices *2014¢/kWh*											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
AK	18.2	18.7	18.7	19.0	19.8	20.3	20.6	20.4	19.6	19.9	19.5	18.5
AL	10.7	11.3	11.6	11.8	11.8	11.9	11.9	11.8	11.9	11.8	11.1	11.1
AR	8.3	8.5	9.1	9.8	10.1	10.1	10.2	10.0	10.2	9.8	9.7	9.1
AZ	10.9	11.2	11.3	12.0	12.6	12.4	12.5	12.4	12.4	12.0	11.2	10.9
CA	16.6	16.2	15.9	10.1	16.5	17.0	17.7	18.1	18.0	13.4	17.1	17.1
CO	11.4	11.7	11.7	12.2	12.2	13.1	13.1	12.9	12.7	11.8	11.6	11.4
CT	18.3	19.4	19.5	19.9	20.2	20.2	19.5	19.7	19.7	20.1	19.9	19.7
DC	12.6	12.8	12.6	13.2	14.3	13.3	12.2	12.7	12.6	13.2	12.8	12.1
DE	12.5	12.4	12.2	13.3	14.0	14.1	13.6	14.1	13.8	14.7	14.1	13.1
FL	11.9	11.9	11.9	11.8	11.8	12.1	12.0	12.0	12.3	12.0	12.2	11.9
GA	10.8	10.9	11.2	11.5	11.8	12.5	12.6	12.5	12.1	11.3	10.7	10.4
HI	37.4	37.1	38.5	38.1	38.0	38.7	38.4	37.8	38.1	36.4	35.1	34.6
IA	10.0	10.3	11.0	11.7	11.5	12.3	12.7	13.4	12.3	11.4	10.5	10.1
ID	9.2	9.1	9.2	9.6	9.6	10.4	10.6	10.5	10.0	10.2	9.8	9.4
IL	9.8	10.3	10.7	11.8	12.0	11.7	11.6	12.0	11.6	13.1	12.0	11.3
IN	10.2	10.5	11.0	11.9	11.8	11.5	11.7	11.6	11.6	12.0	11.5	11.1
KS	10.9	11.1	11.7	12.6	12.7	12.6	12.7	12.7	12.4	12.7	12.2	11.3
KY	9.4	9.5	10.0	10.7	10.6	10.4	10.4	10.1	10.1	10.4	10.1	9.8
LA	8.5	8.8	9.2	10.1	10.2	10.0	10.1	9.8	9.7	9.6	8.8	9.2
MA	16.8	17.5	17.3	18.2	17.6	16.6	16.3	17.8	16.8	16.9	17.6	19.7
MD	13.1	13.5	13.6	14.1	14.2	13.7	13.8	13.7	13.6	14.0	13.2	13.5
ME	14.5	14.6	15.2	15.4	15.4	15.4	15.3	15.4	15.8	15.9	15.8	15.7
MI	13.9	14.0	14.1	14.6	14.9	15.0	15.1	14.9	14.8	14.7	14.4	14.0
MN	11.3	11.5	11.9	12.0	12.2	12.8	13.1	12.9	12.8	12.5	11.8	11.5
MO	8.9	9.0	9.8	10.6	11.9	12.4	12.3	12.2	11.0	10.6	10.0	9.4
MS	10.4	10.6	11.3	11.9	12.0	11.7	11.6	11.6	11.4	11.5	11.7	11.3
MT	9.9	9.8	9.9	10.0	10.3	10.7	10.8	10.9	11.0	10.8	10.3	9.7
NC	10.3	11.0	10.9	11.8	11.4	11.4	11.3	11.4	11.6	11.9	10.7	10.5
ND	7.8	8.4	8.6	9.2	10.0	11.3	11.0	10.9	11.0	9.9	8.7	8.3
NE	8.9	9.2	9.5	10.2	10.5	11.5	12.3	12.1	12.1	10.8	10.1	9.3
NH	16.5	17.2	17.3	17.5	18.0	18.0	17.2	17.2	17.4	18.1	18.2	18.5
NJ	15.3	15.7	15.9	15.7	15.5	15.9	16.5	16.0	15.9	15.6	15.6	15.6
NM	11.3	11.4	11.6	11.9	12.0	13.1	13.6	13.6	12.8	12.7	11.6	11.6
NV	12.5	12.0	13.4	13.6	13.2	12.8	12.7	12.6	12.9	13.2	13.6	13.0
NY	19.5	21.7	20.9	19.6	20.6	20.9	20.3	19.5	19.4	19.4	19.5	19.3
OH	11.0	11.1	11.6	12.4	12.9	13.5	13.4	13.5	12.3	13.0	12.8	12.3

State	2014 Monthly Residential Electrical Prices *2014¢/kWh*											
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
OK	8.3	9.3	9.7	11.1	10.4	10.4	10.5	10.1	11.1	10.7	9.6	8.9
OR	10.1	10.2	10.2	10.4	10.6	10.8	10.8	10.8	10.7	10.8	10.6	10.3
PA	12.7	13.4	13.0	13.1	13.3	13.9	14.0	13.9	13.5	13.4	13.2	13.0
RI	20.2	18.6	16.9	18.3	18.1	16.5	15.9	18.4	17.2	17.2	16.7	17.0
SC	11.7	11.9	12.2	12.5	12.6	12.5	12.6	12.5	12.5	12.6	12.4	11.8
SD	9.4	9.7	9.8	10.3	11.0	11.6	11.6	11.4	11.5	11.3	10.5	10.0
TN	9.7	9.8	10.6	10.8	10.9	10.9	10.8	10.5	10.1	10.4	10.2	10.1
TX	11.2	11.2	11.7	12.0	11.9	12.1	12.0	12.0	12.0	12.0	11.9	11.8
UT	10.0	10.1	10.2	10.2	10.8	11.2	11.6	11.6	11.1	10.3	10.7	10.3
VA	10.1	10.2	10.6	11.1	11.4	11.7	12.0	12.0	12.1	11.7	11.5	11.0
VT	16.9	17.1	17.4	18.1	18.2	18.1	17.9	17.9	17.8	17.4	17.1	16.7
WA	8.6	8.7	8.7	8.8	8.9	8.8	9.0	8.9	9.0	8.8	8.7	8.2
WI	13.1	13.5	13.3	13.8	14.2	14.6	14.5	14.3	14.6	14.1	13.8	13.4
WV	9.0	9.1	9.2	9.6	9.7	9.6	9.4	9.5	9.5	9.7	9.3	9.1
WY	9.8	9.9	10.1	10.2	10.6	11.2	11.3	11.1	11.1	11.2	10.7	10.5

Table 8C.2.2 2014 Monthly Commercial Electrical Prices by State

State	2014 Monthly Commercial Electrical Prices *2014¢/kWh*											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
AK	16.7	16.8	17.0	16.8	17.2	17.8	18.0	17.6	17.3	17.4	17.5	16.3
AL	10.8	10.9	10.9	10.5	10.9	11.0	11.0	11.0	10.7	10.7	11.0	10.7
AR	7.4	7.5	7.8	8.0	8.2	8.4	8.4	8.3	8.2	8.0	8.0	7.8
AZ	9.2	9.5	9.3	9.7	10.4	10.7	10.8	10.5	10.6	10.1	9.5	9.3
CA	13.1	13.2	13.3	13.2	14.7	16.7	17.9	18.2	18.3	17.6	15.4	14.1
CO	9.4	9.7	9.8	10.2	10.4	11.2	10.8	10.8	10.8	10.0	9.8	9.4
CT	15.7	16.6	16.4	15.8	15.0	15.4	15.0	15.4	15.2	15.1	15.2	15.7
DC	13.3	13.2	12.5	12.1	12.5	12.1	11.6	11.8	11.8	12.1	12.1	11.9
DE	10.9	12.3	11.0	11.3	10.4	10.5	10.4	9.3	10.5	10.3	10.3	10.2
FL	9.7	10.3	10.1	9.9	9.9	9.9	9.8	9.8	10.0	10.0	10.3	10.0
GA	10.8	10.5	10.4	10.1	10.1	10.6	10.4	10.4	10.1	9.9	10.4	9.7
HI	34.9	34.4	35.7	34.2	34.8	35.3	34.8	34.5	34.7	33.9	32.6	32.1
IA	8.0	8.2	8.6	8.8	8.6	9.2	9.7	10.4	9.2	8.4	7.9	7.8
ID	7.3	7.5	7.6	7.7	7.7	8.1	8.3	8.1	7.9	7.8	7.8	7.6
IL	8.3	8.7	8.9	8.7	8.8	8.9	8.8	8.9	8.9	8.9	8.6	8.5
IN	9.4	9.8	9.7	9.9	9.8	9.7	9.9	9.9	9.8	10.1	10.1	9.9
KS	9.3	9.4	10.0	10.1	10.2	10.2	10.6	10.6	10.2	10.3	10.0	9.3
KY	8.9	9.3	9.5	9.8	9.5	9.4	9.5	9.2	9.2	9.2	9.3	9.5
LA	8.7	9.0	9.2	9.8	9.6	9.3	9.4	9.0	8.9	8.9	8.5	9.1
MA	15.5	15.9	15.4	14.5	13.6	14.3	14.6	14.7	14.5	14.0	13.7	14.9
MD	11.5	12.3	11.8	11.4	11.0	11.2	11.0	10.9	10.8	10.8	10.9	10.9
MI	10.5	10.8	10.9	11.0	11.0	11.3	11.1	11.3	10.9	10.9	10.9	10.6
MN	9.2	9.5	9.7	9.4	9.5	10.3	10.1	10.1	9.9	9.4	9.2	9.0
MO	7.7	7.9	8.0	8.2	9.3	10.2	10.3	10.2	9.0	8.3	8.1	8.0
MS	10.5	10.7	11.0	11.0	11.0	10.9	11.0	10.9	10.8	10.9	11.1	11.0
MT	9.3	9.2	9.5	9.5	9.6	9.6	9.6	9.7	10.0	10.0	9.8	9.4
NC	8.6	9.0	8.9	8.8	8.7	8.9	9.0	8.9	8.8	8.8	8.4	8.5
ND	7.8	8.3	8.4	8.3	8.8	9.4	8.9	9.0	9.2	8.5	8.2	8.0
NE	8.2	8.2	8.5	8.5	8.6	9.1	9.6	9.3	9.3	8.8	8.2	8.3
NH	15.3	15.6	15.3	14.3	14.2	14.2	14.0	13.6	13.6	13.8	14.4	14.7
NJ	13.9	13.7	13.8	13.3	13.1	13.6	13.6	13.5	13.2	12.1	12.2	12.1
NM	9.5	9.8	9.9	9.7	10.0	10.9	11.5	11.3	10.6	10.4	9.9	10.0
NV	9.6	9.0	9.8	9.9	9.3	9.4	10.2	9.1	10.0	10.2	9.8	9.5
NY	16.4	17.5	16.9	14.9	15.0	16.4	16.7	16.4	16.8	15.8	15.3	14.9
OH	9.3	9.8	9.7	9.9	9.6	9.9	10.0	9.9	9.6	10.0	10.1	9.9
OK	7.4	7.9	7.6	7.6	7.7	8.5	8.9	8.4	9.0	8.0	7.4	7.4

State	2014 Monthly Commercial Electrical Prices *2014¢/kWh*											
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
OR	8.7	8.9	8.9	8.8	8.9	8.7	8.8	8.7	8.8	8.9	8.9	8.7
PA	10.4	10.5	10.1	9.9	9.4	9.5	9.5	9.5	9.5	9.4	9.5	9.5
RI	15.5	17.5	15.7	14.6	13.9	13.2	13.5	16.0	13.9	13.3	13.3	15.4
SC	10.1	10.3	10.2	10.3	9.9	10.3	10.2	10.3	10.2	9.9	10.4	10.2
SD	8.2	8.7	8.6	8.6	8.8	9.1	9.1	8.9	8.9	8.8	8.7	8.6
TN	10.0	10.1	10.9	10.7	10.5	10.8	10.8	10.5	10.1	10.0	10.0	10.1
TX	8.0	8.0	8.3	8.2	8.1	8.2	8.2	8.1	8.0	8.1	8.3	8.0
UT	7.7	8.3	8.3	8.3	9.1	9.5	8.9	9.1	9.3	8.6	8.5	7.7
VA	8.0	7.9	8.0	8.0	8.0	8.1	8.5	8.3	8.5	8.4	8.5	8.5
VT	14.3	14.5	14.7	14.7	14.9	14.9	14.7	14.5	14.6	14.5	14.7	14.4
WA	7.9	8.0	8.1	8.1	7.9	7.7	7.9	7.8	7.9	8.0	8.2	7.8
WI	10.3	10.8	10.5	10.8	11.0	11.4	11.3	11.1	11.3	10.7	10.7	10.7
WV	7.7	8.2	8.2	8.5	8.1	7.9	7.7	7.8	7.9	8.2	8.2	7.8
WY	8.5	8.6	8.8	8.9	9.1	9.2	9.0	8.8	9.1	9.3	9.0	8.7

Table 8C.2.3 2014 Monthly Commercial Electricity Prices by Census Division

Census Division	Census Division Number	2014 Monthly Commercial Electricity Prices *2014¢/kWh*											
		Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
New England	1	15.4	16.0	15.6	14.7	14.0	14.3	14.4	14.6	14.3	14.0	14.0	14.9
Middle Atlantic	2	14.1	14.6	14.2	13.1	13.0	13.8	14.0	13.8	14.0	13.2	13.0	12.7
East North Central	3	9.4	9.8	9.9	9.9	9.9	10.1	10.0	10.1	9.9	10.0	9.9	9.8
West North Central	4	8.4	8.6	8.9	8.9	9.3	9.9	10.0	10.1	9.5	9.0	8.7	8.5
South Atlantic	5	9.7	10.0	9.8	9.7	9.6	9.8	9.7	9.7	9.7	9.6	9.8	9.6
East South Central	6	10.0	10.2	10.6	10.5	10.5	10.6	10.6	10.4	10.2	10.1	10.3	10.3
West South Central	7	8.0	8.1	8.3	8.3	8.3	8.4	8.4	8.3	8.2	8.2	8.2	8.1
Mountain	8	9.0	9.2	9.3	9.5	9.8	10.3	10.3	10.1	10.2	9.8	9.4	9.1
Pacific	9	12.2	12.3	12.5	12.5	13.7	15.0	16.0	16.1	16.3	15.8	14.0	12.9

Table 8C.2.4 2014 Monthly Residential Electricity Prices by Reportable Domain

Reportable Domain Number	Locations	2014 Monthly Residential Electricity Prices *2014¢/kWh*											
		Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1	Connecticut, Maine, New Hampshire, Rhode Island, Vermont	17.5	17.9	17.9	18.4	18.6	18.4	17.8	18.2	18.2	18.5	18.3	18.2
2	Massachusetts	16.8	17.5	17.3	18.2	17.6	16.6	16.3	17.8	16.8	16.9	17.6	19.7
3	New York	19.5	21.7	20.9	19.6	20.6	20.9	20.3	19.5	19.4	19.4	19.5	19.3
4	New Jersey	15.3	15.7	15.9	15.7	15.5	15.9	16.5	16.0	15.9	15.6	15.6	15.6
5	Pennsylvania	12.7	13.4	13.0	13.1	13.3	13.9	14.0	13.9	13.5	13.4	13.2	13.0
6	Illinois	9.8	10.3	10.7	11.8	12.0	11.7	11.6	12.0	11.6	13.1	12.0	11.3
7	Indiana, Ohio	10.7	10.9	11.3	12.2	12.5	12.8	12.8	12.8	12.0	12.6	12.3	11.9
8	Michigan	13.9	14.0	14.1	14.6	14.9	15.0	15.1	14.9	14.8	14.7	14.4	14.0
9	Wisconsin	13.1	13.5	13.3	13.8	14.2	14.6	14.5	14.3	14.6	14.1	13.8	13.4
10	Iowa, Minnesota, North Dakota, South Dakota	10.5	10.8	11.2	11.6	11.8	12.4	12.7	12.8	12.4	11.9	11.1	10.7
11	Kansas, Nebraska	10.2	10.4	10.9	11.7	11.9	12.1	12.5	12.5	12.2	12.0	11.4	10.5
12	Missouri	8.9	9.0	9.8	10.6	11.9	12.4	12.3	12.2	11.0	10.6	10.0	9.4
13	Virginia	10.1	10.2	10.6	11.1	11.4	11.7	12.0	12.0	12.1	11.7	11.5	11.0
14	Delaware, Maryland, West Virginia	12.2	12.4	12.5	13.0	13.2	12.9	12.8	12.9	12.7	13.1	12.5	12.5
15	Georgia	10.8	10.9	11.2	11.5	11.8	12.5	12.6	12.5	12.1	11.3	10.7	10.4
16	North Carolina, South Carolina	10.7	11.3	11.4	12.1	11.8	11.7	11.7	11.8	11.9	12.1	11.2	10.9
17	Florida	11.9	11.9	11.9	11.8	11.8	12.1	12.0	12.0	12.3	12.0	12.2	11.9
18	Alabama, Kentucky, Mississippi	10.2	10.5	11.0	11.4	11.4	11.3	11.3	11.1	11.1	11.2	10.9	10.7
19	Tennessee	9.7	9.8	10.6	10.8	10.9	10.9	10.8	10.5	10.1	10.4	10.2	10.1
20	Arkansas, Louisiana, Oklahoma	8.4	8.9	9.3	10.3	10.3	10.2	10.3	10.0	10.3	10.1	9.3	9.1
21	Texas	11.2	11.2	11.7	12.0	11.9	12.1	12.0	12.0	12.0	12.0	11.9	11.8
22	Colorado	11.4	11.7	11.7	12.2	12.2	13.1	13.1	12.9	12.7	11.8	11.6	11.4
23	Idaho, Montana, Utah, Wyoming	9.7	9.8	9.8	10.0	10.4	10.9	11.2	11.1	10.8	10.4	10.4	10.0
24	Arizona	10.9	11.2	11.3	12.0	12.6	12.4	12.5	12.4	12.4	12.0	11.2	10.9
25	Nevada, New Mexico	12.0	11.8	12.6	12.8	12.7	12.9	13.1	13.0	12.8	13.0	12.8	12.4
26	California	16.6	16.2	15.9	10.1	16.5	17.0	17.7	18.1	18.0	13.4	17.1	17.1
27	Alaska, Hawaii, Oregon, Washington	12.7	12.8	12.9	13.0	13.2	13.2	13.4	13.2	13.2	13.0	12.7	12.3

8C.2.1.3 Annual Natural Gas Prices

DOE obtains data for natural gas prices from EIA's Natural Gas Navigator, which includes monthly natural gas prices by state for residential, commercial, and industrial customers.[2] For areas with more than one state, DOE weights each state's average price by its population. Table 8C.2.5 shows the monthly commercial natural gas prices for each state. Table 8C.2.6 shows the monthly residential natural gas prices for each state. Table 8C.2.7 and Table 8C.2.8 present naural gas prices aggregated to census divisions (for commercial applications) and reportable domains (for residential applications) respectively.

8C.2.1.4 Marginal Natural Gas Prices

DOE calculates marginal gas prices by multiplying annual average gas prices by a marginal price factor, at the census division scale (for commercial applications), and at the reportable domain scale (for residential applications). The marginal price factor is the fraction of expenditures (due to actual energy consumption) to total expenditures (this includes for example, fixed costs, connection fee and surcharges, in addition to usage related expenditures). Table 8C.2.9 and Table 8C.2.10 present the marginal factors for gas and electricity, at the different spatial scales used for residential and commercial applications.

Table 8C.2.5 2014 Monthly Commercial Natural Gas Prices by State

State	2014 Monthly Commercial Natural Gas Prices *2014$/tcf*											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
AL	11.4	11.6	11.7	12.2	12.8	13.1	13.0	13.0	13.1	12.5	11.5	11.1
AK	9.1	9.2	8.9	8.8	6.7	8.8	9.2	9.3	8.8	8.7	8.5	8.3
AZ	8.8	9.6	10.2	10.1	10.4	10.7	10.9	10.3	10.3	11.6	11.0	11.2
AR	7.3	7.2	7.2	8.0	8.8	9.2	9.4	9.4	9.0	8.4	8.5	8.2
CA	8.8	9.1	10.1	9.2	9.0	8.9	9.3	8.8	8.8	8.9	8.5	9.3
CO	7.4	7.5	7.8	8.4	8.7	9.7	11.0	10.9	10.4	8.5	7.9	7.8
CT	8.5	9.9	10.3	12.3	12.6	12.8	11.3	10.9	11.2	11.5	9.2	9.2
DE	10.9	10.9	10.7	11.2	12.3	13.6	14.3	14.6	14.4	13.9	11.9	10.5
DC	11.5	12.4	12.1	14.3	12.9	13.0	13.2	11.6	11.9	11.1	11.9	11.8
FL	11.1	11.1	11.4	11.6	11.7	11.9	12.3	12.1	11.9	11.4	11.4	10.9
GA	8.8	9.4	9.7	10.3	10.7	12.0	11.6	11.4	11.2	11.3	8.6	8.9
HI	38.9	37.9	42.2	43.0	45.0	46.1	42.9	44.4	42.0	36.3	36.6	29.7
ID	7.8	7.8	8.0	8.0	8.1	7.9	7.7	8.0	7.8	7.8	7.7	7.7
IL	6.9	7.5	10.6	12.9	13.1	13.0	13.9	14.8	11.8	8.8	7.2	7.8
IN	7.3	7.8	9.3	10.2	11.8	11.4	10.5	10.0	8.3	7.2	6.6	8.1
IA	7.4	8.6	9.4	7.5	9.2	10.7	10.4	10.5	9.7	7.1	7.0	7.5
KS	8.4	8.9	9.2	10.6	11.3	13.3	14.1	14.0	13.6	12.6	9.6	8.4
KY	8.1	8.1	8.3	9.4	11.8	12.7	12.7	12.8	12.5	11.1	8.9	8.8
LA	8.7	9.1	9.2	9.3	9.6	9.3	9.4	8.7	9.0	8.7	8.6	8.8
ME	14.1	16.1	15.6	15.9	14.9	14.0	14.2	14.4	13.8	13.2	13.9	17.0
MD	9.6	10.4	10.4	11.1	12.3	11.5	11.9	11.0	12.0	10.7	9.3	10.5
MA	11.6	11.9	13.0	13.6	12.2	11.6	11.7	11.5	11.5	9.8	12.1	12.8
MI	7.4	8.0	8.8	8.4	8.9	9.7	10.2	10.1	9.7	8.6	7.9	7.9
MN	7.6	8.5	7.2	9.3	8.2	9.3	9.3	8.4	8.1	8.1	7.8	8.2
MS	7.8	8.1	8.6	8.6	9.2	8.9	8.7	8.5	8.1	9.0	8.5	8.3
MO	7.9	7.6	8.0	9.1	10.3	12.0	12.7	12.6	12.4	11.2	10.3	9.1
MT	8.1	8.3	8.9	9.9	10.8	11.9	11.9	11.5	10.3	9.8	8.4	8.3
NE	6.7	7.2	8.1	8.2	7.1	7.2	7.8	7.6	7.0	7.2	7.1	7.4
NV	7.2	7.4	7.7	7.9	8.2	8.4	9.0	8.1	9.2	9.3	9.0	8.6
NH	12.0	14.5	15.1	16.3	15.1	14.3	15.7	16.0	15.5	12.9	13.0	14.5
NJ	9.9	11.0	11.1	9.5	9.4	10.0	10.3	9.7	9.6	9.6	9.6	9.3
NM	6.8	7.5	8.2	8.4	8.2	8.8	9.1	8.9	8.7	8.5	7.7	7.2
NY	8.4	9.3	9.1	9.1	8.8	7.8	7.7	7.2	7.2	7.1	7.3	7.6

State	2014 Monthly Commercial Natural Gas Prices *2014$/tcf*											
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
NC	8.5	8.9	8.1	9.6	9.9	10.0	10.6	10.3	9.6	9.8	8.7	9.4
ND	6.5	7.3	8.5	8.4	8.0	9.2	9.7	9.0	8.4	7.9	7.4	7.6
OH	7.0	7.8	7.8	8.1	8.8	10.3	10.4	10.1	8.9	7.3	7.3	7.1
OK	6.1	6.6	7.2	9.4	12.5	15.8	16.1	15.8	16.4	15.7	10.4	7.0
OR	8.9	8.6	9.4	9.5	9.8	9.9	9.9	9.7	9.7	9.8	9.4	10.0
PA	9.4	9.6	10.2	11.4	12.7	13.0	13.1	13.0	12.3	10.6	9.4	9.7
RI	11.5	11.6	11.6	12.7	14.8	18.8	20.5	19.8	18.9	18.2	14.7	11.2
SC	9.3	10.4	9.3	9.6	9.6	9.7	10.1	8.8	9.5	9.5	8.7	9.9
SD	7.0	8.4	9.0	7.3	7.8	8.6	9.1	8.8	8.2	7.9	6.9	7.0
TN	8.2	9.1	9.2	10.3	10.8	11.1	11.3	10.8	10.8	10.7	9.3	9.0
TX	7.1	7.3	8.4	8.9	9.2	9.2	9.1	8.9	8.6	8.6	8.0	7.9
UT	7.3	7.5	8.1	7.6	6.8	7.5	8.0	8.2	8.1	8.0	8.0	8.4
VT	9.3	11.3	10.4	8.7	8.4	8.2	8.1	7.8	8.1	8.6	8.7	8.8
VA	8.4	8.5	9.3	9.6	10.0	10.8	11.1	10.7	10.7	10.3	8.5	8.9
WA	9.1	9.0	8.8	8.7	8.9	9.0	9.2	9.3	9.2	9.0	9.3	9.3
WV	8.3	8.4	8.4	8.8	10.3	11.1	10.4	10.7	9.9	9.3	9.1	9.0
WI	7.9	8.7	12.2	10.1	11.1	8.3	8.8	7.7	7.9	6.8	7.8	8.4
WY	7.0	7.1	7.5	7.9	7.7	8.3	9.2	9.4	9.3	8.5	8.2	8.0

Table 8C.2.6 2014 Monthly Residential Natural Gas Prices by State

State	2014 Monthly Residential Natural Gas Prices *2014$/tcf*											
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
AL	13.1	13.1	13.7	15.3	18.5	20.7	21.6	21.6	21.7	20.4	14.4	13.4
AK	9.5	9.4	8.9	8.9	7.8	10.1	12.0	12.1	10.4	9.4	9.2	9.6
AZ	13.1	15.6	18.2	17.7	19.1	21.7	23.4	24.2	23.9	22.1	17.6	16.7
AR	8.9	8.6	9.0	10.6	13.3	16.0	18.2	18.8	18.9	17.4	11.7	10.4
CA	10.7	11.1	11.8	11.5	12.2	12.0	12.5	12.1	12.3	12.3	11.1	11.3
CO	7.6	7.8	8.2	9.3	10.2	12.8	15.4	15.4	13.5	10.0	8.1	7.3
CT	11.3	13.1	13.9	16.5	17.8	20.3	20.4	20.7	20.3	17.8	12.7	12.4
DE	11.9	11.8	11.9	12.8	15.6	20.5	23.0	24.0	23.5	21.2	14.9	12.1
DC	11.9	12.2	15.2	14.6	14.8	17.4	18.7	17.6	17.6	18.4	13.0	12.3
FL	16.0	15.8	17.2	18.7	20.8	22.0	24.6	25.3	24.7	23.6	20.3	17.2
GA	11.4	12.4	13.4	15.8	19.0	24.2	26.1	26.5	26.1	22.4	13.3	13.0
HI	45.7	44.7	49.2	49.3	51.0	52.4	49.3	51.4	49.6	44.8	44.9	38.7
ID	8.4	8.6	8.8	8.6	9.1	9.4	9.3	9.6	9.4	8.8	8.5	8.6
IL	7.4	8.1	11.0	13.4	14.4	17.3	18.0	18.1	15.2	9.9	7.8	8.2
IN	8.0	8.4	9.0	11.0	15.4	21.1	16.3	15.4	13.6	8.0	7.0	8.4
IA	8.5	9.9	11.0	9.6	12.2	15.4	17.0	17.8	16.0	11.3	8.8	8.4
KS	8.9	9.4	9.7	11.4	13.7	18.2	20.3	21.2	20.1	16.9	10.7	9.0
KY	8.8	8.8	9.2	11.4	16.1	20.8	23.3	22.9	22.2	15.9	10.2	9.9
LA	8.9	9.4	9.9	11.6	13.9	15.6	16.4	16.2	16.5	15.9	11.6	10.2
ME	14.9	16.3	16.4	16.2	16.5	19.4	23.1	25.7	22.8	17.5	16.3	18.3
MD	10.5	11.5	12.1	13.2	15.2	18.1	19.9	19.8	18.0	15.3	11.2	11.7
MA	13.4	13.7	14.9	15.7	14.7	14.8	16.1	16.2	15.4	13.1	14.4	14.8
MI	8.1	8.6	9.1	9.9	11.1	13.0	14.0	14.6	12.5	10.0	8.9	9.0
MN	8.3	9.4	8.1	10.0	10.0	14.6	14.5	13.3	12.7	9.9	8.8	8.2
MS	7.9	8.1	8.8	9.7	12.2	14.5	15.2	15.0	15.4	14.6	9.7	9.0
MO	8.4	8.0	8.9	11.3	15.3	21.2	24.9	25.7	24.7	19.0	12.2	8.7
MT	8.0	8.3	8.8	9.8	11.0	12.5	13.4	13.6	11.9	10.1	8.5	8.3
NE	7.5	8.2	8.9	9.6	11.3	14.3	16.5	16.7	15.7	13.2	9.6	8.6
NV	9.1	9.6	10.5	11.5	13.0	14.2	16.2	16.8	16.0	15.5	12.4	10.6
NH	14.3	15.5	16.0	16.8	17.1	16.9	20.2	21.6	20.6	16.4	15.1	16.1
NJ	9.7	9.7	11.8	9.4	11.0	12.2	12.8	13.0	12.9	11.6	9.7	8.2
NM	8.1	8.8	10.2	10.7	11.8	14.4	16.2	16.3	15.6	14.1	10.1	8.7
NY	11.2	11.5	11.7	12.5	14.6	18.0	18.5	18.8	18.0	16.0	12.3	10.7

State	2014 Monthly Residential Natural Gas Prices *2014$/tcf*											
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
NC	10.4	11.3	10.1	13.5	20.9	24.4	21.3	23.0	20.6	17.8	10.8	11.2
ND	7.0	7.7	8.9	9.5	10.7	16.6	20.1	17.0	14.2	10.4	7.9	8.0
OH	7.9	8.4	8.8	9.9	13.5	20.5	24.6	25.2	23.3	15.5	10.0	8.9
OK	7.0	7.5	8.3	11.6	16.2	21.3	24.3	26.5	26.5	23.9	12.9	8.2
OR	10.7	10.2	11.7	12.0	13.8	14.6	14.7	17.0	15.6	13.4	11.3	10.4
PA	10.4	10.5	11.0	11.9	13.8	18.4	20.1	20.3	18.3	14.8	11.5	10.8
RI	13.2	13.4	13.4	14.9	18.1	20.8	22.9	23.4	23.1	21.7	17.0	13.7
SC	10.2	12.2	11.3	14.7	20.8	25.4	27.0	24.7	25.2	18.9	10.6	11.7
SD	8.1	9.3	10.1	9.3	10.4	13.2	15.4	15.7	13.5	10.8	8.5	7.9
TN	8.4	9.2	9.7	11.7	14.3	17.7	19.0	18.3	18.7	16.3	10.2	9.3
TX	8.1	8.5	10.0	12.4	16.0	18.5	20.0	20.5	20.1	19.3	12.5	9.9
UT	8.6	9.0	10.0	9.2	8.5	10.4	11.2	11.9	11.7	11.1	9.8	9.9
VT	13.4	13.0	13.1	13.7	15.9	20.3	22.6	23.8	22.7	19.6	15.6	14.2
VA	10.3	10.6	11.8	12.8	15.7	20.0	21.4	21.0	21.3	19.0	12.1	11.3
WA	10.9	10.8	10.4	10.5	10.7	11.0	11.1	11.4	11.1	10.4	10.4	10.6
WV	9.2	9.3	9.4	10.4	12.4	15.5	17.7	18.0	14.9	11.5	10.3	9.9
WI	8.9	9.7	14.0	11.7	14.7	12.4	14.5	13.9	12.4	9.2	9.1	9.6
WY	7.9	8.0	8.6	9.3	9.9	12.5	15.6	16.8	14.8	12.1	9.4	8.8

Table 8C.2.7 2014 Monthly Commercial Natural Gas Prices by Census Division

Census Division	Division Number	2014 Monthly Commercial Natural Gas Prices *2014$/tcf*											
		Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
New England	1	11.0	12.0	12.6	13.5	12.8	12.7	12.6	12.5	12.4	11.4	11.7	12.2
Middle Atlantic	2	9.0	9.7	9.9	9.9	10.1	9.9	9.9	9.5	9.3	8.7	8.5	8.6
East North Central	3	7.2	7.9	9.5	10.0	10.7	10.8	11.1	11.1	9.7	7.9	7.4	7.8
West North Central	4	7.6	8.1	8.2	8.9	9.3	10.6	11.0	10.7	10.2	9.4	8.5	8.3
South Atlantic	5	9.6	9.9	9.9	10.5	10.9	11.3	11.5	11.1	11.0	10.7	9.6	9.9
East South Central	6	8.9	9.3	9.5	10.3	11.3	11.6	11.7	11.4	11.4	11.0	9.6	9.4
West South Central	7	7.2	7.5	8.3	8.9	9.6	9.9	9.9	9.6	9.5	9.3	8.4	7.9
Mountain	8	7.7	8.1	8.6	8.8	8.9	9.4	9.9	9.7	9.6	9.4	8.9	8.9
Pacific	9	9.7	9.9	10.7	10.0	10.0	10.0	10.2	9.9	9.8	9.7	9.5	9.9

Table 8C.2.8 2014 Monthly Residential Natural Gas Prices by Reportable Domain

Reportable Domain Number	Locations	2014 Monthly Residential Natural Gas Prices *2014$/tcf*											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	Connecticut, Maine, New Hampshire, Rhode Island, Vermont	12.8	14.1	14.5	16.1	17.4	19.7	21.3	22.3	21.3	18.2	14.5	14.3
2	Massachusetts	13.4	13.7	14.9	15.7	14.7	14.8	16.1	16.2	15.4	13.1	14.4	14.8
3	New York	11.2	11.5	11.7	12.5	14.6	18.0	18.5	18.8	18.0	16.0	12.3	10.7
4	New Jersey	9.7	9.7	11.8	9.4	11.0	12.2	12.8	13.0	12.9	11.6	9.7	8.2
5	Pennsylvania	10.4	10.5	11.0	11.9	13.8	18.4	20.1	20.3	18.3	14.8	11.5	10.8
6	Illinois	7.4	8.1	11.0	13.4	14.4	17.3	18.0	18.1	15.2	9.9	7.8	8.2
7	Indiana, Ohio	8.0	8.4	8.9	10.3	14.2	20.7	21.6	21.7	19.8	12.8	9.0	8.7
8	Michigan	8.1	8.6	9.1	9.9	11.1	13.0	14.0	14.6	12.5	10.0	8.9	9.0
9	Wisconsin	8.9	9.7	14.0	11.7	14.7	12.4	14.5	13.9	12.4	9.2	9.1	9.6
10	Iowa, Minnesota, North Dakota, South Dakota	8.3	9.4	9.2	9.8	10.8	14.9	15.7	15.2	13.9	10.5	8.7	8.2
11	Kansas, Nebraska	8.3	8.9	9.4	10.7	12.7	16.7	18.8	19.4	18.3	15.4	10.3	8.9
12	Missouri	8.4	8.0	8.9	11.3	15.3	21.2	24.9	25.7	24.7	19.0	12.2	8.7
13	Virginia	10.3	10.6	11.8	12.8	15.7	20.0	21.4	21.0	21.3	19.0	12.1	11.3
14	Delaware, Maryland, West Virginia	10.4	11.1	11.5	12.6	14.6	17.8	19.8	19.9	17.9	15.1	11.4	11.3
15	Georgia	11.4	12.4	13.4	15.8	19.0	24.2	26.1	26.5	26.1	22.4	13.3	13.0
16	North Carolina, South Carolina	10.3	11.6	10.5	13.9	20.9	24.7	23.2	23.6	22.1	18.1	10.7	11.3
17	Florida	16.0	15.8	17.2	18.7	20.8	22.0	24.6	25.3	24.7	23.6	20.3	17.2
18	Alabama, Kentucky, Mississippi	10.3	10.3	10.9	12.5	16.1	19.2	20.7	20.5	20.3	17.4	11.7	11.1
19	Tennesse	8.4	9.2	9.7	11.7	14.3	17.7	19.0	18.3	18.7	16.3	10.2	9.3
20	Arkansas, Louisiana, Oklahoma	8.3	8.6	9.1	11.3	14.5	17.6	19.5	20.3	20.5	19.0	12.0	9.5
21	Texas	8.1	8.5	10.0	12.4	16.0	18.5	20.0	20.5	20.1	19.3	12.5	9.9
22	Colorado	7.6	7.8	8.2	9.3	10.2	12.8	15.4	15.4	13.5	10.0	8.1	7.3
23	Idaho, Montana, Utah, Wyoming	8.4	8.7	9.4	9.1	9.2	10.7	11.5	12.0	11.4	10.4	9.2	9.2
24	Arizona	13.1	15.6	18.2	17.7	19.1	21.7	23.4	24.2	23.9	22.1	17.6	16.7
25	Nevada, New Mexico	8.7	9.2	10.4	11.2	12.4	14.3	16.2	16.5	15.8	14.9	11.4	9.8
26	California	10.7	11.1	11.8	11.5	12.2	12.0	12.5	12.1	12.3	12.3	11.1	11.3
27	Alaska, Hawaii, Oregon, Washington	14.5	14.2	14.9	15.0	15.8	16.5	16.4	17.4	16.6	14.9	14.3	13.5

Table 8C.2.9 Marginal Price Factors for Natural Gas and Electricity (at the Reportable Domain Scale)

Marginal Price Factors	Natural Gas	Natural Gas	Electricity	Electricity
REPORTABLE_DOMAIN	Non-Winter	Winter	Non-Winter	Winter
1	0.82	0.91	0.95	1.00
2	0.89	1.03	0.96	1.04
3	0.75	0.89	1.13	0.87
4	0.84	0.95	1.21	0.98
5	0.73	0.93	1.08	0.83
6	0.68	0.97	0.98	0.72
7	0.73	0.92	1.00	0.75
8	0.78	0.93	1.14	0.97
9	0.79	0.98	1.01	0.89
10	0.72	0.97	1.07	0.84
11	0.69	0.93	1.16	0.74
12	0.60	0.82	1.21	0.76
13	0.68	0.93	1.08	0.85
14	0.72	0.93	1.11	0.89
15	0.56	0.87	1.16	0.84
16	0.66	0.89	0.97	0.83
17	0.64	0.82	1.01	0.93
18	0.75	0.87	1.00	0.82
19	0.74	0.94	0.93	0.84
20	0.65	0.84	1.04	0.74
21	0.59	0.85	1.05	0.90
22	0.69	0.91	1.08	0.79
23	0.84	0.96	1.11	0.94
24	0.64	0.85	1.05	0.84
25	0.72	0.89	1.04	0.88
26	0.85	1.08	1.21	1.13
27	0.83	0.94	0.94	0.94

Table 8C.2.10 Marginal Price Factors for Natural Gas and Electricity (for Census Division Scale)

Marginal Price Factors	Natural Gas	Natural Gas	Electricity	Electricity
CENSUS_DIVISION	Non-Winter	Winter	Non-Winter	Winter
1	1.04	0.99	1.14	0.88
2	1.02	0.98	1.44	0.86
3	0.82	0.97	1.10	0.73
4	0.85	0.97	1.57	0.66
5	0.93	0.96	1.09	0.89
6	0.93	0.95	1.03	0.76
7	0.78	0.91	1.16	0.72
8	0.90	0.96	1.14	1.07
9	0.96	1.17	1.57	0.85

8C.3 ENERGY PRICE TRENDS

8C.3.1 Commercial Energy Price Trends

DOE applies the same methodology to project energy prices for each of the nine census divisions. To arrive at prices in future years, DOE multiplies the prices described in the preceding section by the forecast of annual average price changes in EIA's *Annual Energy Outlook 2015 with Projections to 2040* (*AEO 2015*).[3] Figure 8C.3.1 and Figure 8C.3.2 show the commercial electricity and natural gas price trends. To estimate the trend after 2040, DOE follows past guidelines provided to the Federal Energy Management Program (FEMP) by EIA and uses the average rate of change during 2030–2040 for electricity and natural gas.

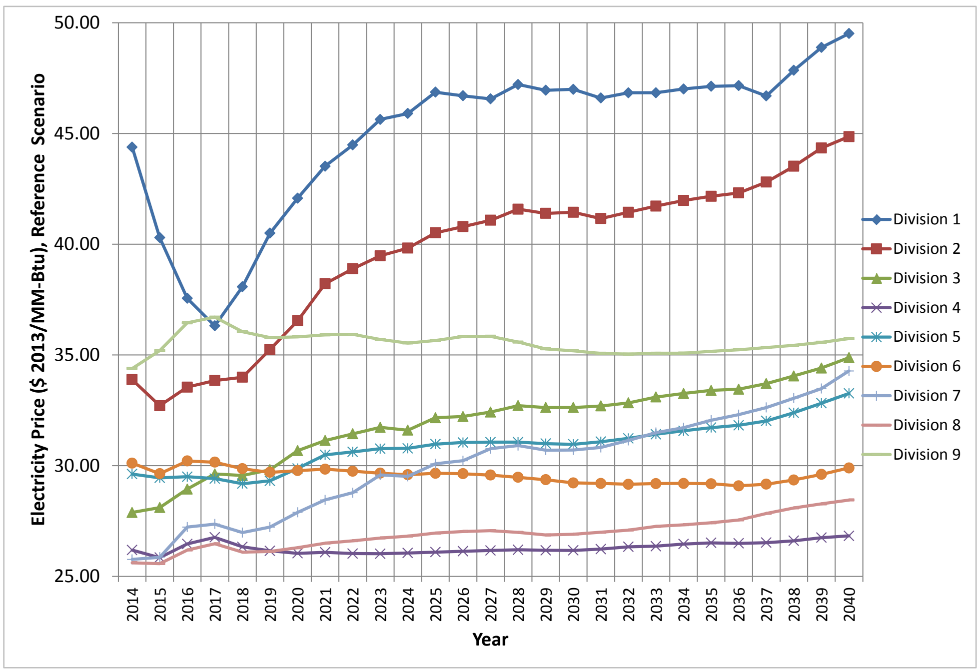

Figure 8C.3.1 Projected Commercial Electricity Prices (based on Census Divisions)

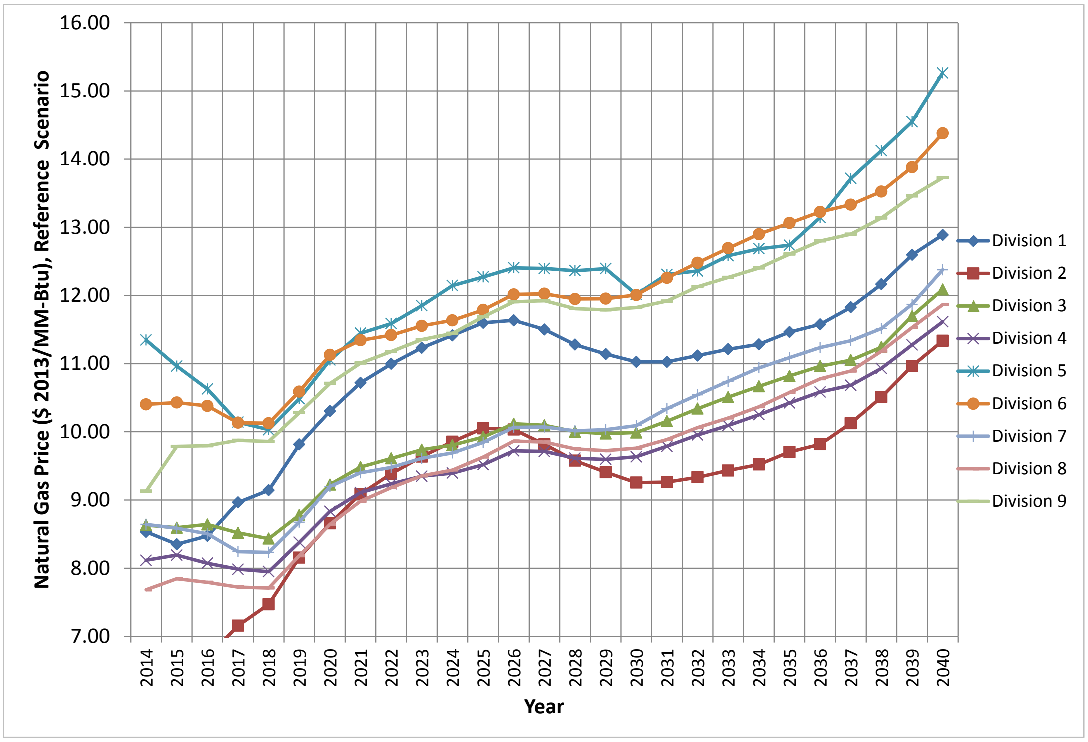

Figure 8C.3.2 Projected Commercial Natural Gas Prices (based on Census Divisions)

8C.3.2 Residential Energy Price Trends

DOE applies the projected energy price for each of the census division to each household in the sample based on the household's location.To arrive at prices in future years, DOE multiplies the prices described in the preceding section by the forecast of annual average price changes in EIA's *AEO2015*. Figure 8C.3.3 and Figure 8C.3.4 show the residential electricity and natural gas price trends. To estimate the trend after 2040, DOE follows past guidelines provided to the Federal Energy Management Program (FEMP) by EIA and uses the average rate of change during 2030–2040 for electricity and natural gas.

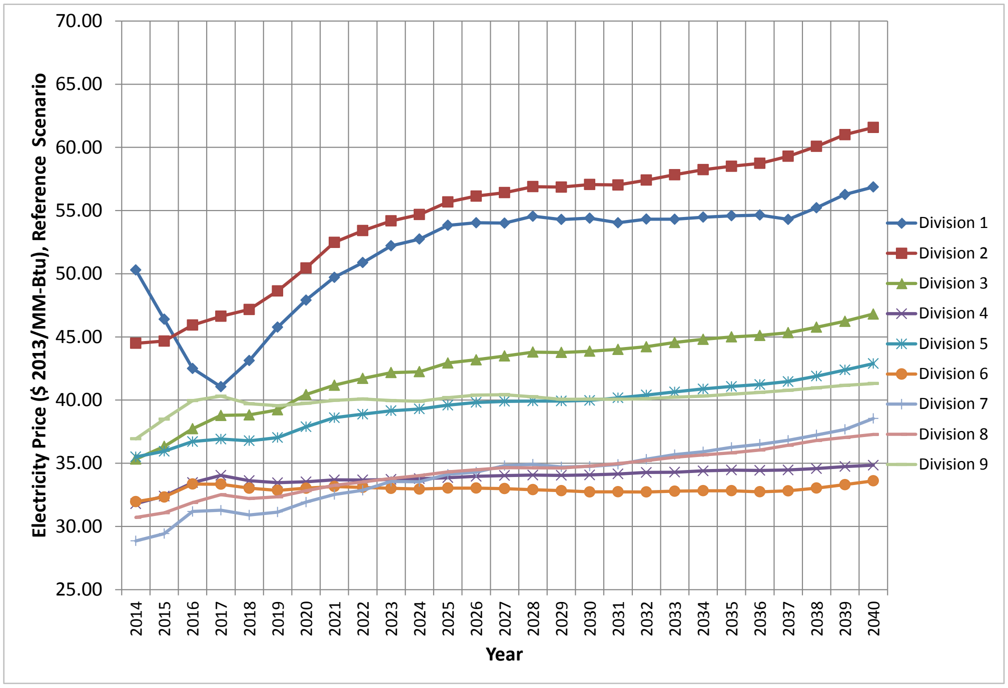

Figure 8C.3.3 Projected Residential Electricity Prices (based on Census Divisions)

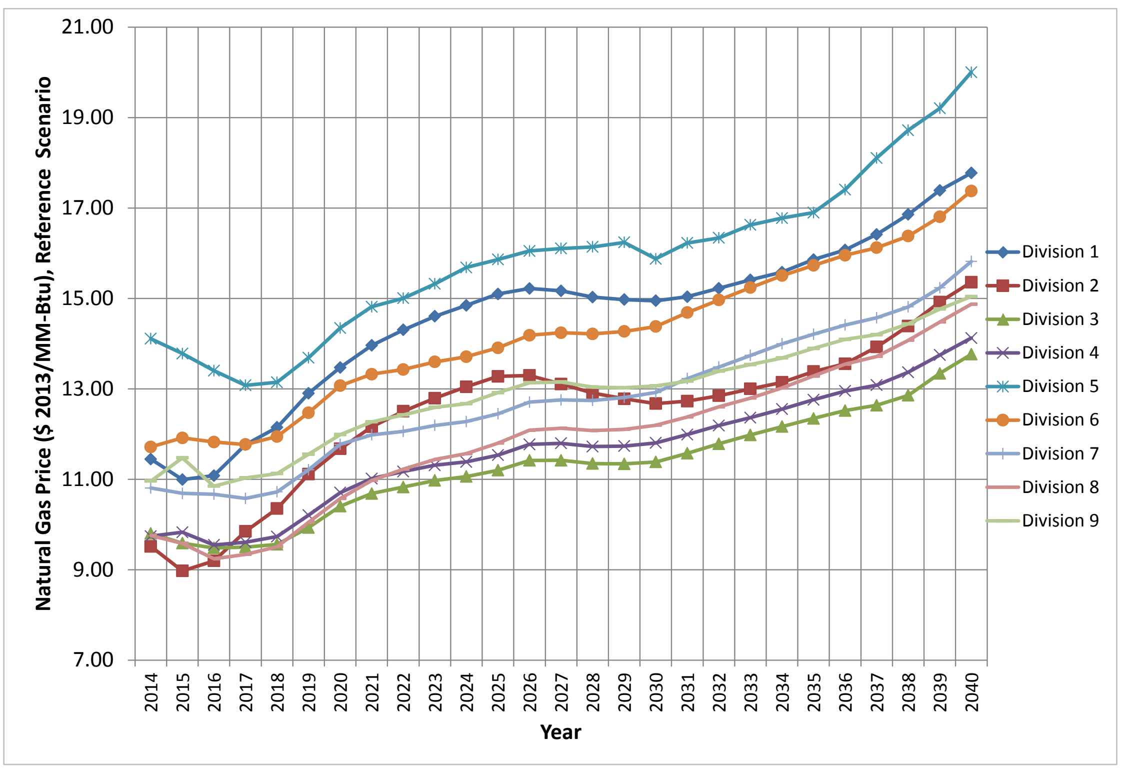

Figure 8C.3.4 Projected Residential Natural Gas Prices (based on Census Divisions)

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APPENDIX 8D. INSTALLATION COST DETERMINATION

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APPENDIX 8D. INSTALLATION COST DETERMINATION

8D.1 INTRODUCTION

This appendix contains the installation cost calculation methodology for commercial water heating (CWH) equipment, which includes the following: commercial gas-fired storage water heaters, residential duty gas-fired storage water heaters, commercial gas-fired tankless water heaters, commercial gas-fired hot water supply boilers, and commercial electric storage water heaters.

To the extent possible, the raw data found in the research were reduced to mathematical expressions to more readily implement the data within the analysis. Mathematical expressions were found using the "TrendLine" curve fitting regression routine analysis in Microsoft Excel. In cases where it was suspected that TrendLine did not provide an adequate representation of the data, the data also were analyzed using regression routines included in Minitab 16. The TrendLine regressions were found to be equally as representative of the data as the more complex regression routines. Therefore, the simple regression equations from TrendLine were used for the analysis.

The labor costs shown in the tables in this appendix are the national average values. In its analysis, the U.S. Department of Energy (DOE) used regional labor costs to more accurately estimate installation costs by region. DOE then applied the appropriate regional labor cost to each sample installation.

8D.2 DEFINITION OF CREW

DOE used the definitions of crew provided in the RS Means data books,[1,2,3,4,5,6] for this analysis. In instances where other reference sources were utilized, the labor descriptions were compared to the closest labor crew found in RS Means. RS Means uses the term "crew" to refer to the classification of labor, regardless of the number or skill of laborers. The crew is related to the cost of labor per hour inclusive of overhead and profit, where this cost is presented in dollars equated to the national average. The costs per hour are different between residential and commercial crews, so the context of the analysis is used to differentiate which labor rate is used as shown in Table 8D.2.1; CWH equipment installations in a residential buildings use residential "crews" and commercial building installations use commercial "crews."

Table 8D.2.1 Crew Definitions

Crew Definitions from RS Means for Classifying Labor Costs	Crew Description	Number of Laborers within the Specified Crew	Cost/ Labor Hour (Including O&P)
Residential Crews			
1 Plumb	1 Plumber	1	$60.66
Q1	1 Plumber, 1 Plumber Apprentice	2	$54.61
Q2	1 Plumber, 2 Plumber Apprentice	3	$52.58
Q9	1 Sheet Metal Worker, 1 Sheet Metal Worker Apprentice	2	$65.34
Commercial Crews			
1 Plumb	1 Plumber	1	$84.03
Q1	1 Plumber, 1 Plumber Apprentice	2	$64.23
Q2	1 Plumber, 2 Plumber Apprentice	3	$61.85
Q9	1 Sheet Metal Worker, 1 Sheet Metal Worker Apprentice	2	$76.95
R-31	1 Electrician 1 Core Drill, Electric, 2.5 H.P.	2	$89.53

8D.3 BASIC INSTALLATION COSTS

DOE developed installation cost data for gas-fired storage water heaters using RS Means books, ENR,[7] Whitestone Research,[8] and DOE technical support documents. The analysis of the available data consisted of comparing the information available from each source and creating a linear regression to adequately estimate the amount of labor required to install each type of product. Figure 8D.3.1 provides a representative sample of the comparison of data sources.

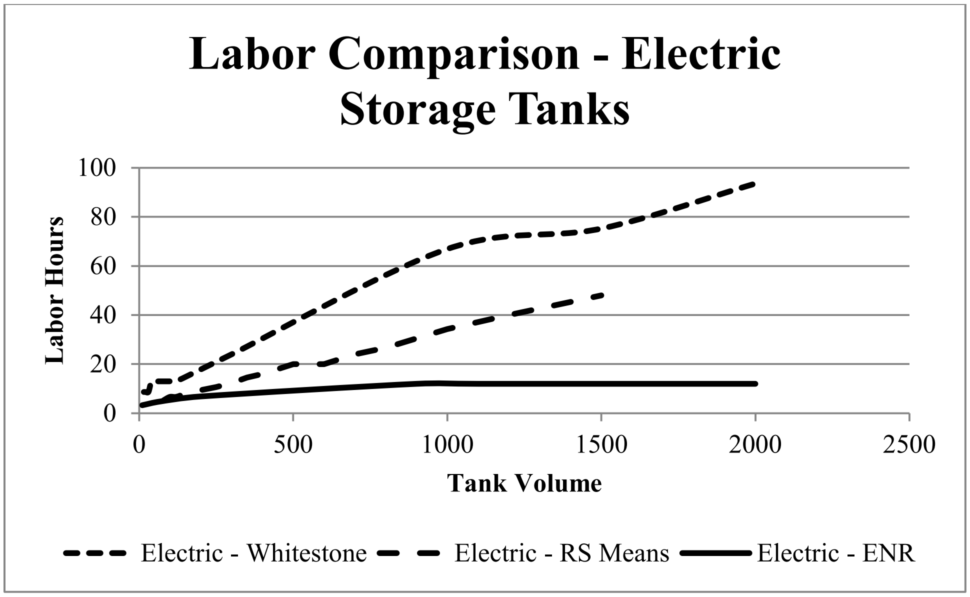

Figure 8D.3.1 Example of Labor Hour Differences Resulting from Different Data Sources

The number of labor hours required to install each of the product sub-categories is presented in Table 8D.3.1 and Table 8D.3.2. Table 8D.3.1 presents the equations developed from the linear regression of the comparison of the available data. Table 8D.3.2 presents the labor hours determined from the noted equations for each of the representative models used in the life-cycle cost (LCC) analysis.

Table 8D.3.1 Assumptions and Equations for CWH Product Classes in Determining Labor Hours

Product Class	RS Means Crew*	Conditional Expressions	Labor Hours Required to Install a Product**
Commercial Gas-Fired Storage Water Heater (CGSWH)	Q1	Minimum of 3 Hours	Labor = (4.7394 × LN(M Btu/h))-18.8447
Residential-Duty Gas-Fired Storage Water Heater (RDGSW)	1 Plumb		Labor = 2.9428+(0.0315 × Volume)
Commercial Gas-Fired Instantaneous Tankless Water Heater (CGITWH)	1 Plumb		Labor = 4 hours†
Commercial Gas-Fired Instantaneous Hot Water Supply Boiler (CGIHWSB)	Q2		Labor = (2.3512 × LN(M Btu/h))-6.6255
Commercial Electric Storage Water Heater (CESWH)	Q1		Labor = 3.4282+(0.03 × Volume)

* See Table 8D.2.1 for the definition of each crew.
** Note that M Btu/h equals 1,000 Btu/h.
† Due to limited data availability, the amount of labor required to install a commercial gas-fired tankless water heater was assumed to be 4 hours.

Table 8D.3.2 Installation Labor Hours for Representative CWH Models

Product Subcategory	Crew*	Description	Labor Hours
Commercial Gas-Fired Storage Water Heater (CGSWH)	Q1	199 M Btu/h – 100 gallon	4.855
Residential-Duty Gas-fired Storage Water Heater (RDGSW)	1 Plumb	76 M Btu/h – 75 gallon	5.305
Commercial Gas-Fired Instantaneous Tankless Water Heater (CGITWH)	1 Plumb	250 M Btu/h	4.000
Commercial Gas-Fired Instantaneous Hot Water Supply Boiler (CGIHWSB)	Q2	399 M Btu/h	7.456
Commercial Electric Storage Water Heater (CESWH)	Q1	18 kW – 120 gallon	7.028

* See Table 8D.2.1 for the definition of each crew.

8D.4 LABOR TO REMOVE EQUIPMENT

For replacement equipment, a nontrivial cost is required to remove the previously failed equipment prior to installing another piece of equipment to provide hot water service. Available national resources were reviewed in order to better understand and quantify this relationship. Due to limited data availability and the format of the available data, DOE established this relationship based upon data for commercial electric storage water heaters and the demolition of generic storage tanks, both found in RS Means data sources. The available data were subjected to the Trendline curve fitting regression routine within Microsoft Excel.

While DOE initially expected that the amount of labor would be either a constant percentage based upon the installation cost, as noted by Rheem,[9] a linear relationship was recognized as possible based upon a percent of the installation cost related to the volume of the tank in question. That is to say, DOE considered it possible that larger storage tanks may require a smaller percentage of time to remove the product as compared to the amount of labor time required to install the product.

As an example of removal and installation labor, Figure 8D.4.1 shows, using RS Means data, a comparison of labor hours for removal and installation of a generic storage tank as a function of storage tank volume. It is noted that the raw data to demolish a generic storage tank exhibited a point of inflection at 550 gallons. A more accurate curve fit was obtained by modeling the labor hours for storage tanks with volumes less than 550 gallons as a linear relationship, while labor hours to remove storage tanks equal to or greater than 500 gallons were accurately modeled using a natural log relationship.

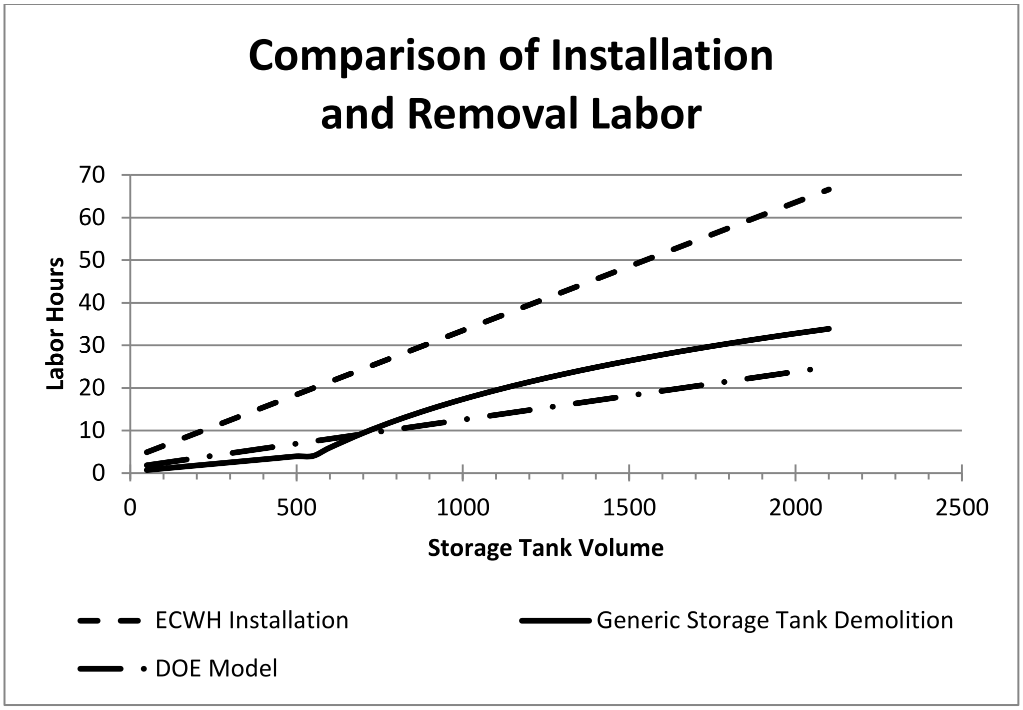

Figure 8D.4.1 Comparison Labor Hours for the Removal and Installation of a Generic CWH Tank

Analysis and comparison of the RS Means data identified that a counter-intuitive trend occurs. The labor to remove a storage tank that is smaller than approximately 250 gallons was found to require approximately 20 percent (19.7 percent) of the labor hours required to complete the installation. However, the labor to install a tank increased with the storage volume until it reached approximately 55 percent (54.2 percent) of installation labor at a volume of 1,200 gallons. This relationship also was observed to be non-linear in nature, significantly complicating the analysis.

DOE therefore estimated the amount of labor required to remove a commercial water heater based upon the average percentage of the calculated amounts of labor to install and remove water heaters with respect to the storage volume. This average was found to be 37.5 percent. Therefore, the following equation will be used to determine the amount of labor required to remove a water heater at the end of service condition:

$$Labor_{Removal} = 37.5\% \times Labor_{Installation}$$

Eq. 8D.1

Available data were not identified for the removal of commercial gas-fired tankless water heaters. The primary difference between installing an instantaneous (tankless) water heater and installing a storage tank water heater is the transportation of the product and management of the larger mass of the storage tank products during transit and installation. Because the installation and removal of these products are somewhat different from storage tank equipment, this product subcategory was modeled as requiring 2 hours or 50 percent fewer labor hours than required to install the equipment.

8D.5 VENTING COSTS

DOE researched the requirements of venting products in the sub-categories considered in this analysis. Research sources include the National Fuel Gas Code (NFGC),[10] equipment manufacturer's websites,[11,12,13] and venting manufacturer's websites including DuraVent,[14] NovaFlex,[15] and Tjernlund.[16] This research identified that the primary factors indicating the cost of venting are the category of venting (efficiency level of the CWH equipment and vent pressure), the vent diameter (input rating of the CWH equipment), and vent length (installation dependent). Each of these considerations is discussed in the following sections with additional information presented to describe how DOE integrated these data into the LCC modeling.

8D.6 VENTING CATEGORIES

NFGC classifies venting systems used in all gas-fired appliances into one of four different categories as identified in the first three columns of Table 8D.6.1. The fourth column in Table 8D.6.1 identifies the commercially recognized materials used to construct the venting systems of each category.

Although the NFGC does not specifically describe categories II and IV as venting systems used for condensing products,[a] DOE interprets Category II and Category IV venting as venting systems used for condensing equipment or for equipment where condensation will occur in the venting system.

Table 8D.6.1 National Fuel Gas Code (NFGC) Venting Categories Applied to CWH Analysis

Venting Category	Vent Pressure*	Appliance Gas Vent Temperature	Common Vent Materials**
I	Non-Positive	Avoids Excessive Condensation in the Vent	Aluminum, Galvanized, B-Vent
II	Non-Positive	Can Cause Excessive Condensation in the Vent	Plastic / AL29-4C
III	Positive	Avoids Excessive Condensation in the Vent	304/316 SS
IV	Positive	Can Cause Excessive Condensation in the Vent	Plastic / AL29-4C

* Vent pressure is referenced relative to atmospheric pressure.
** Plastic venting materials include polyvinyl chloride (PVC), chlorinated polyvinyl chloride (CPVC), and polypropylene (PP).

[a] The NFGC includes a phrase in the definition of Category II and IV venting stating appliance vent temperatures can cause excessive condensation production in the vent, but does not state that the venting is for condensing appliances, or appliances that will experience condensation in the venting system.

DOE understands that the metallic materials used in the condensing category venting systems may be used in any of the non-condensing category venting systems, but recognizes the financial cost differences between these materials prevents this as a general practice. However, the materials used in the non-condensing category venting systems are not suitable for the condensing category applications due to material properties. The plastics listed in the table (which include CPVC, PVC, and polypropylene[b]) are only suitable in condensing applications due to the lower vent temperatures experienced during operation of condensing equipment.

8D.7 VENTING TYPES AND DRAFTS

DOE's investigation verified that, as per the order identified in ANSI Z223.1-86(2015) section 12.4.1 and 12.4.2, the selection of venting[c] is based initially upon the type of draft: natural draft or mechanical draft. In this context, natural draft venting refers to venting or a venting system where the temperature of the flue gas and the vertical height of the vent are the primary mechanisms that allow the flue products to rise up through the vent. For this reason, with natural draft equipment, the pressure inside the venting system is non-positive, the vent is a larger diameter, and the vent has only minimal tolerance for horizontal vent configurations. Hence, DOE did not model any horizontal venting or venting systems for natural draft equipment.

Mechanical draft venting refers to equipment relying upon a mechanical source (blower or inducer) to expel flue gases. This equipment operates at pressures above atmospheric; requiring positive pressure and sealed venting or vent systems. These venting systems are smaller in diameter and can tolerate longer pipe-run distances, including horizontal venting.

DOE observed that the diameter of the venting was a primary factor in determining the cost of the venting system (*i.e.*, the larger the diameter, the higher the cost). The NFGC includes a series of tables to establish the maximum and minimum input for venting combustion flue gas based upon a combination of vent diameter and vent length. For this analysis, DOE referenced the noted NFGC tables and the information provided in the manufacturer's literature to determine the appropriate diameter of venting for the type of draft used in the equipment.[d] For the representative models in each subcategory, the DOE used the vent diameters shown in Table 8D.7.1.

[b] Polypropylene is abbreviated as "PP" when discussing venting materials.
[c] DOE recognizes that the terms "venting" and "venting system" are often used interchangeably. DOE uses the term "venting" to refer to the venting used for one piece of equipment and "venting system" to refer to the venting required to exhaust flue gas from more than one piece of equipment.
[d] DOE recognizes that a physical relationship exists between the diameter and length of venting. For this analysis, DOE chose a statistical distribution of vent lengths within the range of vent lengths obtained from manufacturer's literature using the as-shipped vent diameter.

Table 8D.7.1 National Fuel Gas Code (NFGC) Vent Size by Equipment Subcategory for Determining Vent System Costs

Equipment Subcategory	Input Capacity *kBtu/hr*	Vent Diameter *inch*	
		Natural Draft	Mechanical Draft
Commercial Gas-Fired Storage Water Heater (CGSWH)	199	5	3
Residential-Duty Gas-Fired Storage Water Heater (RDGSWH)	76	4	3
Commercial Gas-Fired Instantaneous Tankless Water Heater (CGITWH)	250	5	3
Commercial Gas-Fired Instantaneous Hot Water Supply Boiler (CGIHWSB)	399	7	4

Power vent CWH equipment is defined as incorporating a blower as part of the CWH equipment. Due to the location of the blower, power vent systems have a positive vent pressure and are therefore only Category III or IV.

Direct vent equipment is defined as CWH equipment that uses air from outside of the building for combustion. This outdoor air is directed through the building using intake venting. The combustion flue gases exiting CWH equipment travels through the appropriate venting depending upon the input and category of the CWH equipment. DOE observed that any material may be utilized for the intake air portion of direct venting; however, the diameter of the vent must remain constant through both the intake and exhaust vent. Direct vent equipment can be any category of venting system.

The venting cost model used in the LCC analysis recognizes that direct vent installations for CWH equipment exist, but that direct venting primarily provides benefit other than directly relating to the efficiency of the CWH equipment. These benefits, which include prevention of room depressurization and safety, are not required for the efficient operation of CWH equipment and are therefore not monetized in DOE's analysis. For this reason, the direct vent fraction included here represents the small fraction of direct vent installations that require direct venting to ensure the average lifetime of equipment is maintained, and hence the integrity of the LCC model. DOE notes that several manufacturers include statements in their literature identifying that equipment life is compromised by allowing corrosive chemicals to enter the combustion system.[11,12,13]

8D.8 VENT LENGTHS

As noted previously, DOE investigated literature available from manufacturer's websites (Bradford White, A.O. Smith, and Rheem) and the NFGC to determine the length of venting to use in the analysis. In order to more accurately represent the national average, DOE used a statistical distribution of vent lengths to meet the various building characteristics found in the Energy Information Administration's (EIA's) 2003 Commercial Building Energy Consumption

Survey (CBECS 2003) and EIA's 2009 Residential Energy Consumption Survey (RECS 2009) data. During the investigation, DOE observed the usage of different terminology to describe the maximum allowable vent length for products. As no common reference to vent lengths exists, DOE applied the term "total equivalent vent length" to reference the maximum pneumatic pressure drop allowable for the CWH equipment to vent at the manufacturer's identified vent diameter.[e] This terminology simplifies the understanding and discussion of the various venting types including direct vent, for which the total equivalent vent length includes the intake vent length and exhaust vent length. Subsequently, as this term references the pneumatic pressure drop, DOE acknowledges the different amounts of pressure drop resulting from the usage of different diameter fittings and elbows. However, installation concerns for the CBECS and RECS data relate to linear distance. Therefore, the vent length distributions used in the Monte Carlo analysis, as shown in Table 8D.8.1, represent linear feet and are somewhat less than the maximum allowable vent lengths identified in the manufacturer's literature.

Table 8D.8.1 Vent Length Distributions Used in the Monte Carlo Analysis

Building Type	Distribution	Minimum Vent Length *linear ft*	Average Vent Length *linear ft*	Maximum Vent Length *linear ft*
Large Building	Triangular	8	42	75
Small Building	Triangular	4	21	40

8D.9 INTEGRATION OF VENTING LOGIC IN LIFE-CYCLE COST

Due to the complicated integration of the findings of the venting research with the CBECS and RECS data in the LCC model, Visual Basic (VB) routines were utilized to simplify the equations in Microsoft Excel. The logic included in the analysis accounts for the different probabilities of venting configurations and installation costs relating to retrofit of existing installations as well as installation of new equipment in new buildings. For example, probabilities were applied to identify a percentage of non-condensing equipment that utilize a chimney for venting. Additional logic was then used to determine if non-condensing replacement equipment would utilize the chimney to vent the replacement equipment, or new venting would be installed. If the replacement equipment utilized the existing chimney, subsequent logic functions were implemented to identify if the chimney required relining as part of the installation of the replacement equipment. These VB routines are included in the LCC model and may be accessed for review. The logic flow used in the primary program is shown in Figure 8D.9.1 for retrofit installations and Figure 8D.9.2 for new installations.

[e] By specifying this term as pneumatic pressure drop, DOE intends to prevent the confusion resulting from the common usage of the term "feet," which is a measure of head or pressure loss within a pipe (vent).

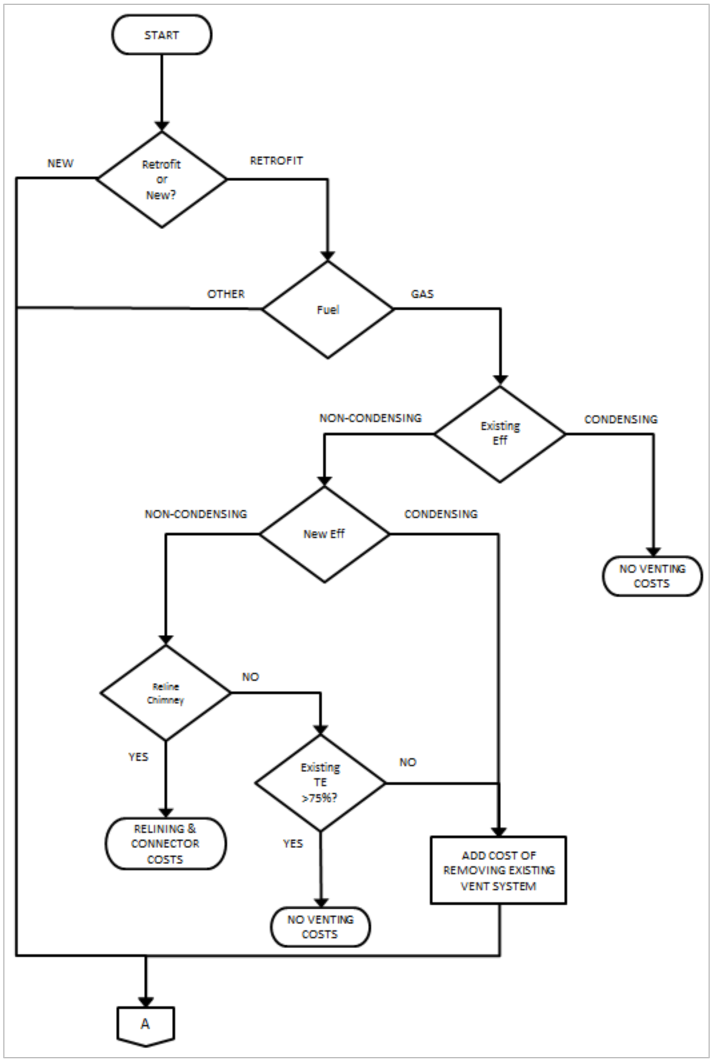

Figure 8D.9.1 Venting Logic Process Used for Retrofit Installations in the Life-Cycle Analysis

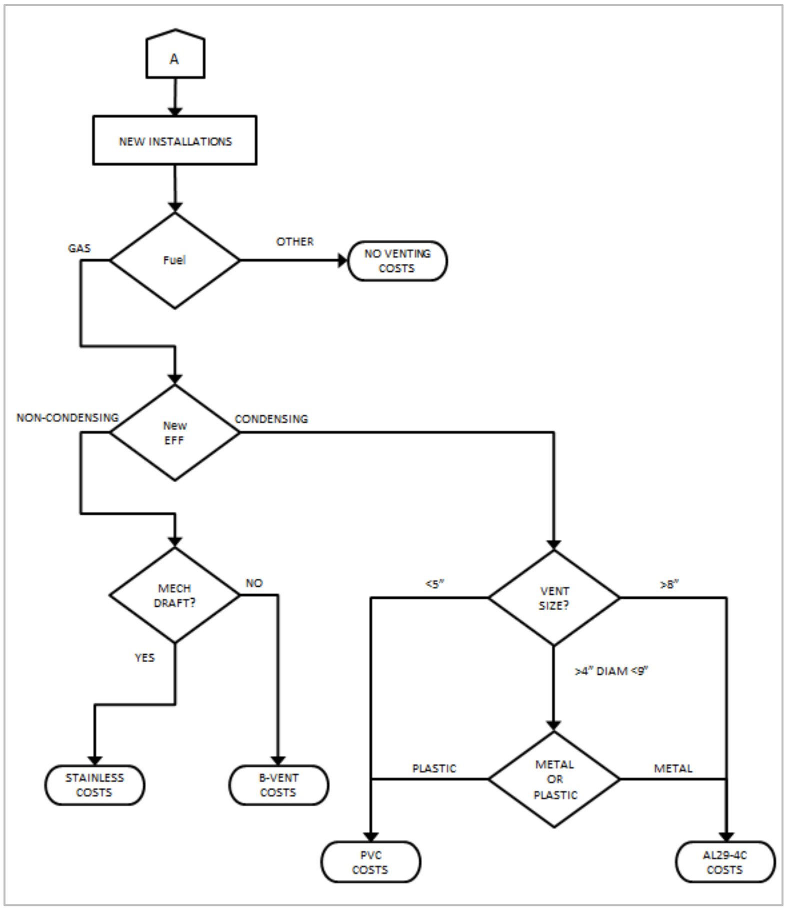

Figure 8D.9.2 Venting Logic Process Used for New Installations in the Life-Cycle Analysis

The major assumptions made in the logic flow are as follows:

- 25 percent of commercial buildings built prior to 1980 were assumed to have a masonry chimney, and 25 percent of masonry chimneys required relining.
- Condensing products with vent diameters smaller than 5 inches were modeled using PVC as the vent material.
- Condensing products with vent diameters larger than 8 inches were modeled using AL29-4C as the vent material.
- Condensing products with vent diameters of 5 inches and up to and including 8 inches were modeled using a random selection process where on average 50 percent of installations use PVC as the vent material and the remaining use AL29-4C.
- 5 percent of all condensing water heater installations with vent lengths less than 31.5 feet were modeled as direct vent installations.
- The intake air pipe material for all equipment was modeled similar to the condensing vent material with intake air pipes 4 inches in diameter and smaller made of plastic. Intake air pipe sizes between 4 inches and 8 inches in diameter have a 50 percent probability of plastic construction, with the remainder of those intake air pipes constructed of 300 series stainless steel material, and intake air pipes larger than 8 inches are constructed of 300 series SS venting.

8D.10 COST OF VENTING COMPONENTS

The costs of individual components within the venting system were obtained from the RS Means data books. In addition, the following sources were used to verify this information and provide data on components in size ranges not addressed by RS Means: SupplyHouse.com,[17] Fleetfarm.com,[18] Houseneeds.com,[19] VentingPipe.com,[20] and Cinnabar Equipment Company.[21]

The following tables (Table 8D.10.1 through Table 8D.10.20) provide the material costs of specific components used in the "Cost Database" worksheet within the LCC workbook. The tables include a reference to indicate when an interpolation was used to better estimate the cost and labor requirement of a component.

Table 8D.10.1 Costs of Miscellaneous Components in Condensing Applications

Source	Section or Part Number	Page Number	Equipment	Crew*	Labor Hours**	Unit of Cost	Material Cost
RS Means 2015 Mech	2321 29.10 0120	304	Condensate Pump with 1 Gal. ABS tank, 115V,1/50th HP	Q9	0.667	each	$197.00
RS Means 2015 Plum	2211 13.74 7400	216	Condensate drain line (PEX) ¾ × 100 ft	Q9	0.035/ft	Linear Feet	$19.80 ($1.32 × 15 ft)
SupplyHouse.com†	101867-01		Condensate Neutralizer	Q9	0.780	each	$56.95
FleetFarm.com†	00000000 44790		Heat Tape	Q9	0.062/ft	Linear Feet	$59.85 ($3.99/ft × 15 ft)
RS Means 2015 Mech	2605 90.10 4010	428	Duplex outlet, 15 amp recpt, 1-gang box, plate‡	1 Elec	0.55	each	$10.80

* Crew is defined in Table 8D.2.1.
** Labor hours are presented relative the amount of time required to install either the equipment identified (when the unit of cost is each) or per unit of cost when the unit of cost is linear feet (LF).
† Material cost taken from identified source, while the crew and labor information is taken from RS Means data.
‡ Electrical outlet applied only to EL0 and EL1 residential duty gas-fired storage water heaters.

8D.10.1 Costs & Labor of Plastic Venting Components

Table 8D.10.2 CPVC Socket Jointed 10-ft Pipe Including Clevis Hanger Assemblies, 3 per 10 ft

RS Means Book	RS Means Section Number	Page Number	Diameter *inch*	Crew*	Labor Hours**	Unit of Cost†	Material Cost
2015 Mech	2211 13.74 5309	204	2.0	Q1	0.271	LF	$12.85
2015 Mech	2212 13.74 5310	204	2.5	Q1	0.286	LF	$19.90
2015 Mech	2213 13.74 5311	204	3.0	Q1	0.302	LF	$23.50
2015 Mech	2214 13.74 5312	204	4.0	Q1	0.333	LF	$31.50
interpolated			5.0	Q1	0.353	LF	$44.50
2015 Mech	2211 13.74 5314	204	6.0	Q1	0.372	LF	$57.50
interpolated			7.0	Q1	0.399	LF	$67.70
interpolated			8.0	Q1	0.427	LF	$77.91
interpolated			10.0	Q1	0.477	LF	$99.62
interpolated			16.0	Q1	0.629	LF	$164.77
interpolated			20.0	Q1	0.730	LF	$208.20
interpolated			22.0	Q1	0.781	LF	$229.91
interpolated			24.0	Q1	0.831	LF	$251.63

* Crew is defined in Table 8D.2.1.
** Labor hours are presented in decimal places of hours where 1.0 = 1 hour.
† LF = linear feet

Table 8D.10.3 PVC, Schedule 40, Socket Joints 90° Elbow

RS Means Book	RS Means Section Number	Page Number	Diameter *inch*	Crew*	Labor Hours**	Unit of Cost†	Material Cost
2015 Mech	2211 13.76 2810	209	2.0	Q1	0.440	ea	$2.89
2015 Mech	2212 13.76 2820	209	2.5	Q1	0.599	ea	$8.80
2015 Mech	2213 13.76 2830	209	3.0	Q1	0.699	ea	$10.50
2015 Mech	2214 13.76 2840	209	4.0	Q1	0.879	ea	$18.80
interpolated			5.0	Q1	1.160	ea	$39.40
2015 Mech	2211 13.76 2860	209	6.0	Q1	1.441	ea	$60.00
interpolated			7.0	Q1	1.886	ea	$107.00
2015 Mech	2211 13.76 2870	209	8.0	Q1	2.330	ea	$154.00
interpolated			10.0	Q1	2.804	ea	$180.02
interpolated			16.0	Q1	4.618	ea	$323.52
interpolated			20.0	Q1	5.828	ea	$419.19
interpolated			22.0	Q1	6.433	ea	$467.03
interpolated			24.0	Q1	7.037	ea	$514.86

* Crew is defined in Table 8D.2.1.
** Labor hours are presented in decimal places of hours where 1.0 = 1 hour.
† LF = linear feet, ea = each.

Table 8D.10.4 PVC 10-ft Pipe with Clevis Hanger Assemblies, 3 per 10 ft

RS Means Book	RS Means Section Number	Page Number	Diameter *inch*	Crew*	Labor Hours**	Unit of Cost†	Material Cost
2015 Mech	2209 13.74 1930	201	3.0	Q1	0.302	LF	$12.60
2015 Mech	2210 13.74 1940	201	4.0	Q1	0.333	LF	$16.10
interpolated			5.0	Q1	0.372	LF	$21.80
2015 Mech	2211 13.74 1960	201	6.0	Q1	0.410	LF	$27.50
interpolated			7.0	Q2	0.455	LF	$32.00
2015 Mech	2211 13.74 1970	201	8.0	Q2	0.500	LF	$36.50
2015 Mech	2211 13.74 1980	201	10.0	Q2	0.558	LF	$75.00
2015 Mech	2211 13.74 2010	201	16.0	Q2	1.043	LF	$205.00
interpolated			20.0	Q2	1.200	LF	$242.16
interpolated			22.0	Q2	1.310	LF	$271.76
interpolated			24.0	Q2	1.421	LF	$301.35

* Crew is defined in Table 8D.2.1.
** Labor hours are presented in decimal places of hours where 1.0 = 1 hour.
† LF = linear feet

Table 8D.10.5 Hole Drilling to 10-ft-High, Concrete Wall, 8 inches thick

RS Means Book	RS Means Section Number	Page Number	Diameter *inch*	Crew*	Labor Hours**	Unit of Cost†	Material Cost
2015 Mech	2605 33.95 0160	424	2.0	R-31	1.818	ea	$0.55
2015 Mech	2605 33.95 0170	424	2.5	R-31	1.818	ea	$0.55
2015 Mech	2605 33.95 0180	424	3.0	R-31	1.818	ea	$0.55
2015 Mech	2605 33.95 0200	424	4.0	R-31	2.424	ea	$0.66
interpolated			5.0	R-31	3.030	ea	$0.77
interpolated			6.0	R-31	3.636	ea	$0.88
interpolated			7.0	R-31	4.242	ea	$0.99
interpolated			8.0	R-31	4.848	ea	$1.10
interpolated			10.0	R-31	6.060	ea	$1.32
interpolated			16.0	R-31	9.696	ea	$1.98
interpolated			20.0	R-31	12.120	ea	$2.42
interpolated			22.0	R-31	13.332	ea	$2.64
interpolated			24.0	R-31	14.544	ea	$2.86

* Crew is defined in Table 8D.2.1.
** Labor hours are presented in decimal places of hours where 1.0 = 1 hour.
† ea = each

Table 8D.10.6 Brick Wall, 8 Inches Thick

RS Means Book	RS Means Section Number	Page Number	Diameter *inch*	Crew*	Labor Hours**	Unit of Cost†
2015 Mech	2605 33.95 1600	425	2.0	R-31	1.404	ea
2015 Mech	2605 33.95 1620	425	2.5	R-31	1.404	ea
2015 Mech	2605 33.95 1640	425	3.0	R-31	1.404	ea
2015 Mech	2605 33.95 1680	425	4.0	R-31	2.000	ea
interpolated			5.0	R-31	2.255	ea
interpolated			6.0	R-31	2.511	ea
interpolated			7.0	R-31	2.817	ea
interpolated			8.0	R-31	3.124	ea
interpolated			10.0	R-31	3.737	ea
interpolated			16.0	R-31	5.576	ea
interpolated			20.0	R-31	6.802	ea
interpolated			22.0	R-31	7.415	ea
interpolated			24.0	R-31	8.028	ea

* Crew is defined in Table 8D.2.1.
** Labor hours are presented in decimal places of hours where 1.0 = 1 hour.
† ea = each

Table 8D.10.7 Wall Penetration and Knockouts 8-ft-High, Metal Boxes & Enclosures

RS Means Book	RS Means Section Number	Page Number	Diameter *inch*	Crew*	Labor Hours**	Unit of Cost†
2015 Mech	2605 33.95 3080	426	2.0	1 Elec	0.296	ea
2015 Mech	2605 33.95 3090	426	2.5	1 Elec	0.400	ea
2015 Mech	2605 33.95 4010	426	3.0	1 Elec	0.500	ea
2015 Mech	2605 33.95 4050	426	4.0	1 Elec	0.727	ea
interpolated			5.0	1 Elec	0.941	ea
interpolated			6.0	1 Elec	1.154	ea
interpolated			7.0	1 Elec	1.370	ea
interpolated			8.0	1 Elec	1.585	ea
interpolated			10.0	1 Elec	2.016	ea
interpolated			16.0	1 Elec	3.309	ea
interpolated			20.0	1 Elec	4.171	ea
interpolated			22.0	1 Elec	4.602	ea
interpolated			24.0	1 Elec	5.033	ea

* Crew is defined in Table 8D.2.1.
** Labor hours are presented in decimal places of hours where 1.0 = 1 hour.
† ea = each

8D.10.2 Cost & Labor of B Vent Components

During the research, DOE observed that metal venting typically utilize more components in the venting system than plastic venting. This observation was repeated for all metal venting, including stainless steel and AL29-4C materials.

Table 8D.10.8 Type B Chimney Vent, Double Wall, Galvanized Steel

RS Means Book	RS Means Section Number	Page Number	Diameter *inch*	Crew*	Labor Hours**	Unit of Cost†	Material Cost
2015 Mech	2351 23.10 0080	355	3.0	Q9	0.222	LF	$5.55
2015 Mech	2351 23.10 0100	355	4.0	Q9	0.235	LF	$7.20
interpolated			5.0	Q9	0.251	LF	$8.33
2015 Mech	2351 23.10 0140	355	6.0	Q9	0.267	LF	$9.45
interpolated			6.0	Q9	0.288	LF	$13.43
2015 Mech	2351 23.10 0180	355	8.0	Q9	0.308	LF	$17.40
2015 Mech	2351 23.10 0200	355	10.0	Q9	0.333	LF	$36.00
2015 Mech	2351 23.10 0260	355	16.0	Q9	0.400	LF	$103.00
2015 Mech	2351 23.10 0300	355	20.0	Q10	0.667	LF	$150.00
2015 Mech	2351 23.10 0320	355	22.0	Q10	0.706	LF	$187.00
2015 Mech	2351 23.10 0340	355	24.0	Q10	0.750	LF	$236.00

* Crew is defined in Table 8D.2.1.
** Labor hours are presented in decimal places of hours where 1.0 = 1 hour.
† LF = linear foot.

Table 8D.10.9 Type B Elbows, 45 degree

RS Means Book	RS Means Section Number	Page Number	Diameter *inch*	Crew*	Labor Hours**	Unit of Cost†	Material Cost
2015 Mech	2351 23.10 0660	356	3.0	Q9	0.444	each	$13.50
2015 Mech	2351 23.10 0670	356	4.0	Q9	0.471	each	$16.35
interpolated			5.0	Q9	0.502	each	$19.93
2015 Mech	2351 23.10 0690	356	6.0	Q9	0.533	each	$23.50
interpolated			7.0	Q9	0.574	each	$36.75
2015 Mech	2351 23.10 0710	356	8.0	Q9	0.615	each	$50.00
2015 Mech	2352 23.10 0720	356	10.0	Q9	0.667	each	$107.00
2015 Mech	2351 23.10 0750	356	16.0	Q9	0.800	each	$232.00
2015 Mech	2351 23.10 0770	356	20.0	Q10	1.333	each	$340.00
2015 Mech	2351 23.10 0780	356	22.0	Q10	1.412	each	$545.00
2015 Mech	2351 23.10 0790	356	24.0	Q10	1.500	each	$695.00

*Crew is defined in Table 8D.2.1.
** Labor hours are presented in decimal places of hours where 1.0 = 1 hour.
† ea = each

Table 8D.10.10 Type B Wall Thimble, Adjustable

RS Means Book	RS Means Section Number	Page Number	Diameter *inch*	Crew*	Labor Hours**	Unit of Cost†	Material Cost
2015 Mech	2351 23.10 1020	356	3.0	Q9	0.444	ea	$14.45
2015 Mech	2351 23.10 1022	356	4.0	Q9	0.471	ea	$16.25
interpolated			5.0	Q9	0.335	ea	$16.90
2015 Mech	2351 23.10 1026	356	6.0	Q9	0.533	ea	$17.55
interpolated			7.0	Q9	0.574	ea	$34.53
2015 Mech	2351 23.10 1030	356	8.0	Q9	0.615	ea	$51.50
interpolated			10.0	Q9	0.697	ea	$85.45
interpolated			16.0	Q9	0.943	ea	$187.30
interpolated			20.0	Q10	1.107	ea	$255.20
interpolated			22.0	Q10	1.189	ea	$289.15
interpolated			24.0	Q10	1.271	ea	$323.10

* Crew is defined in Table 8D.2.1.
** Labor hours are presented in decimal places of hours where 1.0 = 1 hour.
† ea = each

Table 8D.10.11 Roof Flashing

RS Means Book	RS Means Section Number	Page Number	Diameter *inch*	Crew*	Labor Hours**	Unit of Cost†	Material Cost
2015 Mech	2351 23.10 1040	356	3.0	Q9	0.444	ea	$8.50
2015 Mech	2351 23.10 1050	356	4.0	Q9	0.471	ea	$9.90
interpolated			5.0	Q9	0.502	ea	$16.70
2015 Mech	2351 23.10 1070	356	6.0	Q9	0.533	ea	$23.50
interpolated			7.0	Q9	0.574	ea	$28.50
2015 Mech	2351 23.10 1090	356	8.0	Q9	0.615	ea	$33.50
2015 Mech	2352 23.10 1100	356	10.0	Q9	0.667	ea	$45.00
2015 Mech	2351 23.10 1130	356	16.0	Q9	0.889	ea	$201.00
2015 Mech	2351 23.10 1150	356	20.0	Q10	1.333	ea	$305.00
2015 Mech	2351 23.10 1160	356	22.0	Q10	1.714	ea	$375.00
2015 Mech	2351 23.10 1170	356	24.0	Q10	2.000	ea	$440.00

* Crew is defined in Table 8D.2.1.
** Labor hours are presented in decimal places of hours where 1.0 = 1 hour.
† ea = each.

Table 8D.10.12 Type B Vent Termination

RS Means Book	RS Means Section Number	Page Number	Diameter *inch*	Crew*	Labor Hours**	Unit of Cost†	Material Cost
2015 Mech	2351 23.10 1750	357	3.0	Q9	0.348	ea	$13.05
2015 Mech	2351 23.10 1760	357	4.0	Q9	0.364	ea	$13.75
interpolated			5.0	Q9	0.382	ea	$18.63
2015 Mech	2351 23.10 1780	357	6.0	Q9	0.400	ea	$23.50
interpolated			7.0	Q9	0.422	ea	$35.00
2015 Mech	2351 23.10 1800	357	8.0	Q9	0.444	ea	$46.50
2015 Mech	2352 23.10 1810	357	10.0	Q9	0.471	ea	$105.00
2015 Mech	2351 23.10 1840	357	16.0	Q9	0.571	ea	$263.00
2015 Mech	2351 23.10 1860	357	20.0	Q10	0.857	ea	$550.00
2015 Mech	2351 23.10 1870	357	22.0	Q10	1.091	ea	$840.00
2015 Mech	2351 23.10 1880	357	24.0	Q10	1.200	ea	$1,050.00

* Crew is defined in Table 8D.2.1.
** Labor hours are presented in decimal places of hours where 1.0 = 1 hour.
† ea = each

8D.10.3 Cost & Labor of Stainless Steel Venting

Table 8D.10.13 SS Vent Pipe

RS Means Book	RS Means Section Number	Page Number	Diameter *inch*	Crew*	Labor Hours**	Unit of Cost†	Material Cost
	interpolated		3.0	Q9	0.149	VLF	$43.50
	interpolated		4.0	Q9	0.178	VLF	$47.00
	interpolated		5.0	Q9	0.222	VLF	$50.50
2015 Mech	2351 26.10 3220	358	6.0	Q9	0.267	VLF	$54.00
	interpolated		7.0	Q9	0.288	VLF	$57.50
2015 Mech	2351 26.10 3221	358	8.0	Q9	0.308	VLF	$61.00
2015 Mech	2351 26.10 3222	358	10.0	Q9	0.333	VLF	$68.00
2015 Mech	2351 26.10 3225	358	16.0	Q9	0.400	VLF	$99.00
2015 Mech	2351 26.10 3227	358	20.0	Q10	0.667	VLF	$127.00
	interpolated		22.0	Q10	0.709	VLF	$145.00
2015 Mech	2351 26.10 3229	358	24.0	Q10	0.750	VLF	$163.00

* Crew is defined in Table 8D.2.1.
** Labor hours are presented in decimal places of hours where 1.0 = 1 hour.
† VLF = vertical linear feet

Table 8D.10.14 SS Elbow 90

RS Means Book	RS Means Section Number	Page Number	Diameter *inch*	Crew*	Labor Hours**	Unit of Cost†	Material Cost
	interpolated		3.0	Q9	0.299	ea	$141.00
	interpolated		4.0	Q9	0.355	ea	$158.00
	interpolated		5.0	Q9	0.444	ea	$265.60
2015 Mech	2351 26.10 3354	359	6.0	Q9	0.533	ea	$405.00
			7.0	Q9	0.574	ea	$430.00
2015 Mech	2351 26.10 3355	359	8.0	Q9	0.615	ea	$455.00
2015 Mech	2351 26.10 3356	359	10.0	Q9	0.667	ea	$515.00
2015 Mech	2351 26.10 3359	359	16.0	Q9	0.800	ea	$745.00
2015 Mech	2351 26.10 3361	359	20.0	Q10	1.333	ea	$955.00
	interpolated		22.0	Q10	1.417	ea	$1,090.00
2015 Mech	2351 26.10 3362	359	24.0	Q10	1.500	ea	$1,225.00

* Crew is defined in Table 8D.2.1.
** Labor hours are presented in decimal places of hours where 1.0 = 1 hour.
† ea = each

Table 8D.10.15 SS Ventilated Roof Thimble

RS Means Book	RS Means Section Number	Page Number	Diameter *inch*	Crew*	Labor Hours**	Unit of Cost†	Material Cost
	interpolated		3.0	Q9	0.379	ea	$217.36
	interpolated		4.0	Q9	0.442	ea	$224.88
	interpolated		5.0	Q9	0.528	ea	$235.94
2015 Mech	2351 26.10 3620	360	6.0	Q9	0.615	ea	$247.00
			7.0	Q9	0.671	ea	$252.00
2015 Mech	2351 26.10 3624	360	8.0	Q9	0.727	ea	$257.00
2015 Mech	2351 26.10 3625	360	10.0	Q9	0.800	ea	$264.00
2015 Mech	2351 26.10 3628	360	16.0	Q9	1.000	ea	$305.00
2015 Mech	2351 26.10 3630	360	20.0	Q10	1.500	ea	$345.00
	interpolated		22.0	Q10	1.607	ea	$362.50
2015 Mech	2351 26.10 3631	360	24.0	Q10	1.714	ea	$380.00

* Crew is defined in Table 8D.2.1.
** Labor hours are presented in decimal places of hours where 1.0 = 1 hour.
† ea = each

Table 8D.10.16 SS Roof Guide

RS Means Book	RS Means Section Number	Page Number	Diameter *inch*	Crew*	Labor Hours**	Unit of Cost†	Material Cost
	interpolated		3.0	Q9	0.382	ea	$77.41
	interpolated		4.0	Q9	0.451	ea	$81.73
	interpolated		5.0	Q9	0.545	ea	$83.61
2015 Mech	2351 26.10 3724	361	6.0	Q9	0.640	ea	$85.50
			7.0	Q9	0.701	ea	$92.50
2015 Mech	2351 26.10 3725	361	8.0	Q9	0.762	ea	$99.50
2015 Mech	2351 26.10 3726	361	10.0	Q9	0.842	ea	$109.00
2015 Mech	2351 26.10 3729	361	16.0	Q9	1.067	ea	$139.00
2015 Mech	2351 26.10 3731	361	20.0	Q10	1.600	ea	$155.00
	interpolated		22.0	Q10	1.723	ea	$158.50
2015 Mech	2351 26.10 3732	361	24.0	Q10	1.846	ea	$162.00

* Crew is defined in Table 8D.2.1.
** Labor hours are presented in decimal places of hours where 1.0 = 1 hour.
† ea = each

Table 8D.10.17 SS Vent Termination

RS Means Book	RS Means Section Number	Page Number	Diameter *inch*	Crew*	Labor Hours**	Unit of Cost†	Material Cost
	interpolated		3.0	Q9	0.182	ea	$155.78
	interpolated		4.0	Q9	0.217	ea	$191.45
	interpolated		5.0	Q9	0.282	ea	$240.73
2015 Mech	2351 26.10 3774	361	6.0	Q9	0.348	ea	$290.00
			7.0	Q9	0.365	ea	$312.50
2015 Mech	2351 26.10 3775	361	8.0	Q9	0.381	ea	$335.00
2015 Mech	2351 26.10 3776	361	10.0	Q9	0.400	ea	$390.00
2015 Mech	2351 26.10 3779	361	16.0	Q9	0.444	ea	$580.00
2015 Mech	2351 26.10 3781	361	20.0	Q10	0.857	ea	$765.00
	interpolated		22.0	Q10	0.890	ea	$842.50
2015 Mech	2351 26.10 3782	361	24.0	Q10	0.923	ea	$920.00

* Crew is defined in Table 8D.2.1.
** Labor hours are presented in decimal places of hours where 1.0 = 1 hour.
† ea = each

8D.10.4 Cost & Labor of AL29-4C Venting

The labor requirements of AL29-4C are the same as those required to install stainless steel venting. The material cost used for AL29-4C components were obtained from the websites listed previously in this appendix: supplyhouse.com, houseneeds.com, ventingpipe.com, and stainlessventingandchimneyliners.com.

Table 8D.10.18 AL29-4C Elbow 90

Diameter	Crew	Labor Hours	Unit of Cost*	Material Cost
3.0	Q9	0.299	ea	$150.85
4.0	Q9	0.355	ea	$164.95
5.0	Q9	0.444	ea	$185.56
6.0	Q9	0.533	ea	$206.16
7.0	Q9	0.574	ea	$235.43
8.0	Q9	0.615	ea	$264.70
10.0	Q9	0.667	ea	$340.58
16.0	Q9	0.800	ea	$672.19
20.0	Q9	1.333	ea	$979.92
22.0	Q10	1.417	ea	$1,159.79
24.0	Q10	1.500	ea	$1,356.98

* ea = each

Table 8D.10.19 AL29-4C Venting

Diameter	Crew	Labor Hours	Unit of Cost	Material Cost
3.0	Q9	0.149	VLF	$71.81
4.0	Q9	0.178	VLF	$80.08
5.0	Q9	0.222	VLF	$90.42
6.0	Q9	0.267	VLF	$100.75
7.0	Q9	0.288	VLF	$113.82
8.0	Q9	0.308	VLF	$126.88
10.0	Q9	0.333	VLF	$158.52
16.0	Q9	0.400	VLF	$286.36
20.0	Q9	0.667	VLF	$399.04
22.0	Q10	0.709	VLF	$463.62
24.0	Q10	0.750	VLF	$533.68

Table 8D.10.20 AL29-4C Adjustable Length Sections

Diameter	Crew	Labor Hours	Unit of Cost	Material Cost
3.0	Q9	0.299	ea	$107.38
4.0	Q9	0.355	ea	$126.43
5.0	Q9	0.444	ea	$159.71
6.0	Q9	0.533	ea	$193.00
7.0	Q9	0.574	ea	$197.00
8.0	Q9	0.615	ea	$201.00
10.0	Q9	0.667	ea	$227.00
16.0	Q9	0.800	ea	$325.00
20.0	Q9	1.333	ea	$415.00
22.0	Q10	1.417	ea	$475.00
24.0	Q10	1.500	ea	$535.00

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APPENDIX 8E. MAINTENANCE AND REPAIRS

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APPENDIX 8E. MAINTENANCE AND REPAIRS

8E.1 INTRODUCTION

Maintenance costs are associated with maintaining the operation of the equipment. Repair costs are the cost to the customer of replacing or repairing failed components or sub-systems within the commercial water heating (CWH) equipment. For this analysis, DOE employed a combination of references from Whitestone Research, RS Means, and internet research to identify the maintenance schedule, costs of consumables, labor hours, and cost of service components. Specific references are called out in the subsections that follow.

8E.2 MAINTENANCE

Maintenance costs are associated with maintaining the operation of the equipment and occur through the life of the equipment. DOE referenced the maintenance schedule identified by Whitestone Research[1] for the equipment subcategories of this rulemaking. This schedule includes the costs of consumables and labor hours for the costs relating to maintenance. Whitestone presents the most complete set of data for the equipment subcategories in consideration. Whitestone presents the information in a similar manner as RS Means, with labor hours and crew identified. For consistency, the RS Means labor rates[2,3,4,5,6] were used to calculate the installation labor costs based upon these data.

It is noted that the Whitestone reference is from 2012. Also, the cost of consumables obtained in the Whitestone reference is listed relative to costs in Washington, DC, while the RS Means data presents costs relative to the national average. To account for these differences, the costs of consumables were first corrected for inflation between 2013 and 2015 using the price deflator[7] values, and then the costs were corrected to national average values in order to provide a consistent approach to maintenance cost determination with respect to installation cost determinations described in appendix 8D.

Review of the manufacturer's maintenance requirements presented in equipment manuals[a] identified similarities in the routine maintenance of commercial gas-fired storage water heaters. Equipment manuals reviewed include Rheem Universal,[8] A.O. Smith Cyclone Mxi,[9] HTP, Inc. Phoenix,[10] and Bradford White Corporation EF Series Models.[11]

The water-side maintenance requirements of all storage tank equipment is reasonably similar in that periodic draining of the tank is undertaken in order to minimize sediment buildup and allow inspection of anodes. Rheem and A.O. Smith include information relating to the use of chemicals to remove sediment buildup, also referred to as "lime." Due to the similarities in water-side maintenance requirements, DOE determined that maintenance costs do not change with regard to equipment efficiency.

[a] It is noted that manufacturers refer to the product literature provided on their websites by different titles, the most common of which were noted as: "Instruction Manual," "Use and Care Manual," and "Installation and Operation Manual."

For gas-fired combustion systems, the general maintenance activities include 1) visually inspecting the burner operation, 2) cleaning the burner, and 3) cleaning the combustion chamber and around the water heater.[b] However, there are significant variations in the maintenance requirements of combustion systems within the industry. Specifically, the Rheem equipment manual, which addresses maintenance of atmospheric burners and power assisted burners, includes detailed instruction on removal of the burners for cleaning and maintenance. While the Bradford White and A.O. Smith manuals, which address equipment incorporating modulation of the firing rate and mixing of the air and fuel prior to the air-fuel mixture entering the burner, have limited maintenance information on the combustion systems. Bradford White recommends a visual inspection of the burner flames using a ”sight glass” installed in the product, while A.O. Smith makes no note of maintenance of the combustion system. Alternatively, HTP, Inc. recommends specific steps in maintenance including checking combustion properties, electrode ignition parameters, and vacuuming the combustion chamber.

In light of the variation in required maintenance for combustion systems, DOE has not identified significant differences between maintenance costs of the combustion system relating to the efficiency of equipment.

Review of commercial gas-fired instantaneous tankless water heater (CGITWH) manufacturer’s maintenance requirements presented in equipment manuals[c] identified chemical descaling is the common water-side cleaning method. Water-side maintenance consists of periodically draining and flushing the water heater and using a “de-liming” solution to remove the sediment that collects in the heat exchanger. Additionally, some manufacturers include a strainer or filter in the water circulation system that requires periodic cleaning. DOE reviewed equipment literature from Rinnai RUC90i,[12] RLX94i,[13] and HTP Inc. Hydra Smart[14] for these products.

Combustion system maintenance of CGITWH equipment was observed to be similar to requirements found in commercial gas-fired storage water heater equipment. Manufacturer tasks range from requiring a simple visual inspection of the flame and removal of dust from the combustion system components, to no mention of maintenance on the combustion system.

For commercial gas-fired hot water supply boilers, DOE reviewed the manufacturer maintenance requirements for the Lochinvar Armor[15] and Laars Rheos[16] models. These requirements present a significant level of detail with respect to maintenance, including cleaning of the heat exchanger. DOE observed that these products represent different equipment efficiencies, but require similar amounts of maintenance. Hence, DOE determined that maintenance requirements for commercial gas-fired hot water supply boilers do not change with efficiency.

[b] Vacuuming the inside of the combustion removes accumulations of rust and burnt remnants of miscellaneous small debris caught in the incoming air flow and either passing through the combustion process or exposed to the high temperatures within the combustion chamber.

[c] It is noted that manufacturers refer to the product literature provided on their websites by different titles, the most common of which were noted as: “Instruction Manual,” “Use and Care Manual,” and “Installation and Operation Manual.”

DOE's review of manufacturer maintenance documentation for commercial electric water heaters indicated the same tank maintenance tasks as the maintenance of gas-fired tanks. In addition, electrical connections and materials are inspected for wear and deterioration. DOE reviewed Bradford White Corporation Brute[17] documentation and Rheem Manufacturing Company Heavy Duty[18] equipment documentation.

Whitestone Research identified the labor hours and material costs for routine maintenance of each of the equipment classes as shown in Table 8E.2.1. Assumptions include that all maintenance is performed by one plumber, and the frequency is the time between repetitions of successive instances of the same task in years. It is noted that the material costs include replacement of gaskets and sealants.

Table 8E.2.1 Maintenance Schedule for Commercial Water Heating Equipment

Equipment Subcategory	Task	Labor Hours*	Material Costs**	Service Frequency†
Commercial Gas-fired Storage Water Heater / Residential-duty Gas-fired Storage Water Heater	Clean (Volumes ≤275 Gallons)	2.67		1
	Clean (Volumes >275 Gallons)	8		2
	Overhaul	1.84	$25.92	5
Commercial Gas-fired Instantaneous Tankless Water Heater / Commercial Gas-fired Instantaneous Hot Water Supply Boiler	Service	0.33		1
Commercial Electric Storage Water Heater	Check	0.33		3
	Drain & Flush (Volume ≤30 Gallons)	2.67		7
	Drain & Flush (Volume >30 Gallons)	4		7

* Maintenance hours are constant for each CWH type; however, the local wage rates will vary.
** The maintenance material costs will be adjusted for local cost variances.
† Frequency is the time between repetitions of successive instances of the same task in years

DOE observed that the service frequencies identified by Whitestone are not consistent with the manufacturer recommendations presented in the equipment literature. Differences between the two sources were noted and included in the lifecycle cost (LCC modeling) since realistically not all CWH equipment is serviced as desired by manufacturers. Therefore, DOE applied the service frequency identified in Table 8E.2.1 to all equipment instead of applying the manufacturer recommended maintenance schedule to a percentage of the equipment in service.

The data presented in Table 8E.2.1 were combined with the crew rate, converted to the present value of the maintenance, and then converted to an equivalent series of annual maintenance expenses that were applied in the LCC to determine the impact of maintenance costs on the various equipment categories.

8E.2.1 Maintenance Costs by Efficiency Level

Comments from stakeholders indicated that maintenance costs would increase with higher efficiency equipment (AHRI, No. 5 at p. 5; BWC, No. 3 at p. 3; Rheem, No. 10 at p. 7; A.O. Smith, No. 2 at p. 4). DOE's review of available literature did not identify a relationship between efficiency level and maintenance costs, but related maintenance cost to the size of the equipment for two of the equipment subcategories in consideration for this analysis, as identified in the section 8E.2.

8E.3 REPAIRS

Repair costs are the costs to the commercial consumer of replacing or repairing failed components and typically occur outside of the warranty period. DOE recognizes that Weibull distributions are utilized in other aspects of this analysis to calculate approximate failure rates for each equipment subcategory. However, limited data resolution in the available national sources resulted in excessive uncertainty between what can be considered maintenance tasks and what can be considered repair tasks. Specifically, Whitestone includes the cost of minor repairs within the preventative maintenance costs. Additionally, the cost of "overhaul" of equipment, which DOE understands to be a repair cost, is also included within the replacement cost of equipment.

Therefore, DOE utilized an alternative analysis by assuming a relatively low annual failure rate of equipment, identifying the number and average cost of components replaced, and distributing the resulting repair cost across the relevant equipment. In order to determine the rate of repairs for equipment, DOE assumed an equipment level simple failure rate of 2 percent per year. Based on manufacturer literature,[d] five components[e] are replaced, on average, over the lifetime of gas-fired equipment. An approximation of the annual failure rate was calculated by conducting a linear estimation of component failure rate, where the failure rate per year is divided by the average number of components being repaired or replaced, equaling 0.4 percent of shipments per year. A markup value was then applied to account for regional cost variations.

The labor required to replace a component was estimated as 2 hours for combustion systems, 1 hour for combustion controls, and 45 minutes (¾ hour) to replace an electric water heater thermostat. DOE estimates that it will require 3 hours, on average, to replace an electric heating element, accounting for the time required to drain a storage tank prior to element replacement and to refill the tank afterwards. These values are based upon the time requirements presented in Table 8E.2.1 with rounding of the time requirements to account for the differences between maintenance and replacement.

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[d] Manufacturer literature identified in section 8E.2 includes references 8 through 18 were used in the analysis of repair costs. Additional references are noted as discussed.

[e] This analysis assumes the five most common components repaired or replaced on gas-fired products are the blower, gas valve, controller, ignitor/pilot light, and burner/orifice valves. Equipment utilizing electric resistance heating is modeled assuming the heating element and thermostat are the most common components replaced during repair. DOE recognizes that this analysis therefore may overestimate the repair costs of electric resistance based equipment.

Due to the variation in the equipment offerings within each subcategory, the cost a commercial consumer would pay to obtain replacement parts was found for only the representative models of each subcategory. The representative models analyzed for each subcategory are presented in Table 8E.3.1.

Table 8E.3.1 Representative Models of Each Equipment Subcategory Used in LCC and PBP Analysis

Equipment Subcategory	Input Rate	Volume *Gallons*
Commercial Gas-Fired Storage Water Heater	199 M Btu/h	100
Residential-Duty Gas-Fired Storage Water Heater	76 M Btu/h	75
Commercial Gas-Fired Instantaneous Tankless Water Heater	250 M Btu/h	–
Commercial Gas-Fired Instantaneous Hot Water Supply Boiler	399 M Btu/h	–
Commercial Electric Storage Water Heater	18 kW	119

8E.3.1 Repair Costs – Commercial Electric Storage Water Heaters

The heating elements and thermostat were identified as the most common parts of commercial electric storage water heaters. For this analysis, DOE reviewed costs available online from manufacturer, wholesaler, and commercial distributer websites. As shown in Table 8E.3.1, an average cost of $38 was found for heating elements in the range of 4,500 watts to 6,500 watts. DOE considers this a sufficient estimate due to the understanding that using the same element in different voltages results in different wattages.

Table 8E.3.2 Average Cost of Heating Elements for Commercial Electric Storage Water Heaters

Component	Sheath Material	Part #	Source	Price
6000 Watt Element	Nickel-Based Alloy	# 2E768	Grainger.com	$51.35
4500 Watt Element	Zinc Coated Copper	# 2E303	Grainger.com	$17.99
4500 Watt Element	Nickel-Based Alloy	# 2E673	Grainger.com	$34.65
5000 Watt Element	Nickel-Based Alloy	# 2E767	Grainger.com	$46.20
Average Price				**$37.55**

A surface mount thermostat is used in many commercial electric storage water heaters. As shown in Table 8E.3.2, an average thermostat cost of $58 was used in the analysis.

Table 8E.3.3 Average Cost of a Surface Mount Thermostat for CWH Applications

Component	Part #	Source	Price
Thermostat, Electric, Commercial	# SP11231	Grainger.com	$69.35
Thermostat 180 °F	# 2XE70	Grainger.com	$45.30
Thermostat 180 °F	# 2XE72	Grainger.com	$59.85
Average Price			**$58.17**

8E.3.2 Repair Costs – Commercial Gas-fired Hot Water Supply Boilers

Heat exchanger failure is a unique repair scenario for hot water supply boilers. The use of condensing or non-condensing technology determines the rate and timing of heat exchanger failure as well as the cost of repair.

Non-condensing hot water supply boilers (ELs 0-2) are assumed to experience heat exchanger failure in 17% of shipments. The year at which this heat exchanger failure occurs is based on Weibull distribution with a mean of 20 years. On the other hand, condensing hot water supply boilers (ELs 3-5) are assumed to experience heat exchanger failure in 50% of shipments due to increased corrosion. The year at which this failure occurs is also based on a Weibull distribution, but with a mean of 15 years. DOE's assumptions for heat exchanger mean year of failure are based on a report from the Gas Research Institute (GRI).[19]

DOE estimates repair costs at each considered efficiency level using a variety of sources, including manufacturer literature and information from experts. Heat exchanger replacement costs are assumed to be 1/3 of the total boiler replacement cost.

DOE assumes that all boilers have a one-year warranty for parts and labor and a ten-year warranty on the heat exchanger. If any component of a boiler fails in one year or less, then the cost of the repair is presumed free for the owner. If the heat exchanger fails between 1 and 10 years, it is presumed that there is no material cost to the owner, but there is still a labor cost.

8E.3.3 Costs of Components Commonly Replaced

DOE obtained service pricing information for manufacturers of commercial gas-fired storage water heating equipment from wholesale websites and pricing lists found on their respective websites.[20] Due to limited data availability, some pricing data from previous years were utilized. When these data were used, the costs were adjusted to 2015 dollars.

For commercial gas-fired storage water heaters, some manufacturers list a breakdown of service parts and pricing on their websites,[21] which were used to determine total subsystem costs, as shown in Table 8E.3.3. Other manufacturers list the complete cost of pre-assembled subsystems[22] within the commercial gas-fired storage water heaters as shown in Table 8E.3.4. Using these sources, DOE investigated the total cost of a representative standard efficiency (atmospheric combustion) water heater[23]; shown in Table 8E.3.5, mid-range efficiency (powered atmospheric combustion) water heater[24], and high efficiency water heater (pre-mixed combustion).[25]

Table 8E.3.4 Combined Components for Determining the Cost of High Efficiency Combustion System

Component	Part #	Price
Blower (natural & propane)	9006274005	$1,280.23
Burner (natural & propane)	9006279005	$305.02
Flame Sensor (natural & propane)	9006106205	$81.55
Igniter (natural & propane)	9006101205	$138.36
Gas Valve - Venturi Assembly	9006285005	$636.24
Total Cost of Combustion System		**$2441.39**

Table 8E.3.5 Total Manufacturer Cost of a Standard Efficiency Combustion System

Component	Part #	Price
Burner Assembly, Material of Construction Metal and Plastic, For Use With 3CFJ5 (100 G/199 MBTUH)	# AM39732	$1,183.00
Burner Assembly, Material of Construction Metal, For Use With 3RA88 (91G/199 MBTUH)	# AM39189	$1,194.00
Average Cost of Combustion Assembly		**$1188.50**

Data analysis revealed that it would be improbable to replace the complete combustion system during an average service call. In order to more accurately account for less common replacement parts, which were not costed, and assuming that a typical service call will require replacing more than one component in this list, 50 percent of the sum of the identified component costs was used as the material cost of repairs for the equipment.

Although an understanding of the component level failure rate would be beneficial, the availability of these data prevents DOE from using such an approach to estimate the cost of repairs for each equipment subcategory. Constrained by the available data, which provide some cost information as subassemblies and other cost information relative to individual components, a reasonable approximation can be made as to the average cost of replacement parts used annually. This average cost is therefore modeled as one half of the cost or the most commonly replaced components for each of the equipment subcategories. Because this approach is conservative with respect to all subcategories, and also predicts the replacement of other components (sensors, wiring harnesses, switches, relays, etc.) not specifically identified in this analysis, DOE considers this approach to be justifiable.

Table 8E.3.6 Atmospheric Combustion System Costs

Component	Part #	Notes	Price
Kit swordfish burner	9005889205	–	$60
Kit burner assy / pilot bkt	9005291205	–	$65
Kit manifold	9006062205	–	$49
Orifice 1/2" hex rh	076243-032	$3.20 each x 8 burners	$26
Kit 60" pilot tubing 1/4" with ftgs	9003925115	–	$23
Kit inlet tube	9006044205	–	$49
Kit ground wire assy	9004991215	–	$31
Kit gas valve natural	9006055205	–	$258
Total Combustion System Cost			**$561**

Due to the limited data available, the average cost of repair parts was determined by identifying the cost difference between the gas valve, blower, and burner costs of commercial gas-fired storage water heaters and residential-duty gas-fired storage water heaters. Excerpts from the same resources were used to determine the cost differences, with additional data presented in Table 8E.3.6 and Table 8E.4.1. From this research, the cost difference for a gas valve was found to be $91,[f] and the cost difference for a blower was estimated at $30.[g] The cost difference for a burner was estimated based upon the sum of the first four components in Table 8E.3.5 ($200) and the cost of high efficiency burner[h] ($291) at $91. The differential cost of the gas valve was applicable to equipment utilizing atmospheric combustion systems. These costs were subtracted from the relevant combustion system repair costs in the commercial gas water heater efficiency level to determine the residential-duty gas-fired storage water heaters costs.

[f] This value is the difference between information in Table 8E.3.6 and Table 8E.4.1. Data were obtained from reference 21 and 22 respectively.

[g] Due to limited data availability for the residential duty sized equipment, no specific costs were obtained, and this value is therefore an estimate of the cost difference between blowers. It is noted that by under estimating this cost difference, that a conservative cost of annual repairs is maintained in the LCC model.

[h] Part # 9006279005 available at http://web.archive.org/web/20150306010739/http://www.statewaterheaters.com/parts/SSMPB00309.pdf. Last accessed 3/18/2016.

Table 8E.3.7 Average Cost of a Residential Duty Gas Valve

Component	Part #	Price
3/4” natural gas, step opening gas valve, 750 millivolt, 3.5” adjustable main pressure regulator setting.	A 9004806105	$389
Propane gas, 150,000 Btu/h max. Cap, 10” main pressure regulator setting; 10” to 12” pilot pressure plus gas inlet screen and baffle, energy cutoff at 195 °f water temperature, range; warm (120 °f) to hot (180 °f).	9004812105	$294
3/4” natural gas, slow opening gas valve, 24 volt, 3.5” adjustable main pressure regulator setting.	B 9004527205	$306
3/4” propane gas, slow opening gas valve, 24 volt, 11” adjustable main pressure regulator setting.	B 9004528205	$306
Average Residential Duty Gas Valve Cost		**$346**

8E.4 REPAIR COSTS BY EFFICIENCY LEVEL

The cost of repairs for commercial electric storage water heaters was not found to vary with efficiency levels. For this case, a simple analysis was used to account for repair costs in the LCC model.

Table 8E.4.1 Average Cost of a Commercial Gas Valve

Component	Part #	Price
Gas valve, commercial	# SP10963D	$351
Kit gas valve natural	9006055205	$258
1” natural gas, slow opening gas valve, 24 Volt, 3.5” adjustable main pressure regulator setting.	C 9005017205	$553
1” propane gas, slow opening gas valve, 24 Volt, 11” adjustable main pressure regulator setting.	C 9005018205	$587
Average Cost of Commercial Gas Valve		**$437**

Table 8E.4.2 Standard Efficiency (Atmospheric Combustion) Controller Average Cost

Component	Part #	Price
Automatic reset limit. Includes 5091 lower well and 5090 top well. 3/4 100-180 (Diff. 4) 195/120	J 9004968105	$353
Manual reset limit, direct immersion. 3/4 120-180 (Diff. 4) 195 120	J 9004531205	$379
Automatic reset limit, direct immersion. 3/4 120-180 (Diff. 4) 195 120	J 9004975105	$344
Manual reset, dual control. 3/4 120-180 (Diff. 4) 205 125	J 9004529005	$321
Automatic reset limit. Includes 9005078205 well. 3/4 100-240 (Diff. 5-45)	K 9005044205	$200
Direct immersion. 1/2 100-240 (diff.10-45)	M 9004793105	$269
Dual control	M 9004506205	$582
Tank temp. 3/4 100-240 (diff. 5)	M 9005925205	$259
Average Cost of Standard Efficiency Controller		**$338**

The combustion systems and controls used in commercial gas-fired storage water heaters, residential-duty gas-fired storage water heaters, commercial gas-fired instantaneous tankless water heaters, and commercial gas-fired instantaneous hot water supply boilers were found to have different costs related to the efficiency levels of the equipment. The costs of higher efficiency components were more expensive than the cost of lower efficiency components. This is in agreement to comments provided by AHRI, Bradford-White, Rheem, and A.O. Smith (AHRI, No. 5 at p. 5; BWC, No. 3 at p. 3; Rheem, No. 10 at p. 7; A.O. Smith, No. 2 at p. 4).

DOE recognized that the cost of the controller used on the appliance also varied with efficiency. Controllers used on atmospheric equipment were found to be minimally less expensive ($5) than the controllers used on powered combustion systems as evidenced by the summary of Table 8E.4.2 compared with Table 8E.4.3. However, the costs of controllers for high efficiency combustion systems were discovered to be significantly higher. State Industries high efficiency controller (part number 9006841005i) was found to cost $588, which is $245 higher than the mid-level efficiency controller. This cost was then adjusted for 2014 costs to be $257. As with previous components; in order to account for less common replacement parts, 50 percent of the sum of the identified component costs was used as the material cost of repairs for this equipment.

Table 8E.4.3 Midrange Efficiency (Powered Combustion) Controller Average Cost

Component*	Part #	Price
Honeywell® I.I.D. control - natural gas	H 9004996105	$300
Honeywell® I.I.D. control with lockout - propane gas	H 9004997105	$300
Johnson® I.I.D. control - natural gas	J 9004470205	$216
Fenwall® I.I.D. control with wire harness(6594 & 6594-1) for all BTP-540A or 700A series	K 9004487105	$607
Honeywell® I.I.D. control - nat.& prop. For BTC 120 thru 500A series 970 and up	L 9004544205	$195
Honeywell® upgrade kit for BTC models-nat. & prop.	L 9004951205	$195
Ram h.s.i control - standard legend models	M 9004492005	$552
Honeywell I.I.D. control - natural gas	NI 9004477205	$408
Johnson (G-67) I.I.D. control - natural gas	NI 9004525105	$312
Average cost of Standard efficiency controller		**$343**

* Information found in 2011 Replacement Parts Price List from State Industries (ssmpb00309.pdf available from www.statewaterheaters.com as of 3/11/2015.)

8E.5 MAINTENANCE AND REPAIR COST ANNUALIZATION

DOE has determined that, if the costs of known items occurring at predictable intervals are appropriately discounted when annualized, there will be no impact on LCC and NIA results, regardless of whether or not the costs are annualized. Additionally, in the commercial water heater equipment analyses, repairs and replacements have been modeled as a combination of known, expected items, plus others modeled as a fraction of failed components that are expected to be replaced during equipment lifetime. Such a characterization of maintenance and repair

[i] 2011 Replacement Parts Price List from State Industries (ssmpb00309.pdf available from www.statewaterheaters.com as of 3/11/2015.)

costs does not lend itself to specification of a particular time, during the equipment lifetime, when such repairs are likely to occur. Further, the PBP by its very definition cannot be calculated unless the costs are annualized. Finally, if multiple explicit repair and maintenance line items were tracked individually in the NIA model, the size and complexity of the computer model would grow exponentially without a commensurate improvement in value.

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APPENDIX 8F. LIFETIME DETERMINATION

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APPENDIX 8F. LIFETIME DETERMINATION

8F.1 INTRODUCTION

The U.S. Department of Energy (DOE) defines the term “lifetime” as the age when a product or a piece of equipment is retired from service.

DOE developed average lifetimes for commercial water heating (CWH) equipment based on the average of lifetime estimates presented in reviewed literature as shown in Table 8F.1.1. Where an average equipment lifetime is presented in Table 8F.1.1, DOE assumed that the average was representative of the source referenced. Where a range of lifetimes was presented, DOE used the midpoint of the range as representative. All final lifetime estimates were rounded to whole-year estimates.

Individuals with experience in the manufacturing or distribution of CWH equipment suggested general trends relating to lifetimes of glass-lined storage water heating equipment.[a] Experts suggested that gas-fired storage water heaters are expected to have shorter lifetimes than electric water heaters because gas-fired equipment utilizes a heat exchanger with a glass-lining on the water side, while electric resistance heating elements are submerged directly in the water and do not significantly increase the temperature of glass-lined interior surface of the storage water tank. The higher local temperatures of gas-fired equipment tend to cause the glass-lined interior tank surfaces to degrade faster than the glass-lined interior surfaces found in electric storage water heater tanks. The experts also suggested that commercial water heaters have shorter lifetimes than residential water heaters. The greater level of usage, due to both higher temperatures and greater water throughput, tends to deplete the anodes used to protect the water-side surfaces from corrosion. Another side to this, however, is that with regular maintenance such as anode rod replacement and draining of tanks, the life of commercial storage tank water heaters could be significantly extended. This is particularly true in certain high-usage applications, such as restaurants, with a crucial dependence on the availability of hot water. However, available data indicate that water storage tank maintenance is performed less often than recommended by the hot water storage tank manufacturers. Additional details on this topic may be found in appendix 8E Maintenance and Repairs.

As the majority of storage tank water heaters currently on the market utilize cathodic protection systems (which are comprised of an anode and a glass-lining covering the water-side surface of the water storage tan), DOE estimated the average equipment lifetimes of storage tank equipment are taken to be the lifetimes of glass-lined storage tank equipment.

No particular source identified a lifetime estimate or range of expected lifetime for residential-duty gas-fired water heaters.[b] Recognizing that these water heaters are found in some single-family residential, multi-family residential, and commercial applications, DOE used an

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[a] DOE recognizes that the glass-lining on the water side of storage tank water heater is composed of porcelain enamel, but references the industry terminology in this appendix.

[b] Water heaters of this size were also referred to as “light-duty commercial” in discussions with industry experts.

average of the life span identified for commercial gas-fired storage water heaters and that for residential gas-fired water heaters from previous DOE rulemaking efforts. As shown in Table 8F.1.2, this resulted in an average lifetime estimate of 12 years for residential-duty gas-fired water heaters. Table 8F.1.2 shows the average equipment lifetimes used in the life-cycle cost (LCC) analysis described in chapter 8 of this technical support document.

Table 8F.1.1 Commercial Water Heaters: Product Lifetime Estimates and Sources

Residential Storage Water Heaters –All Fuels	
13 years	DOE[A]
Residential Gas-Fired Instantaneous Water Heaters	
20 years	DOE[A]
Commercial Gas-Fired Storage Water Heaters	
6–12 years	San Francisco Apartment Association[B]
7 years	DOE[C,L]
7 years	National Renewable Energy Laboratory (NREL)[D]
8 years	Gas Foodservice Equipment Network[E]
10 years	Lawrence Berkeley National Laboratory (LBNL)[F]
10 years (heavy use) 15 years (normal use)	Building Owner and Managers Association (BOMA)[G]
Ave=11, Low=7, High=15	DOE[H]
12 years	Energy Information Agency (EIA)[J]
13 years	Federal Energy Management Program (FEMP)[K]
15 years	LBNL[M]
Commercial Electric Storage Water Heaters	
7 years	DOE[C]
7 years	NREL[D]
Ave=13, Low=4, High=20	DOE[H]
10 years (heavy use) 15 years (normal use)	BOMA[G]
13 years	FEMP[K]
14 years	EIA[J]
15 years	LBNL[M]
Gas-Fired Instantaneous Water Heater, Tankless	
10 years	BOMA[G]
15 years	DOE[C]
15 years	NREL[D]
20 years	Gas Foodservice Equipment Network[E]
20 years	EIA[J]
20 years	National Grid[N]
Gas-Fired Instantaneous Water Heater, Hot Water Supply Boiler	
25 years	NREL[D]

[A] DOE. *Energy Conservation Program: Energy Conservation Standards for Residential Water Heaters, Direct Heating Equipment, and Pool Heaters; Final Rule*. 2010. U.S. Department of Energy, Ofice of Energy Efficiency and Renewable Energy. Docket Number EE–2006–BT–STD–0129.
[B] Shevick, David. *An Alternative to Conventional Water Heaters. 2007.* San Francisco Apartment Association web site. http://www.sfaa.org/0709shevick.html
[C] DOE. *Screening Analysis for EAPACT-Covered Commercial HVAC and Water-Heating Equipment. Volume 1–Main Report.* 2000. U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy. Can be found on Regulations.Gov under docket EERE–2006–STD–0098–0015.
[D] National Renewable Energy Laboratory. *U.S. Department of Energy Commercial Reference Building Models of the National Building Stock.* 2011. Prepared for the U.S. Department of Energy, Office of Energy Efficiency & Renewable Energy.
[E] Gas Foodservice Equipment Network. *Straight Talk About Tankless Water Heaters: Can They Really Keep You in Hot Water?*
[F] Lawrence Berkeley National Laboratory. Energy Analysis Department, *FEMP Designated Product Assessment for Commercial Gas Water Heaters.* 2010. Prepared for the U.S. Department of Energy's Federal Energy Management Program (FEMP).

[G] Schoen, Lawrence. *Preventative Maintenance Guidebook: Best Practices to Maintain Efficient and Sustainable Buildings.* BOMA. 2010. http://icap.sustainability.illinois.edu/files/projectupdate/2289/Project%20Lifespan%20Estimates.pdf
[H] DOE. *Buildings Energy Data Book. 2011*. 2012. U.S. Department of Energy. Table 5.7.15 Major Residential and Small Commercial Appliance Lifetimes.
[J] U.S. Energy Information Administration. 2013. *Updated Buildings Sector Appliance and Equipment Costs and Efficiency*. *Appendix A: EIA – Technology Forecase Updates – Residential and Commercial Building Technologies – Reference Case*.
[K] DOE. *FEMP Energy Cost Calculator for Electric and Gas Water Heaters*. http://www.energy.gov/eere/femp/energy-cost-calculator-electric-and-gas-water-heaters-0
[L] DOE. *Technical Support Document: Energy Efficiency Program for Commercial and Industrial Equipment: Commercial Heating, Air-Conditioning, and Water-Heating Equipment.* 2014. U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy. Docket EERE-2014-BT-STD-0015.
[M] Sezgen, Osman and Jonathan G. Koomey. Technology Data Characterizing Water Heating In Commercial Buildings: Application To End-Use Forecasting. 1995. LBNL
[N] National Grid. 2011. *Massachusetts Technical Reference Manual for Estimating Savings from Energy Efficiency Measures. 2010 Program Year – Report Version.*

Table 8F.1.2 Average Lifetime Used in NOPR Analyses (by product class)

Water Heater Class	Average Lifetime years
Commercial Gas-Fired Storage Water Heaters and Gas-Fired Storage-Type Instantaneous Water Heaters	10
Residential-Duty Gas-Fired Storage Water Heaters	12
Gas-Fired Instantaneous: Tankless	17
Gas-Fired Instantaneous: Hot Water Supply Boilers	25
Commercial Electric Storage Water Heaters	12

APPENDIX 8G. DISTRIBUTIONS USED FOR DISCOUNT RATES

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APPENDIX 8G. DISTRIBUTIONS USED FOR DISCOUNT RATES

8G.1 INTRODUCTION

The U.S. Department of Energy (DOE) estimates discount rate distributions by customer type: commercial and consumer (*i.e.*, non-commercial residential end user). This appendix describes the distributions used.

8G.2 DISTRIBUTIONS USED FOR COMMERCIAL DISCOUNT RATES

DOE derives commercial discount rates (*i.e.*, weighted average cost of capital) for the life-cycle cost (LCC) analysis using the capital asset pricing model and firm-level data provided by Damodaran Online.[1] State and local government discount rates are estimated using the rate of return on 20-year municipal bonds, as provided by the Federal Reserve Board.[2] Separate distributions are constructed for each major industry. Figure 8G.2.1 through Figure 8G.2.10 show the probability distributions of commercial discount rates by industry.

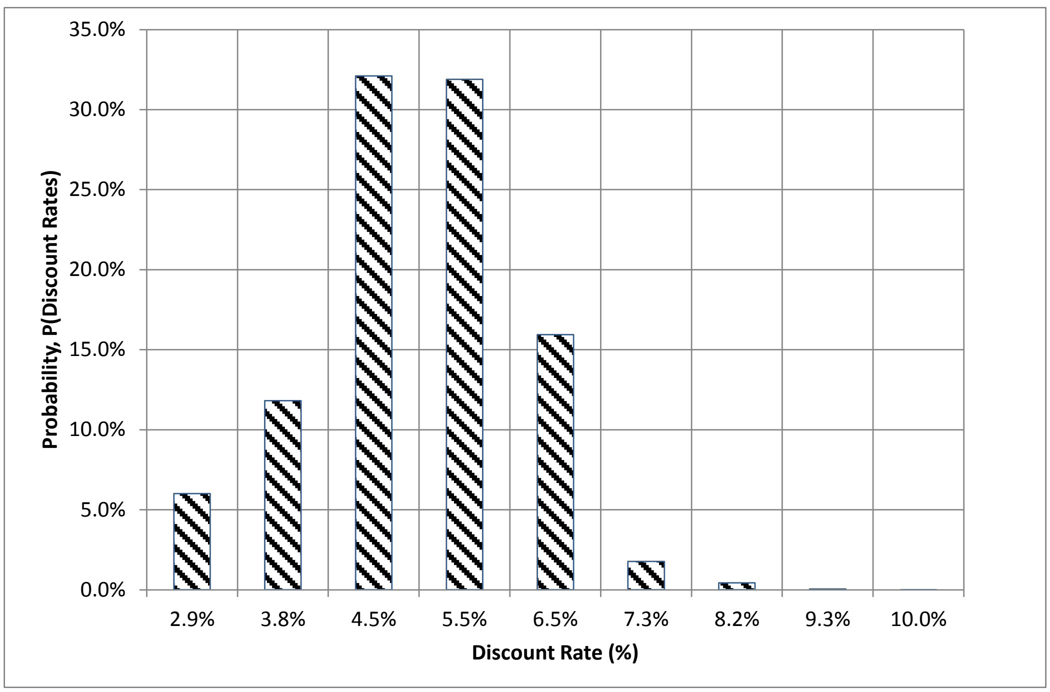

Figure 8G.2.1 Distribution of Commercial Discount Rates: Retail

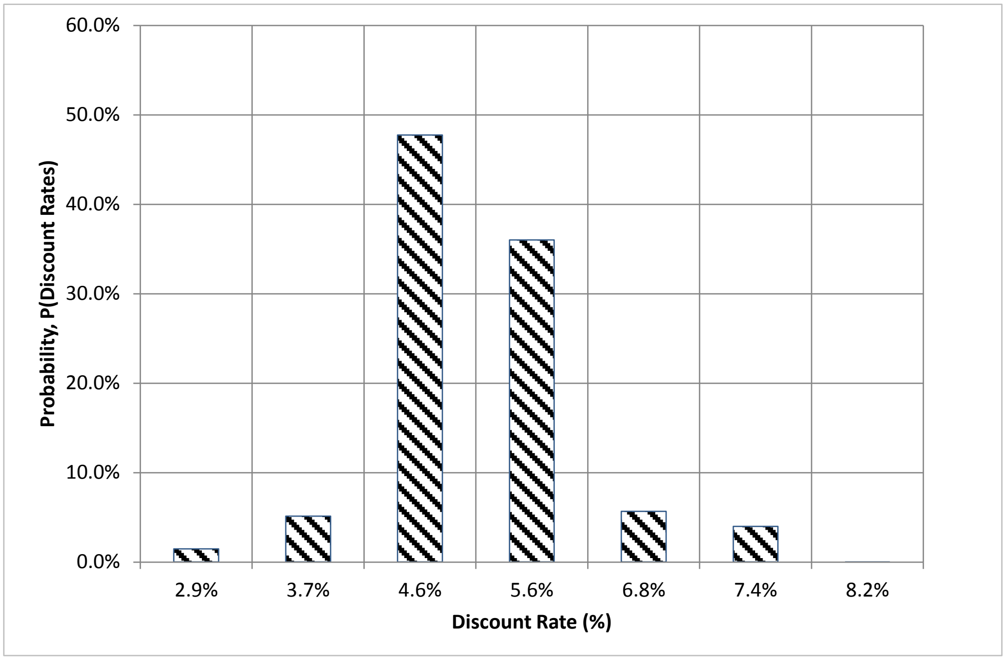

Figure 8G.2.2 Distribution of Commercial Discount Rates: Property

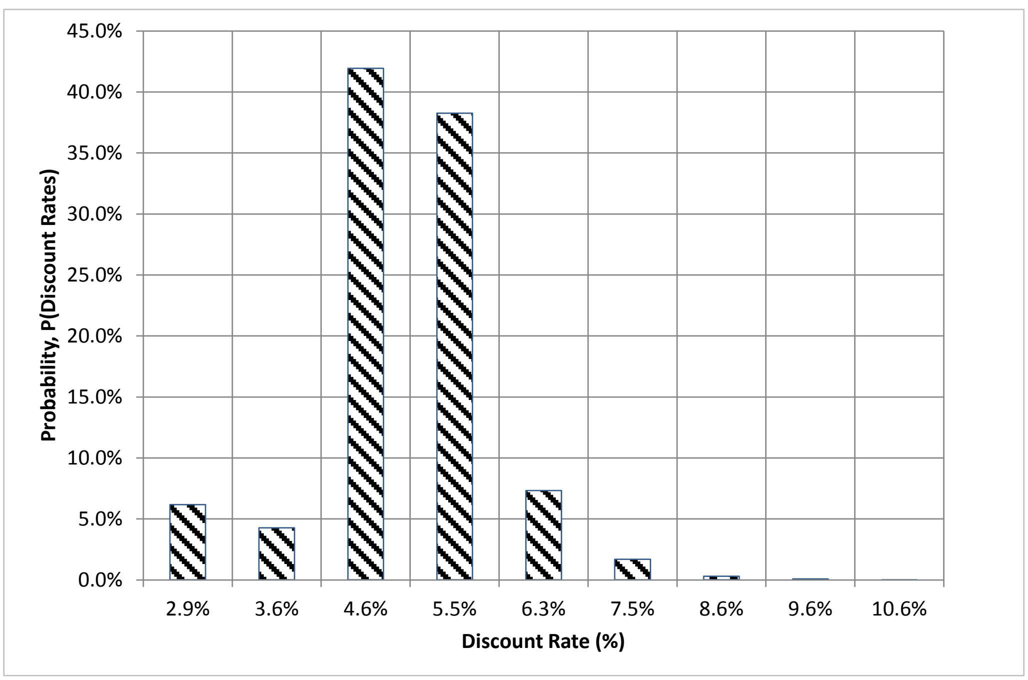

Figure 8G.2.3 Distribution of Commercial Discount Rates: Medical

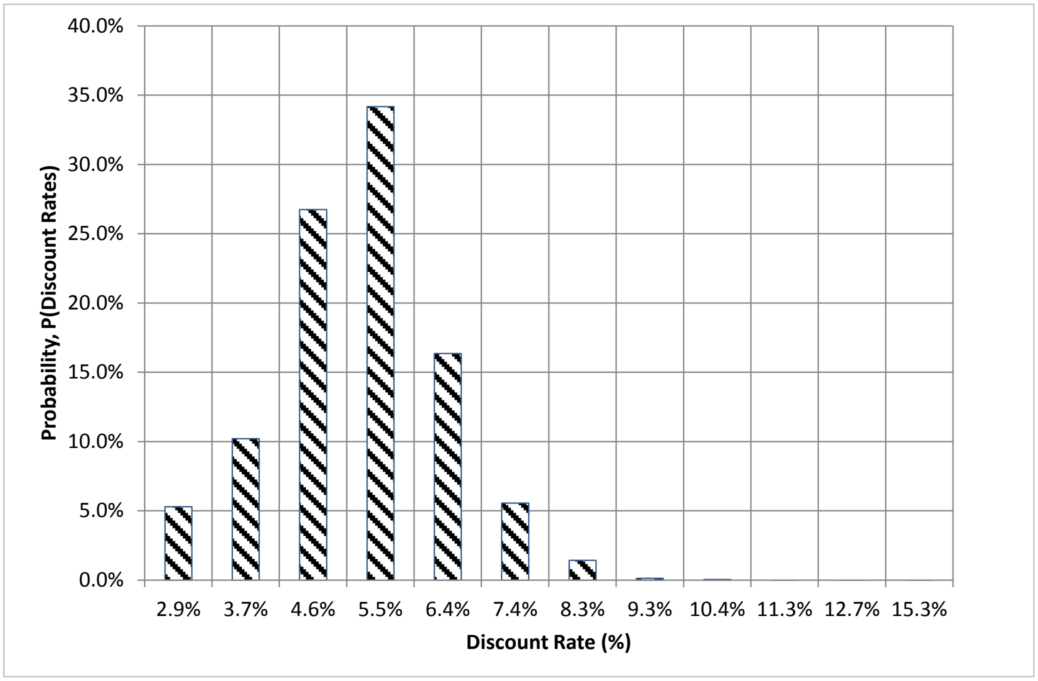

Figure 8G.2.4 Distribution of Commercial Discount Rates: Industrial

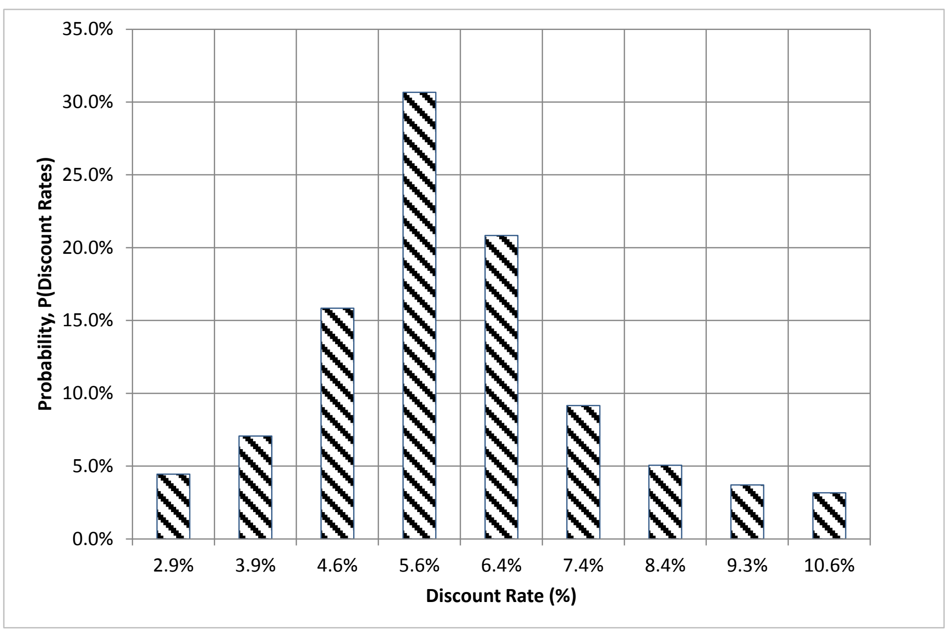

Figure 8G.2.5 Distribution of Commercial Discount Rates: Hotels/Lodging

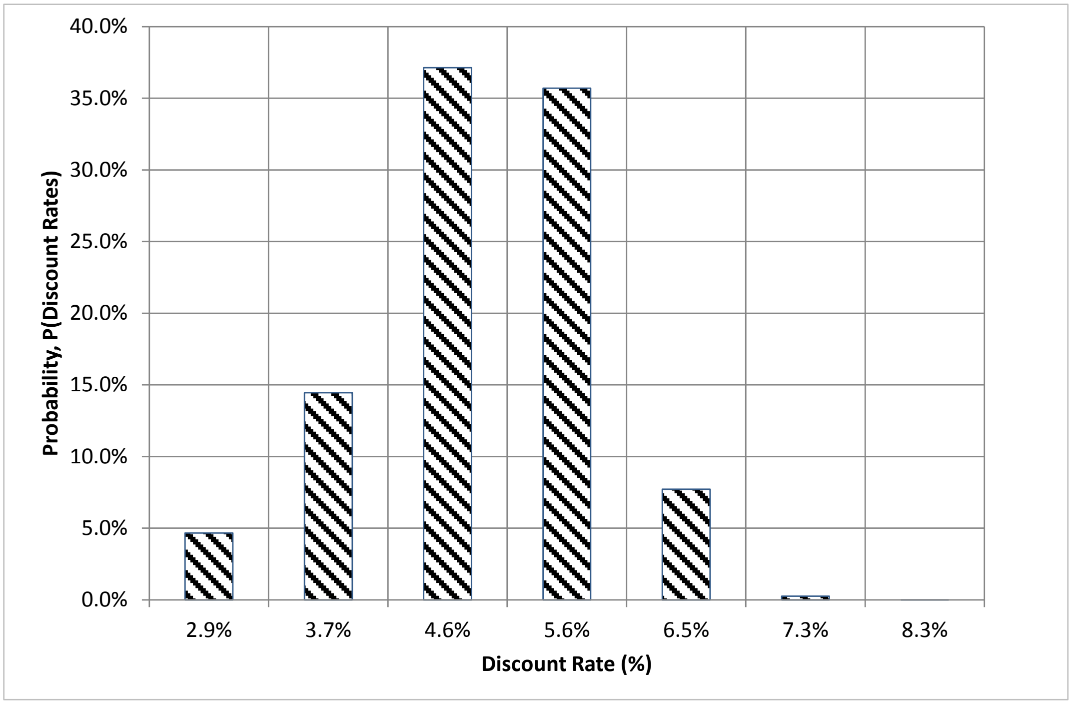

Figure 8G.2.6 Distribution of Commercial Discount Rates: Food Service

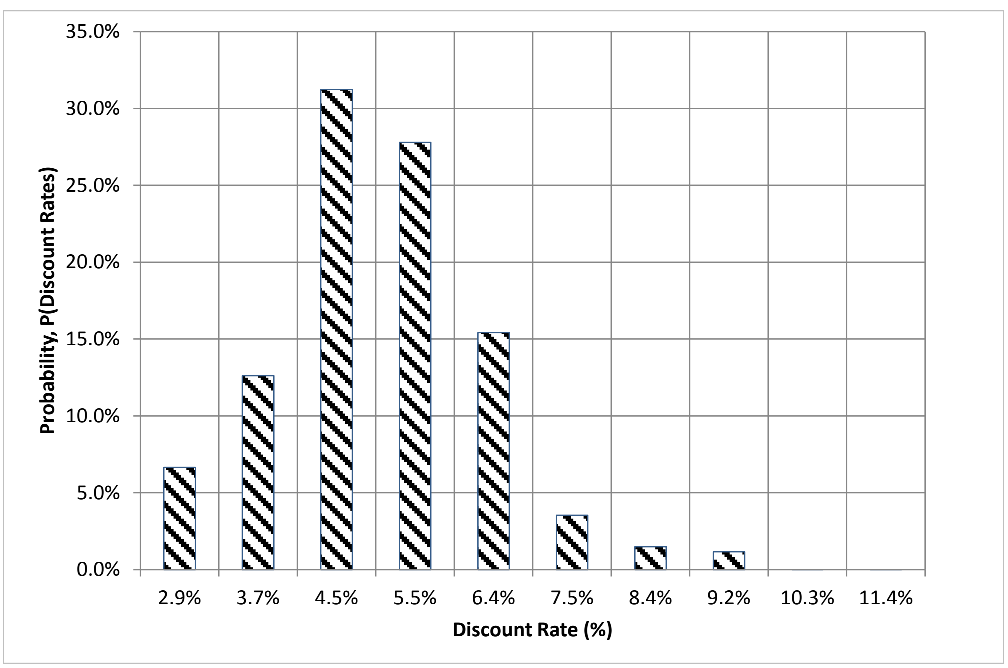

Figure 8G.2.7 Distribution of Commercial Discount Rates: Office

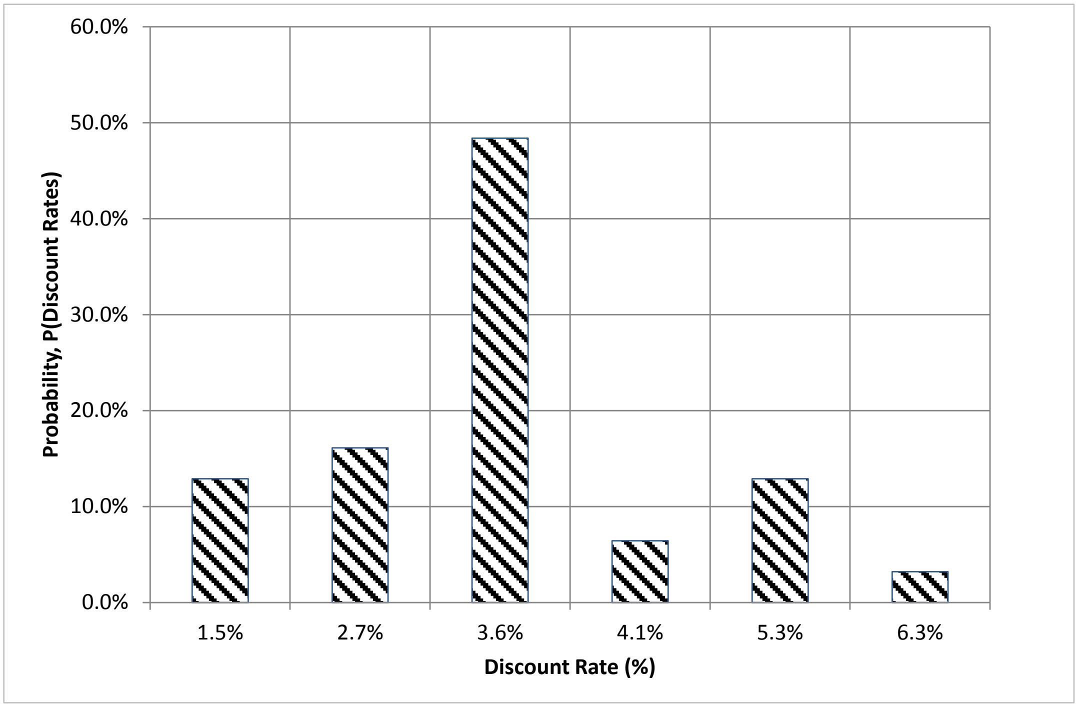

Figure 8G.2.8 Distribution of Commercial Discount Rates: State and Local Government

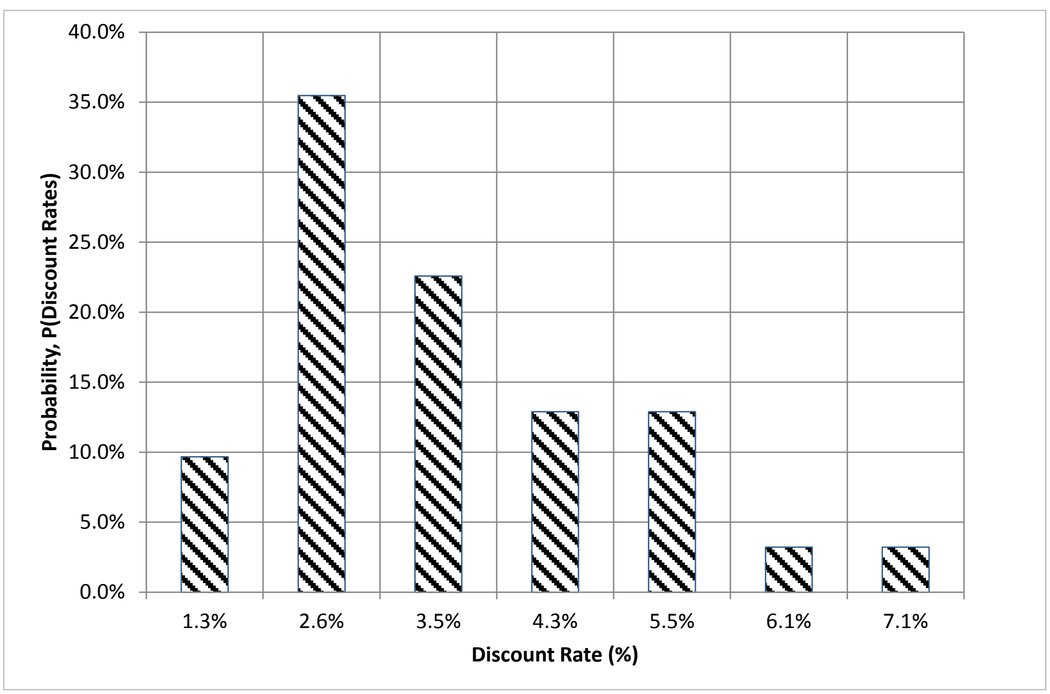

Figure 8G.2.9 Distribution of Commercial Discount Rates: Federal Government

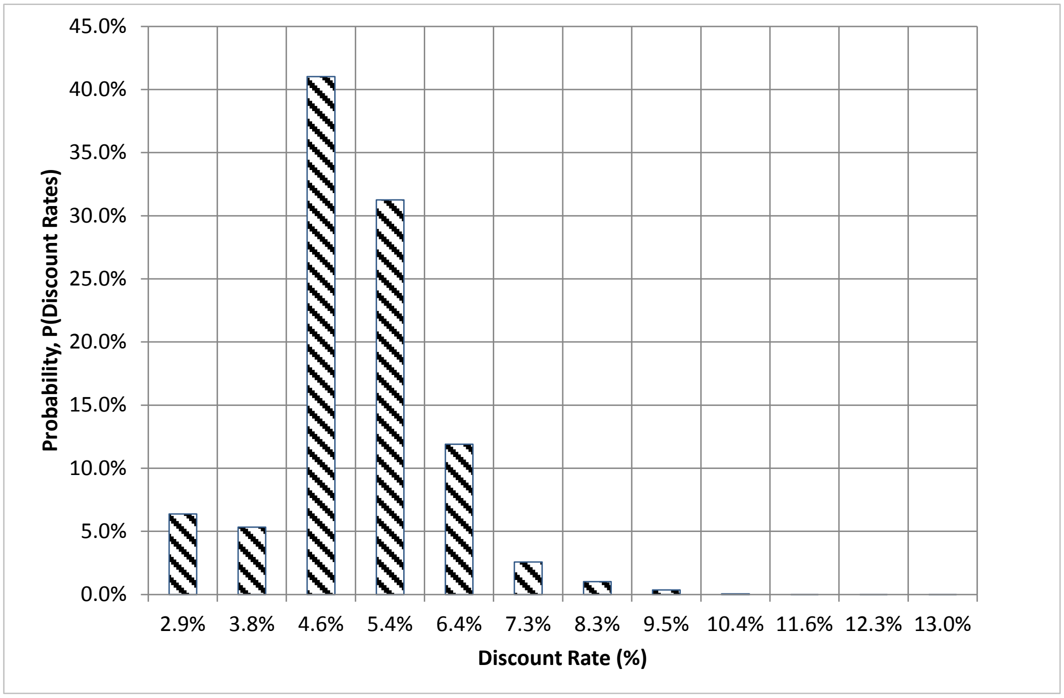

Figure 8G.2.10 Distribution of Commercial Discount Rates: Other

8G.3 DISTRIBUTIONS USED FOR RESIDENTIAL CONSUMER DISCOUNT RATES

DOE derives consumer discount rates for the LCC analysis using data about interest or return rates, for various types of debt and equity, to calculate a real effective discount rate for each household in the Federal Reserve Board's *Survey of Consumer Finances (SCF)* in 1995, 1998, 2001, 2004, 2007, and 2010.[3] To account for variation among households in rates for each type of debt and equity, DOE samples a rate for each household in its building sample from a distribution of discount rates for each of six income groups. Upon identifying the specific income group (from a total of six possible income groups) the selected building sample belongs to, DOE utilizes the rate applicable for that income group. This appendix describes the distributions used.

8G.3.1 Distribution of Rates for Debt Classes

Figure 8G.3.1 through Figure 8G.3.6 show the distribution of real interest rates for different types of household debt. The data source for the interest rates for mortgages, home equity loans, credit cards, installment loans, other residence loans, and other lines of credit is the Federal Reserve Board's *SCF* in 1995, 1998, 2001, 2004, 2007, and 2010.[3] DOE adjusts the nominal rates to real rates using the annual inflation rate in each year.

Using the appropriate *SCF* data for each year, DOE adjusts 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 sets the real effective interest rate to zero.

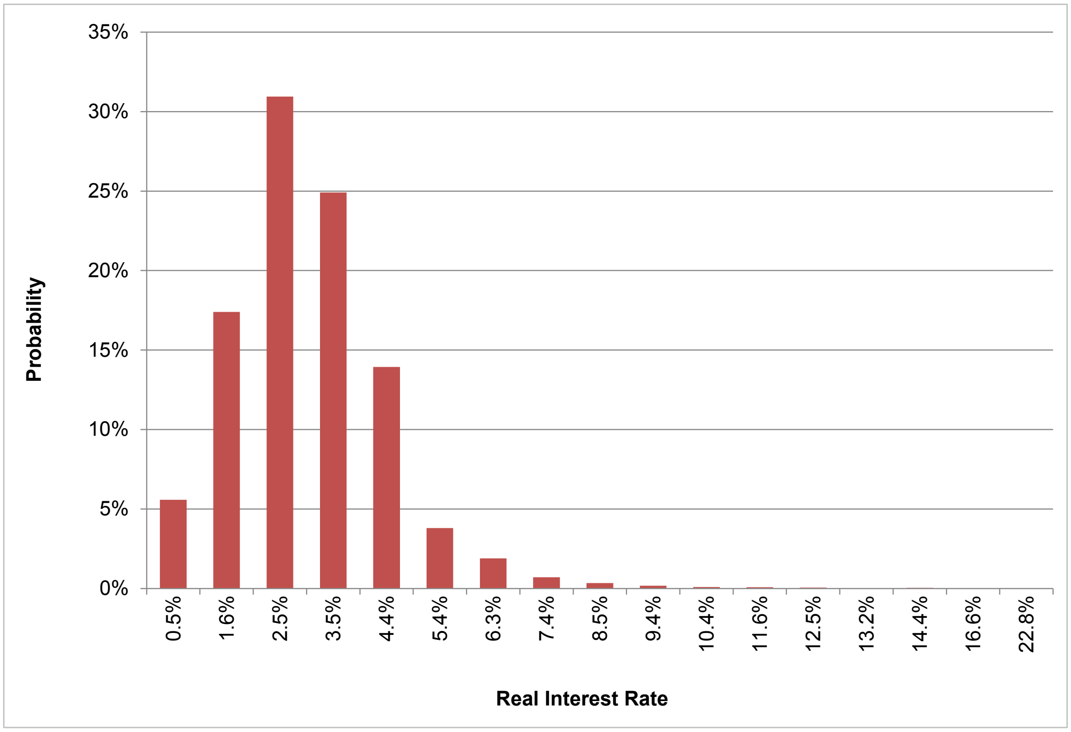

Figure 8G.3.1 Distribution of Mortgage Interest Rates

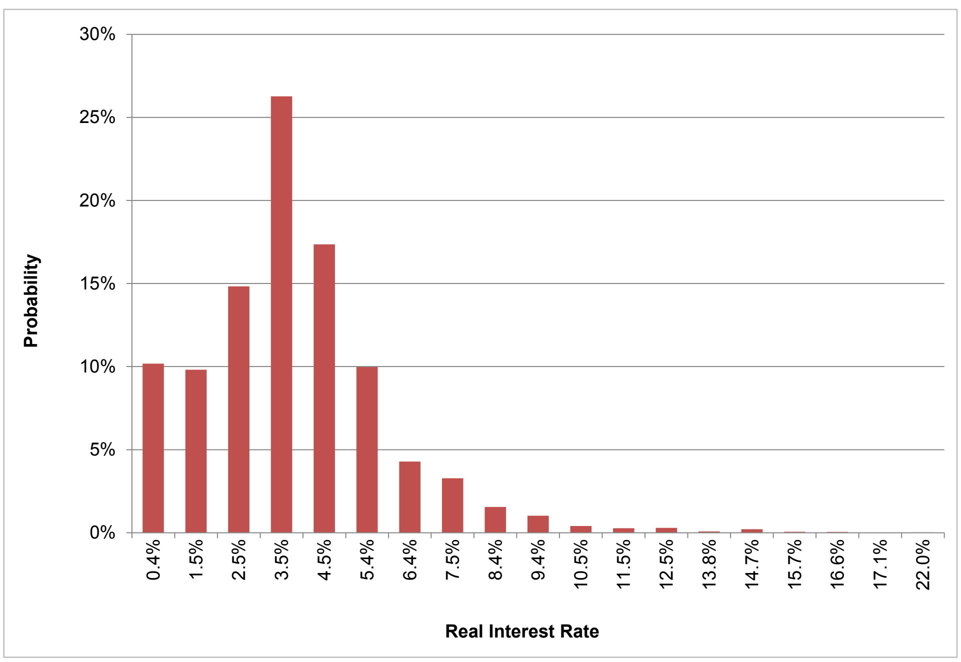

Figure 8G.3.2 Distribution of Home Equity Loan Interest Rates

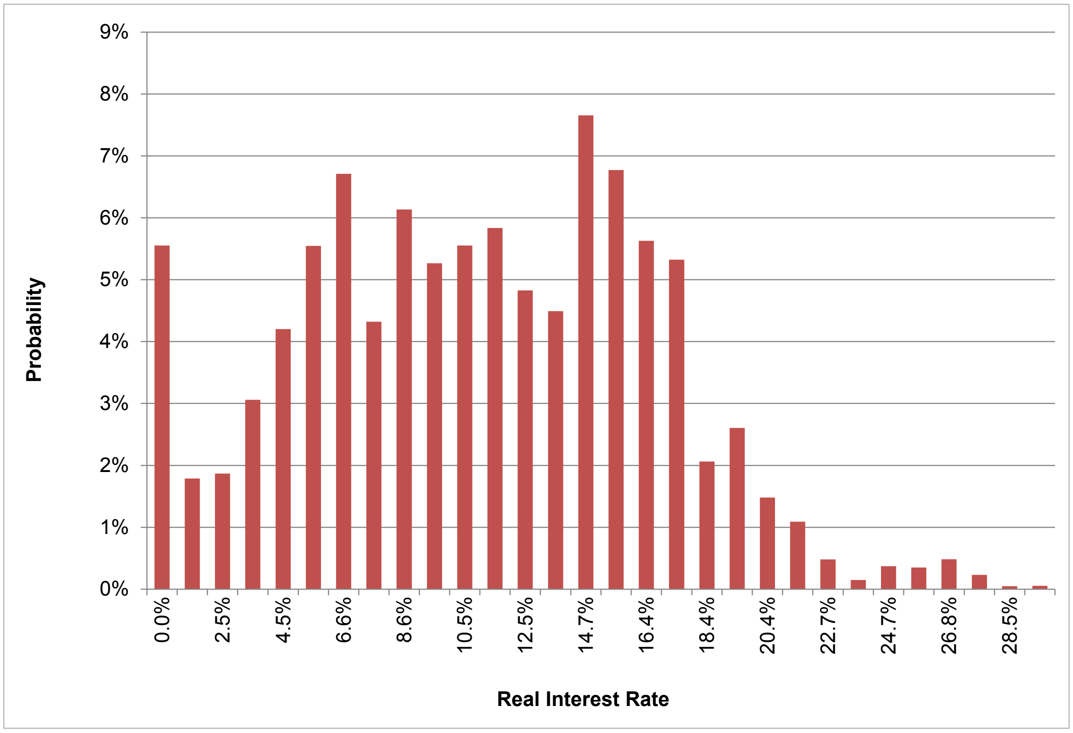

Figure 8G.3.3 Distribution of Credit Card Interest Rates

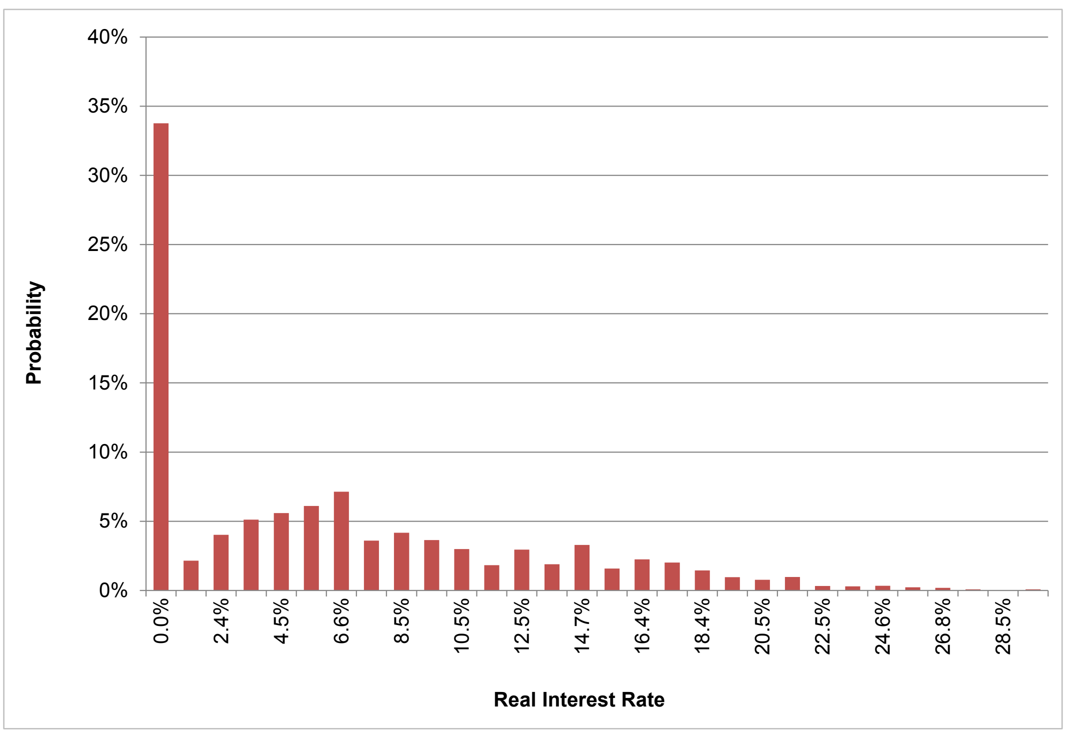

Figure 8G.3.4 Distribution of Installment Loan Interest Rates

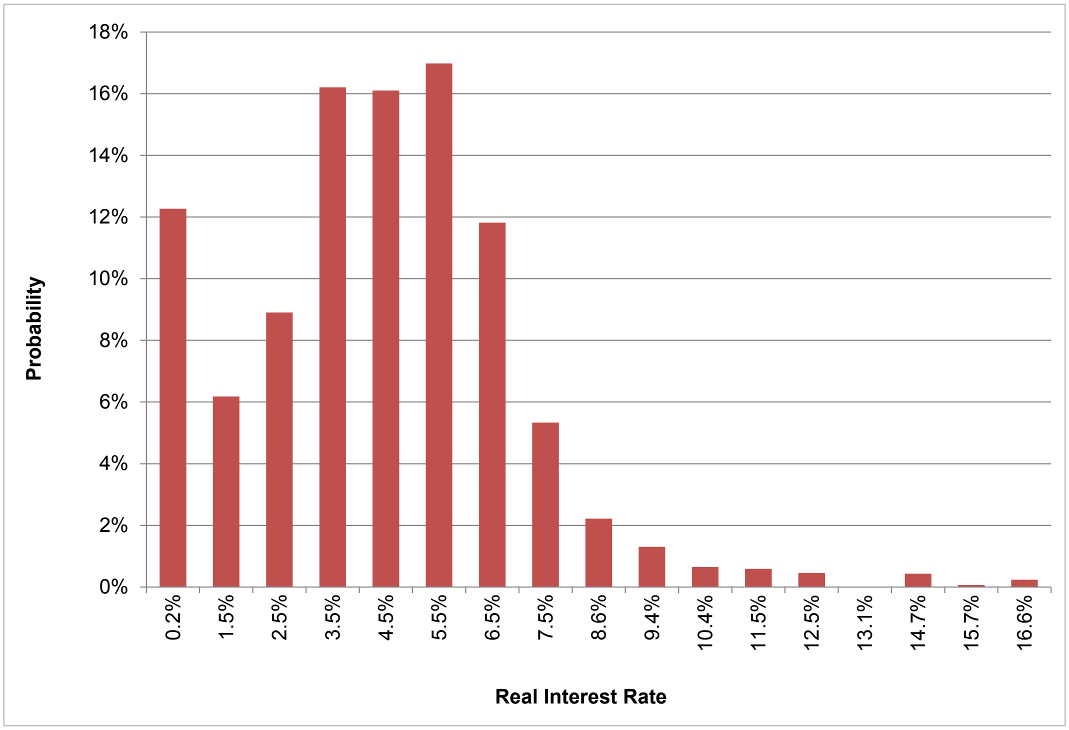

Figure 8G.3.5 Distribution of Other Residence Loan Interest Rates

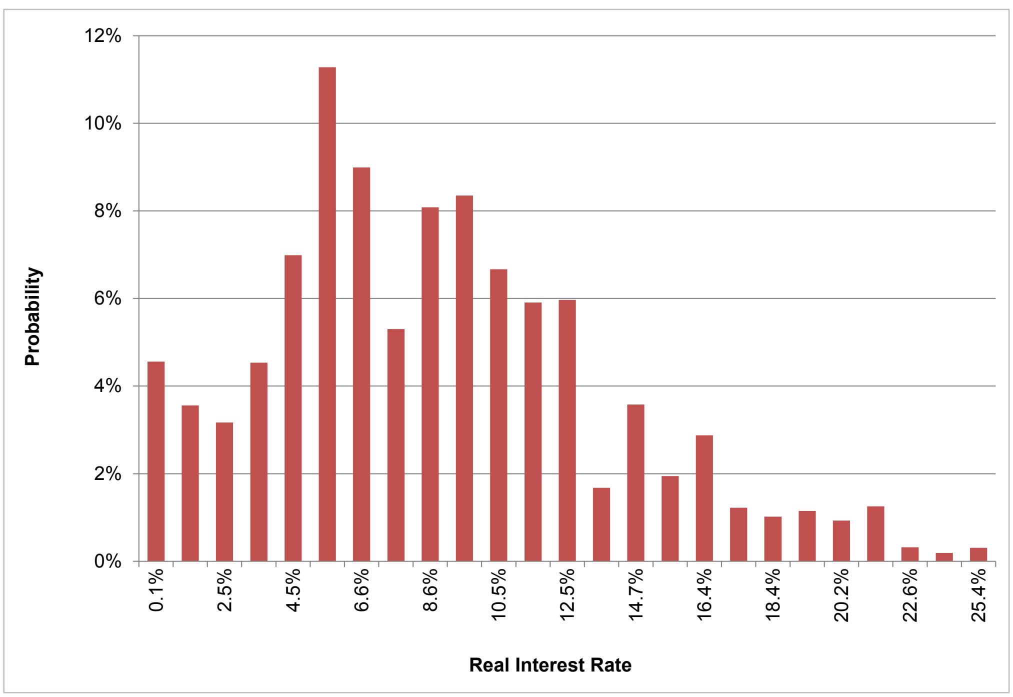

Figure 8G.3.6 Distribution of Other Lines of Credit Loan Interest Rates

8G.3.2 Distribution of Rates for Equity Classes

Figure 8G.3.7 through Figure 8G.3.13 show the distribution of real interest rates for different types of equity. Data for equity classes are not available from the Federal Reserve Board's *SCF*, so DOE derived data for these classes from national-level historical data (1984–2013). The interest rates associated with certificates of deposit (CDs),[4] savings bonds,[2] and AAA corporate bonds[5] are from Federal Reserve Board time-series data. DOE assumes rates on checking accounts to be zero. Rates on savings and money market accounts are from Cost of Savings Index data.[6] The rates for stocks are the annual returns on the Standard and Poor's (S&P) 500.[7] The mutual fund rates are a weighted average of the stock rates (two-thirds weight) and the bond rates (one-third weight) in each year. DOE adjusts the nominal rates to real rates using the annual inflation rate in each year.

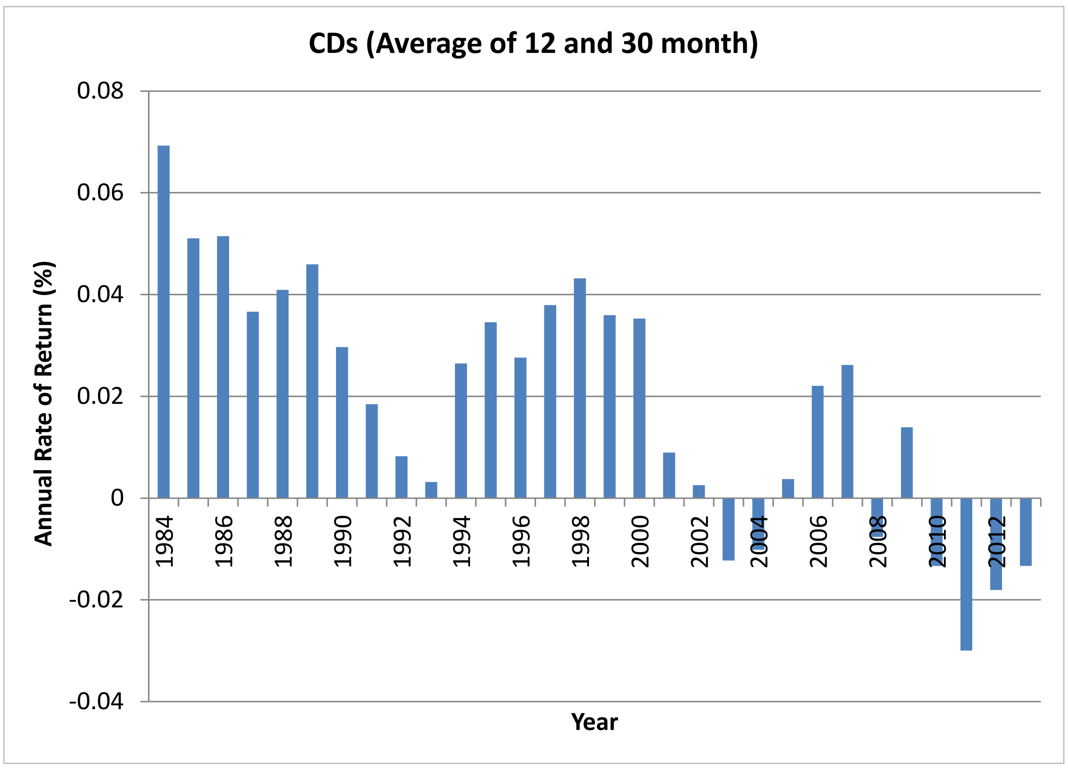

Figure 8G.3.7 Distribution of Annual Rate of Return on Certificates of Deposit

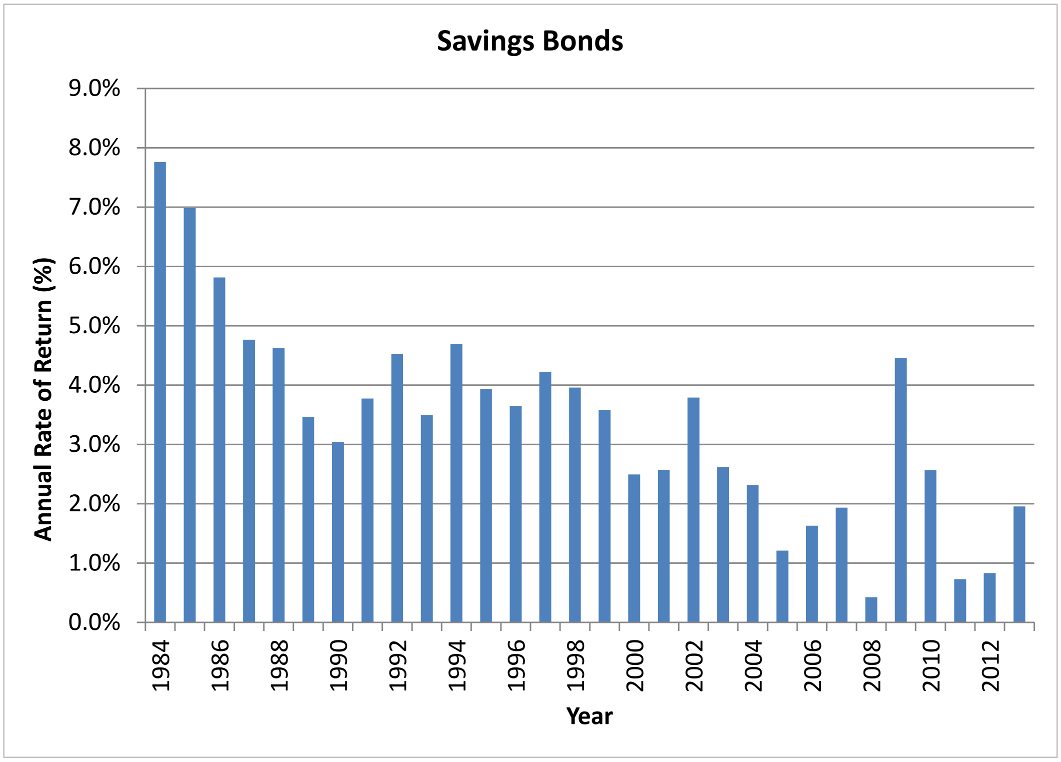

Figure 8G.3.8 Distribution of Annual Rate of Return on Savings Bonds

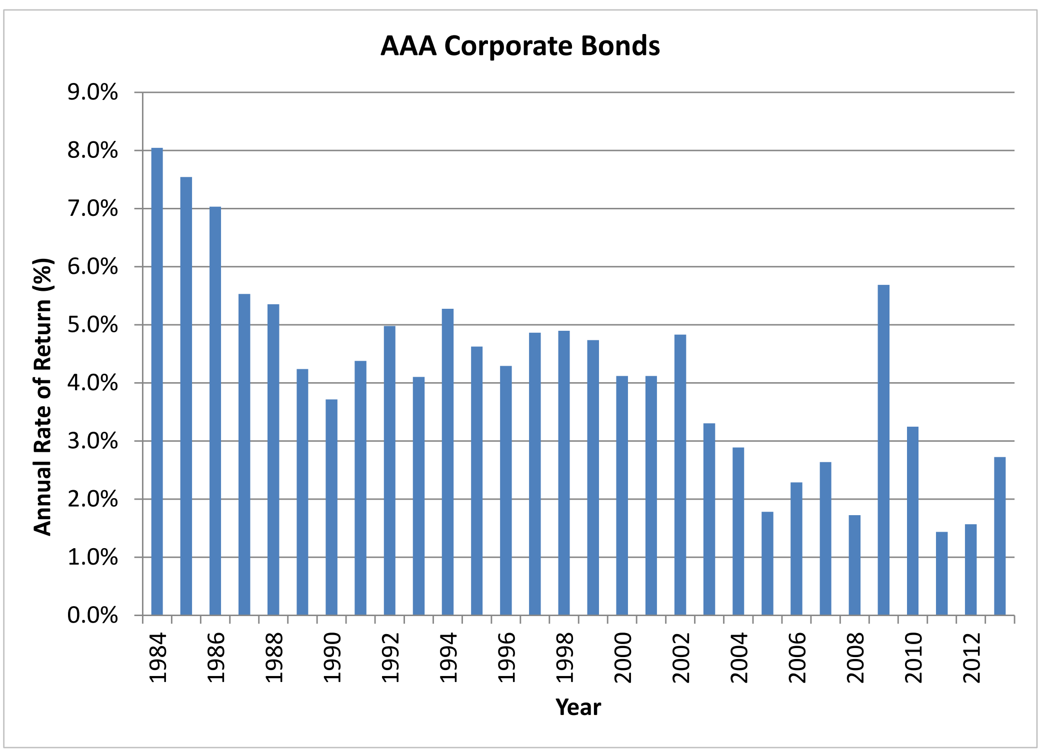

Figure 8G.3.9 Distribution of Annual Rate of Return on Corporate AAA Bonds

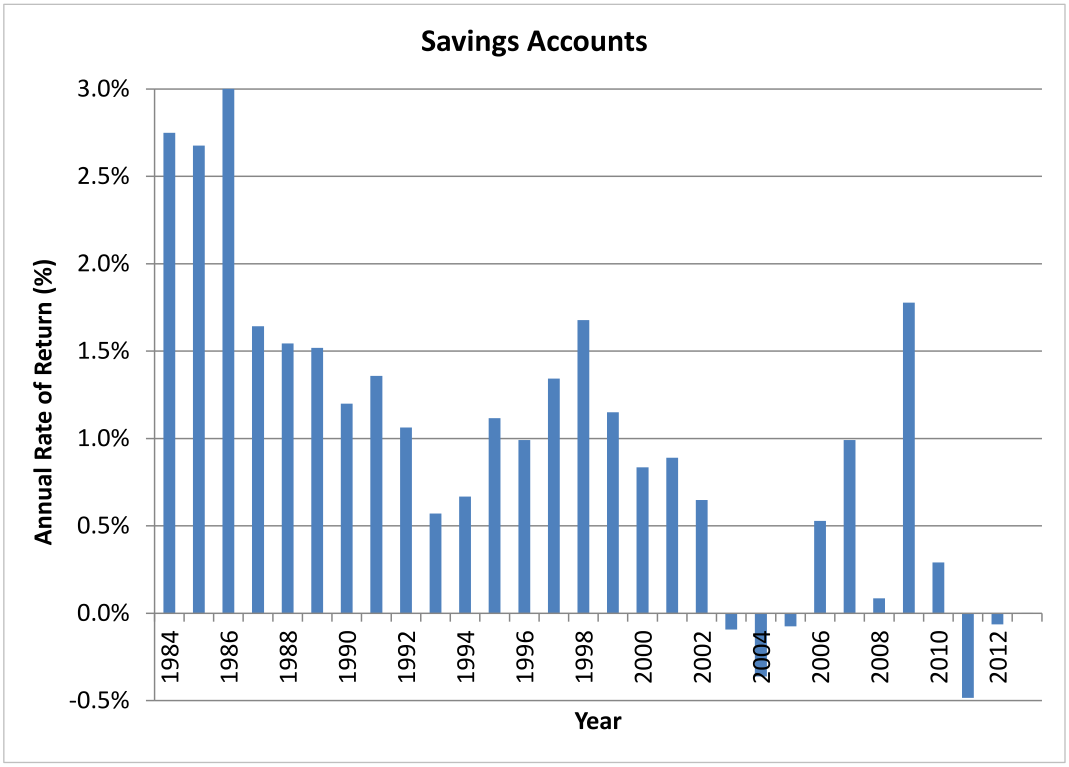

Figure 8G.3.10 Distribution of Annual Rate of Savings Accounts

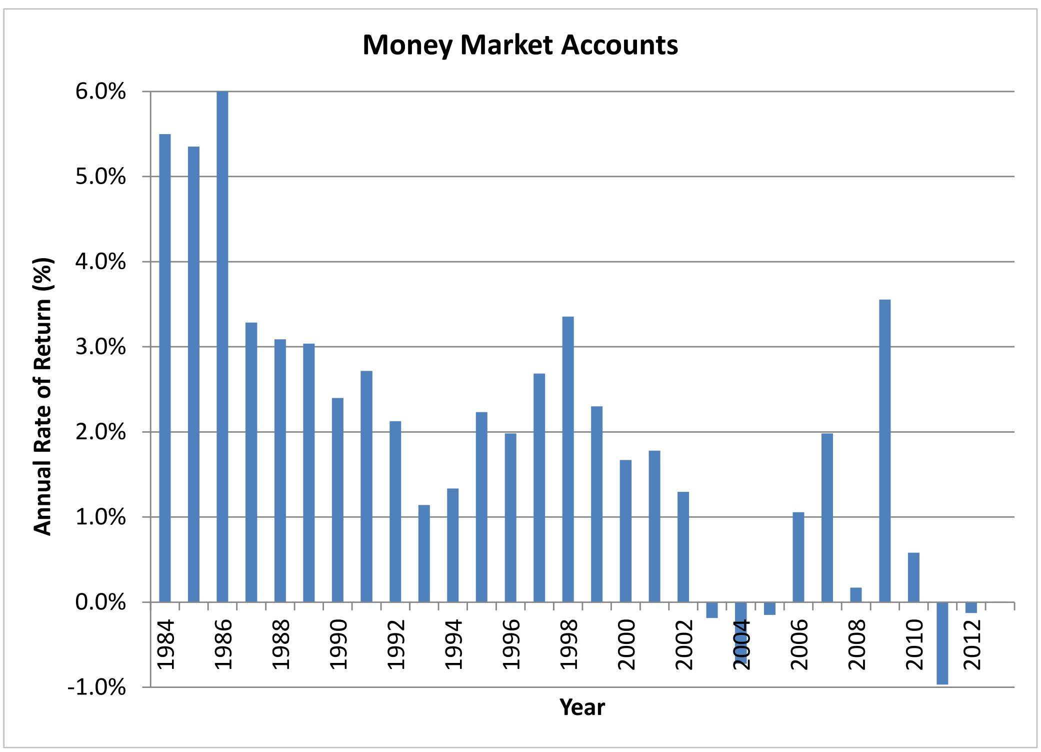

Figure 8G.3.11 Distribution of Annual Rate of Money Market Accounts

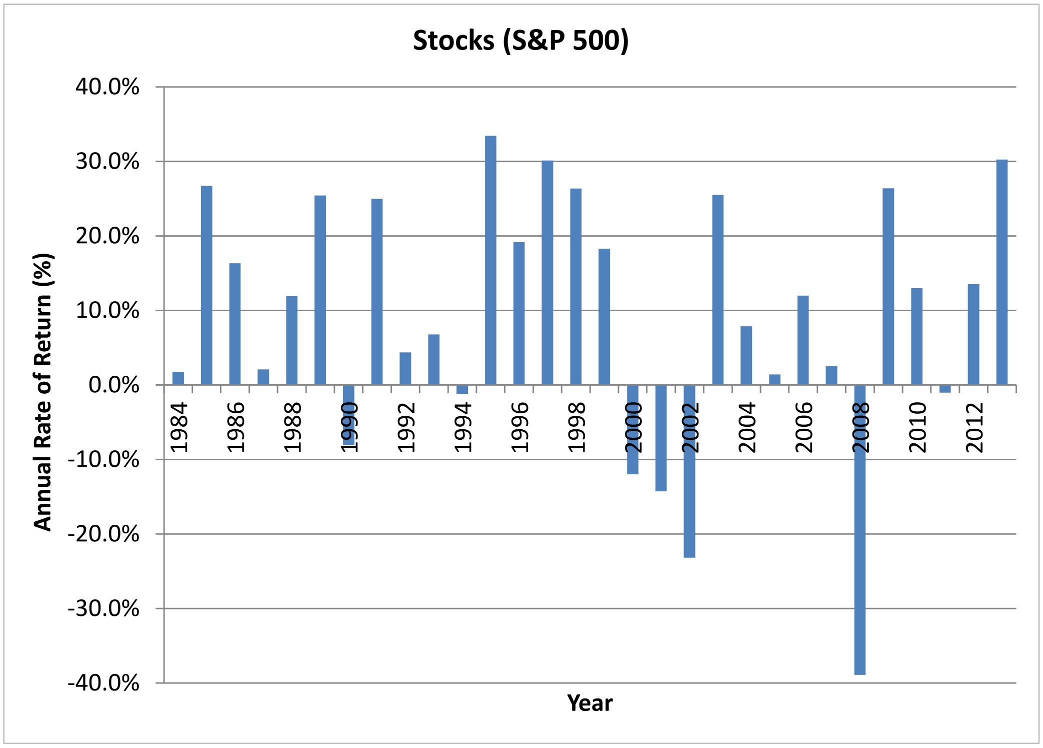

Figure 8G.3.12 Distribution of Annual Rate of Return on Standard and Poor's 500

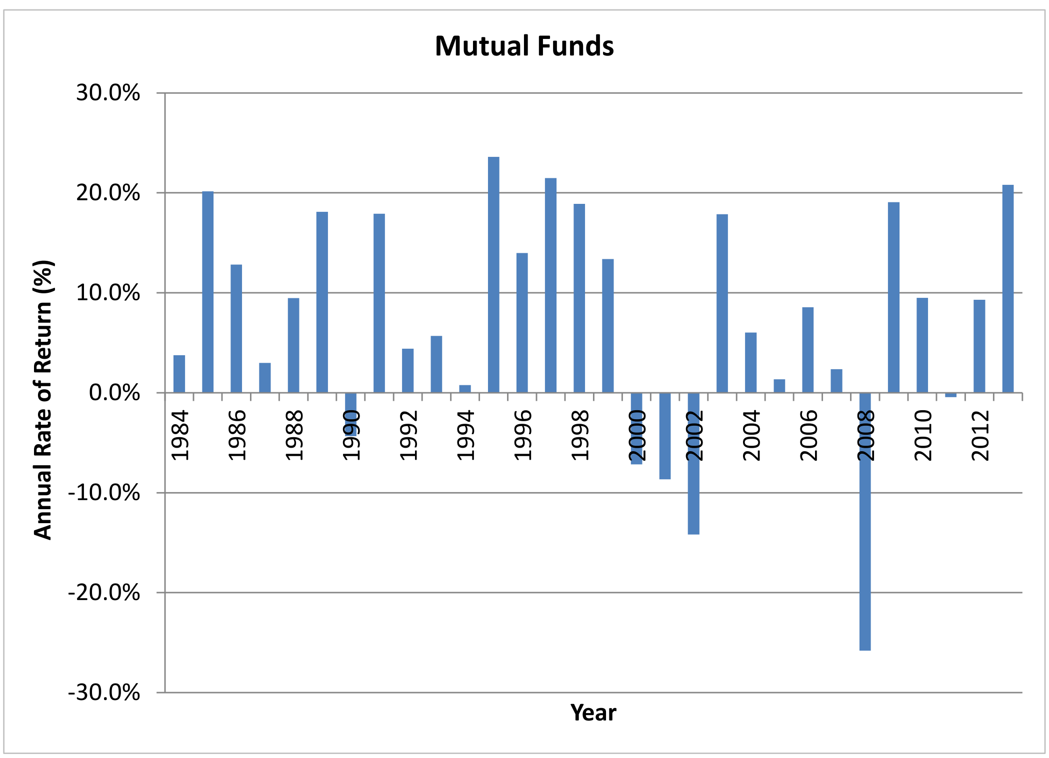

Figure 8G.3.13 Distribution of Annual Rate of Return on Mutual Funds

8G.4 DISTRIBUTION OF REAL EFFECTIVE DISCOUNT RATES BY INCOME GROUP

Figure 8G.4.1 and Table 8G.4.1 present the distributions of real discount rates for each income group.

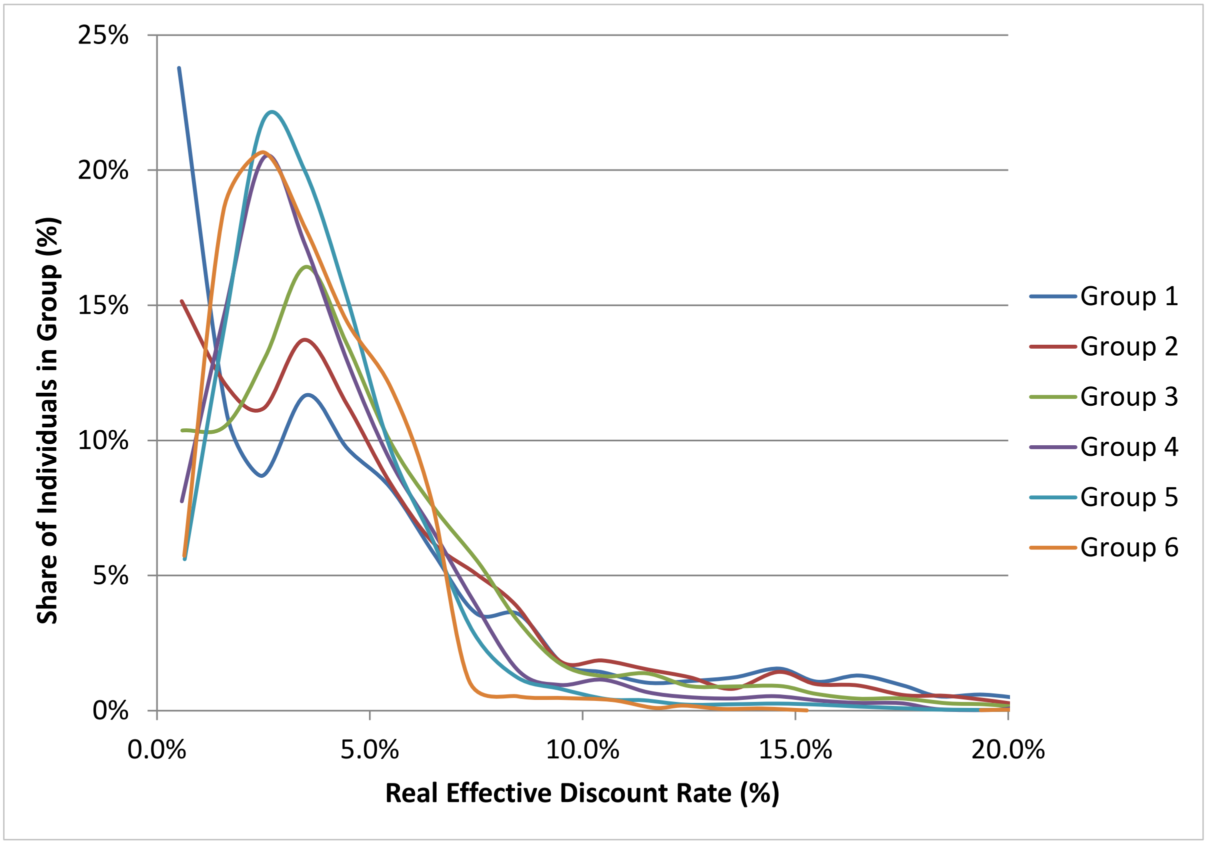

Figure 8G.4.1 Distribution of Real Discount Rates by Income Group

Table 8G.4.1 Distribution of Real Discount Rates by Income Group

DR Bin	Income Group 1 (1-20 percentile)		Income Group 2 (21-40 percentile)		Income Group 3 (41-60 percentile)		Income Group 4 (61-80 percentile)		Income Group 5 (81-90 percentile)		Income Group 6 (90-99 percentile)	
	rate	wt.	rate	wt.	rate	wt.	rate	wt.	rate	wt.	rate	wt.
0-1	0.5%	0.238	0.6%	0.152	0.6%	0.104	0.6%	0.077	0.6%	0.056	0.6%	0.057
1-2	1.6%	0.110	1.6%	0.120	1.6%	0.105	1.6%	0.146	1.6%	0.142	1.6%	0.185
2-3	2.5%	0.087	2.5%	0.112	2.6%	0.131	2.5%	0.205	2.5%	0.219	2.5%	0.207
3-4	3.5%	0.117	3.5%	0.137	3.5%	0.164	3.5%	0.173	3.5%	0.200	3.5%	0.178
4-5	4.5%	0.097	4.5%	0.113	4.5%	0.136	4.5%	0.129	4.5%	0.153	4.5%	0.144
5-6	5.5%	0.083	5.5%	0.084	5.5%	0.100	5.5%	0.093	5.5%	0.098	5.5%	0.120
6-7	6.5%	0.058	6.5%	0.062	6.5%	0.075	6.5%	0.067	6.5%	0.063	6.4%	0.079
7-8	7.5%	0.036	7.5%	0.051	7.6%	0.054	7.4%	0.041	7.4%	0.029	7.3%	0.011
8-9	8.5%	0.036	8.4%	0.039	8.4%	0.034	8.5%	0.015	8.4%	0.012	8.5%	0.005
9-10	9.5%	0.017	9.5%	0.018	9.5%	0.017	9.5%	0.010	9.5%	0.008	9.6%	0.005
10-11	10.5%	0.014	10.5%	0.019	10.5%	0.013	10.5%	0.011	10.6%	0.004	10.7%	0.004
11-12	11.5%	0.010	11.5%	0.015	11.5%	0.014	11.5%	0.007	11.4%	0.004	11.7%	0.001
12-13	12.5%	0.011	12.5%	0.012	12.5%	0.009	12.4%	0.005	12.4%	0.002	12.4%	0.002
13-14	13.6%	0.012	13.5%	0.008	13.5%	0.009	13.5%	0.004	13.5%	0.002	13.3%	0.001
14-15	14.6%	0.016	14.6%	0.014	14.6%	0.009	14.5%	0.005	14.6%	0.003	14.2%	0.001
15-16	15.5%	0.011	15.5%	0.010	15.5%	0.006	15.6%	0.004	15.6%	0.002	15.3%	0.000
16-17	16.5%	0.013	16.5%	0.009	16.5%	0.004	16.5%	0.003	16.5%	0.001	0.0%	0.000
17-18	17.5%	0.009	17.6%	0.006	17.5%	0.005	17.5%	0.003	17.6%	0.001	17.7%	0.001
18-19	18.4%	0.005	18.5%	0.005	18.6%	0.003	18.4%	0.001	18.2%	0.000	0.0%	0.000
19-20	19.4%	0.006	19.4%	0.004	19.4%	0.002	19.7%	0.000	19.7%	0.000	19.4%	0.000
20-21	20.6%	0.004	20.4%	0.002	20.5%	0.001	20.3%	0.001	20.5%	0.000	20.3%	0.000
21-22	21.4%	0.003	21.4%	0.002	21.4%	0.001	21.5%	0.001	0.0%	0.000	21.4%	0.000
22-23	22.5%	0.002	22.4%	0.001	22.6%	0.001	22.9%	0.000	22.8%	0.000	22.3%	0.000
23-24	23.6%	0.001	23.4%	0.001	23.6%	0.001	0.0%	0.000	0.0%	0.000	24.0%	0.000
24-25	24.6%	0.001	24.5%	0.000	24.6%	0.000	24.1%	0.000	24.3%	0.000	0.0%	0.000
25-26	25.4%	0.001	25.4%	0.001	25.5%	0.000	0.0%	0.000	0.0%	0.000	0.0%	0.000
26-27	26.5%	0.001	26.5%	0.000	26.4%	0.000	0.0%	0.000	0.0%	0.000	0.0%	0.000
27-28	27.8%	0.000	27.6%	0.000	27.8%	0.000	0.0%	0.000	0.0%	0.000	0.0%	0.000
28-29	28.2%	0.000	0.0%	0.000	0.0%	0.000	0.0%	0.000	0.0%	0.000	0.0%	0.000
29-23	29.9%	0.000	29.3%	0.000	0.0%	0.000	0.0%	0.000	0.0%	0.000	0.0%	0.000
>30	59.1%	0.001	142.7%	0.002	0.0%	0.000	53.3%	0.000	0.0%	0.000	0.0%	0.000

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1. Damodaran Online. *Data Page: Costs of Capital by Industry Sector*. 2012. Damodaran. http://pages.stern.nyu.edu/~adamodar/. Last accessed August 18, 2015.

2. The Federal Reserve Board. Federal Reserve Statistical Release, Selected Interest Rates, Historical Data, Instrument: State and local bonds, Maturity: 20-year, Frequency: Monthly, Description: Bond buyer go 20-bond municipal bond index. *Historical Data*. 2013. www.federalreserve.gov/releases/H15/data.htm. Last accessed August 18, 2015.

3. The Federal Reserve Board. *Survey of Consumer Finances 1989, 1992, 1995, 1998, 2001, 2004, 2007, 2010.* www.federalreserve.gov/pubs/oss/oss2/scfindex.html. Last accessed August 18, 2015.

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5. The Federal Reserve Board. Federal Reserve Statistical Release, Selected Interest Rates, Historical Data, Instrument: Corporate bonds/Moody's Seasoned AAA, Frequency: Annual, Description: Moody's yield on seasoned corporate bonds—all industries, AAA. *Historical Data*. 2013. www.federalreserve.gov/releases/H15/data.htm. Last accessed August 18, 2015.

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APPENDIX 8H. NO-NEW-STANDARDS CASE EFFICIENCY DISTRIBUTION LEVELS

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APPENDIX 8H. NO-NEW-STANDARDS CASE DISTRIBUTION OF EFFICIENCY LEVELS

8H.1 INTRODUCTION

DOE determined the market distribution of equipment efficiency by analyzing the presence of models in the market. DOE developed a database of unique models from data in the Air-Conditioning, Heating, and Refrigeration Institute (AHRI) Directory of Certified Product Performance[1] and California Energy Commission (CEC) Appliance Efficiency Database.[2] Duplicate models (both within each brand and amongst brands made by the same manufacturer) were removed to ensure the analysis was conducted specifically on unique models.

8H.2 ESTIMATE OF EFFICIENCY DISTRIBUTIONS BY EQUIPMENT CLASS AND EFFICIENCY LEVEL

DOE categorized models based on their equipment class specifications, then binned them within each equipment class based on their thermal efficiency performance. Each thermal efficiency bin started with baseline efficiency (*e.g.*, 80 percent) and increased by increments of whole percentages to max tech thermal efficiency. A thermal efficiency bin included all models up to the performance of the next thermal efficiency bin. Hence, the 80 percent thermal efficiency bin included all models from 80 percent up to 81 percent thermal efficiency.

Once the distribution of thermal efficiency performance was calculated for each equipment class, DOE determined the distribution of standby loss performance. In its engineering analysis, DOE developed standby loss performance relative to both the baseline thermal efficiency and baseline standby loss performance. To align with the engineering analysis methodology, DOE binned standby loss based on the ratio of the more efficient standby loss efficiency levels to the baseline standby loss efficiency level. To determine which models fall into which standby loss efficiency bins, first DOE converted the standby loss performance of each model to sensible standby loss by multiplying the standby loss (Btu/h) rate by the model's thermal efficiency.

$$SL_{sensible} = SL_{model} * Et$$

Eq. 8H.1

Where:

$SL_{sensible}$ = Sensible standby loss performance for the model, Btu/h,
SL_{model} = Reported standby loss performance for the model, Btu/h, and
Et = Thermal efficiency performance for the model, %.

Then, DOE converted the maximum allowable standby loss for the baseline model into maximum allowable sensible standby loss using this same equation. Next, DOE divided the model's sensible standby loss by the maximum allowable sensible standby loss of the baseline model to determine the ratio of sensible standby loss performance to the maximum allowed. DOE used the calculated ratios of each model to determine which bin each model fell into. Each standby loss bin contained the number of models meeting the percentage-below-the-standard up to the next bin. The distribution of standby loss performance was determined for each thermal efficiency bin. The final thermal efficiency and standby loss distributions were used to analyze the market impact of more stringent commercial water heating (CWH) equipment standards across efficiency levels of each equipment class. Table 8H.2.1 presents the efficiency distributions used in the LCC model for the different equipment classes. Since, DOE considered standby loss levels for each equipment class, the fraction of units is presented based on both thermal efficiency and standby loss levels, within each equipment class.

Table 8H.2.1 Fraction of Commercial Water Heater Models by Thermal Efficiency (EL) and Standby Loss (SL) Levels*

SL	EL	CGSWH		RDGSWH		CGITWH		CGIHWSB		CESWH	
		Options	Percentages	Options	Percentages	Options	Percentages	Options	Percentages	Options	Percentages
0	0	1	43.0%	1	53.7%	1	16.0%	1	40.2%	1	97.2%
0	1	2	10.7%	2	1.5%	2	40.0%	2	23.8%	2	0.0%
0	2	3	0.0%	3	0.0%	3	28.0%	3	13.8%	3	0.0%
0	3	4	4.3%	4	0.0%	4	4.0%	4	1.7%	4	0.0%
0	4	5	7.6%	5	0.0%	5	4.0%	5	7.1%	5	0.0%
0	5	6	0.9%	6	0.0%	6	8.0%	6	13.4%	6	0.0%
0	6	7	0.0%	7	0.0%	7	0.0%	7	0.0%	7	0.0%
1	0	8	11.3%	8	7.5%					8	2.8%
1	1	9	0.0%	9	0.0%					9	0.0%
1	2	10	0.0%	10	3.0%					10	0.0%
1	3	11	1.2%	11	16.4%					11	0.0%
1	4	12	3.4%	12	6.0%					12	0.0%
1	5	13	0.3%	13	0.0%					13	0.0%
1	6	14	0.0%	14	0.0%					14	0.0%
2	0	15	2.4%	15	3.0%						
2	1	16	1.5%	16	1.5%						
2	2	17	0.3%	17	0.0%						
2	3	18	0.9%	18	0.0%						
2	4	19	12.2%	19	0.0%						
2	5	20	0.0%	20	0.0%						
2	6	21	0.0%	21	0.0%						
3	0			22	1.5%						
3	1			23	6.0%						
3	2			24	0.0%						
3	3			25	0.0%						
3	4			26	0.0%						
3	5			27	0.0%						
3	6			28	0.0%						

* Note: CGSWH is commercial gas storage water heater, RDGSWH is residential-duty gas storage water heater, CGITWH is commercial gas instantaneous tank less water heater, CGIHWSB is commercial gas instantaneous hot water supply boiler, and CESWH is commercial electric storage water heater.

8H.3 TRANSITION FROM NO-NEW STANDARDS CASE EFFICIENCY POINT TO REGULATORY COMPLIANCE POINT

Since the regulatory standard is set based on both thermal efficiency and standby loss levels, when evaluating the commercial consumer's current equipment, DOE considers both components as well. If the consumer's current level in either (thermal efficiency or standby loss) component is equal to or higher than the “ Prospective Standard Level” then the consumer does not move (*i.e*., no impact). If in either of those cases, the consumer is at a lower level than the “Prospective Standard Level,” then the consumer is bound to move to the “Standard Level.” The LCC savings are calculated based on the costs of such transition.

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CHAPTER 9. SHIPMENTS ANALYSIS

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CHAPTER 9. SHIPMENTS ANALYSIS

9.1 INTRODUCTION

Estimates of future equipment shipments are a necessary input to calculations of the national energy savings (NES) and net present value (NPV), as well as to the manufacturer impact analysis (MIA). This chapter describes the data and methods the U.S. Department of Energy (DOE) used to project annual equipment shipments and presents results for commercial water heating (CWH) equipment classes considered in this analysis.

The shipments model divides the shipments of commercial water heaters into specific market segments. The model starts from a historical base year and calculates retirements and shipments by market segment for each year of the analysis period. This approach produces an estimate of the total equipment stock, broken down by age or vintage, in each year of the analysis period. In addition, the equipment stock efficiency distribution is calculated for a no-new-standards case and for each standards case for each equipment class. The stock distribution is used in the national impact analysis (NIA) to estimate the total costs and benefits associated with each efficiency level.

The shipments model was developed as a Microsoft Excel spreadsheet that is accessible on DOE's appliance and equipment standards website (https://www1.eere.energy.gov/buildings/appliance_standards/standards.aspx?productid=36). Appendix 10A discusses how to access and utilize the shipments model spreadsheet, which is integrated into the spreadsheet for the NIA. This chapter explains how the shipments model is constructed and provides summary output. Sections 9.2 and 9.3 describe the methodological approach.

Table 9.1.1 lists the product classes for which shipment projections were developed. The CWH shipments model considers three equipment placement channels (hereafter referred to as "channels") as follows:

1) New construction: this is defined as the fraction of new buildings that acquire commercial water heaters in each future year. This fraction is defined as the new construction saturation, which varies by year and by equipment class.

2) Existing owners (replacements): these are defined as existing buildings with commercial water heaters installed. This category receives new shipments when existing equipment is replaced.

3) New owners: these are defined as buildings that switch CWH type during the analysis period at the time of replacement or, in the case of new construction, that acquire a different CWH type than would be expected if the model simply extended the current market saturation rates to the new construction (see section 9.3.4).

Table 9.1.1 Commercial Water Heater Equipment Classes

Product Name
Commercial Gas-Fired Storage Water Heater (CGSWH)
Residential Duty Gas-Fired Storage Water Heater (RGSWH)
Gas-fired instantaneous water heaters and hot water supply boilers
• Commercial Gas-Fired Instantaneous Tankless Water Heater (CGITWH)
• Commercial Gas-Fired Instantaneous Hot Water Supply Boiler (CGIHWSB)
Commercial Electric Storage Water Heater (CESWH)

9.2 FUNDAMENTAL MODEL EQUATIONS

The fundamental dependent variable in the shipments model is the equipment stock, which is represented as a function of analysis year (indexed by *j)*, and equipment vintage or age (the equipment age is noted as *a,* and is equal to the analysis year minus the vintage). The stock function is adjusted in each year of the analysis period by new shipments coming in and broken or demolished equipment being taken out.

For existing stock,

$$Stock_p(j,a) = Stock_p(j-1,a-1) - Rem_p(j,a) + Ship_p(j-1,a-1)$$

Eq. 9.1

and for new shipments,

$$Stock_p(j,a=1) = Ship_p(j-1).$$

Eq. 9.2

Where:

$Stock_p\ (j,\ a)$ = number of units of equipment class *p* and age *a* in analysis year *j,*
$Rem_p\ (j,\ a)$ = number of units of equipment class *p* and age *a* removed in analysis year *j,* and
$Ship_p(j)$ = number of units of equipment class *p* shipped in year *j*.

Removals due to equipment failure contain a survival function $f_p(a)$ that is used to represent the probability that a unit of age *a* will survive in a given year; equivalently, the probability that this unit will fail is 1- $f_p(a)$.

Total removals in the no-new-standards case are then as follows:

$$Rem_p(j,a) = [1 - f_p(a)] \times Stock_p(j,a)$$

Eq. 9.3

9.2.1 Replacement Shipments

The shipments model assumes that units that are taken from demolished buildings, *Dem(j*), are included in the mix of broken units $Rem_p\ (j)$. As the demolished units do not need to be replaced, they are deducted from $Rem_p(j)$ when calculating the required replacements, as represented by the following expression:

$$Rpl_p(j) = Rem_p(j) - Dem(j)$$

Eq. 9.4

When a commercial water heater fails, it is removed from the stock. The following retirement function $r_p(a)$ is used to represent the probability that a unit will fail at age a.

$$Rem_p(j) = \sum_a r_a(a) \times Stock_p(j,a)$$

Eq. 9.5

Retirement functions and equipment lifetimes are discussed in more detail in chapter 8.

In each year, equipment is removed from demolished buildings. As represented by the following expression, the shipments model assumes that the saturation of the equipment in the demolished buildings is the same as that of the overall building population.

$$Dem(j) = D(j) \times sat(p, j-1)$$

Eq. 9.6

The number of demolished buildings is calculated by:

$$D(j) = H\_Stock(j-1) + H\_Starts(j) - H\_Stock(j)$$

Eq. 9.7

Where:

H_Stock (j) = number of building units in analysis year *j,*
H_Starts(j) = number of new building units in year *j*,
D(j) = number of demolished buildings,
Dem (j) = number of equipment demolished in analysis year *j,* and
sat(p,j) = saturation of equipment of equipment class p for all buildings in year *j*.

9.2.2 Shipments to New Construction

DOE multiplied new construction market saturations by projections of new buildings to estimate shipments to the new construction channel. On an equipment class basis, the determination of shipments to new construction is represented by the following expression:

$$NC_p(j) = NC\_Starts\_com(j) \times NC\_Sat\_com_p(j) + NC\_Starts\_res(j) \times NC\_Sat\_res_p(j)$$

Eq. 9.8

Where:

NC_Starts_com(j) = number of new commercial building starts in year *j,*
$NC\_Sat\_com_p(j)$ = new commercial saturation for equipment class *p* and year *j,*
NC_Starts_res(j) = number of new residential housing starts in year *j,* and
$NC\_Sat\_res_p(j)$ = new residential saturation for equipment class *p* and year *j*.

9.2.3 Shipments to New Owners

The third market segment consists of new owners of equipment in a given equipment class, and also includes an adjustment for switching to a different equipment class. Because there are no data on the extent of these phenomena, DOE estimated historical shipments to this market segment as a residual, using the following equation:

$$NO(j) = Shipment(j) - (RU(j) + NU(j))$$

Eq. 9.9

Where:

j = year where historical shipment data is available,
$NO(j)$ = new owners (if positive) or adjustment for switching (if negative) for year j,
$Shipment(j)$ = historical shipment in year j,
$RU(j)$ = estimated replacement units in year j, and
$NU(j)$ = estimated new units for new buildings in year j.

9.3 DATA INPUTS AND SUPPORTING CALCULATIONS

9.3.1 Historical Shipments

DOE obtained historical data from 1994 through 2013 for commercial gas and electric storage water heater shipments from the Air-Conditioning, Heating, & Refrigeration Institute (AHRI) website.[1] The AHRI shipments information is shown in Table 9.3.1. Also shown in Table 9.3.1 are shipments for 1989–1993 obtained by DOE from the Gas Appliance Manufacturers Association (GAMA)[a] for use a 2000 energy conservation standard rulemaking.[2] The AHRI and GAMA data overlapped for 1994–1996 and the shipment values are identical, so the earlier data were added to extend the database back to 1989.

[a] GAMA merged with the Air-Conditioning and Refrigeration Institute in 2008, becoming AHRI.

Table 9.3.1 Commercial Storage Water Heater Historical Shipments

Year	Gas-Fired Storage Water Heaters* *units*	Electric Storage Water Heaters *units*
1989	106,401	19,768
1990	98,872	20,121
1991	91,143	19,768
1992	103,386	22,646
1993	118,923	21,142
1994	91,027	22,288
1995	96,913	23,905
1996	127,978	26,954
1997	96,501	30,339
1998	94,577	35,586
1999	100,701	39,845
2000	99,317	44,162
2001	93,969	46,508
2002	96,582	45,819
2003	90,292	48,137
2004	96,481	57,944
2005	82,521	56,178
2006	84,653	63,170
2007	90,345	67,985
2008	88,265	68,686
2009	75,487	55,625
2010	78,614	58,349
2011	84,705	60,257
2012	80,490	67,265
2013	88,539	69,160

*Gas-fired storage water heater shipments are assumed to include only commercial gas-fired water heaters and not to include residential duty gas-fired water heaters.

The residential duty gas-fired storage water is a separate equipment class, distinct from the commercial gas-fired storage water heater. Using a database of available units compiled from AHRI,[3] the California Energy Commission database of available units,[4] and manufacturer webpages, DOE identified 67 unique residential duty gas-fired water heaters and 328 unique commercial gas-fired water heaters. For more information on how this database was compiled, refer to NOPR technical support document (TSD) chapter 3. Based on available models, residential duty gas-fired water heater shipments were assumed to equal 20 percent of the commercial gas-fired water heater shipments shown in Table 9.3.1. Estimates of historical shipments of residential duty gas-fired water heaters are shown in Table 9.3.2.

Table 9.3.2 Residential Duty Gas-Fired Storage Water Heater Historical Shipments

Year	Residential Duty Gas-Fired Storage Water Heaters *units*
1989	21,734
1990	20,196
1991	18,618
1992	21,118
1993	24,292
1994	18,594
1995	19,796
1996	26,142
1997	19,712
1998	19,319
1999	20,570
2000	20,287
2001	19,195
2002	19,729
2003	18,444
2004	19,708
2005	16,856
2006	17,292
2007	18,455
2008	18,030
2009	15,420
2010	16,058
2011	17,303
2012	16,442
2013	18,086

During manufacturer interviews, DOE heard that the commercial gas-fired storage water heater historical shipments might include some residential duty gas-fired storage shipments because such shipments were made to commercial consumers and thus were considered "commercial shipments" by the reporting manufacturer. DOE was not provided estimates of such mislabeling of shipments. Similarly, it appeared possible that commercial gas-fired storage water heater shipments were not included as "commercial shipments" because they were marketed to residential consumers and are thus considered "residential shipments" by the reporting manufacturer. For the notice of proposed rulemaking (NOPR), DOE made no adjustments for mislabeled shipments.

9.3.1.1 Instantaneous Gas-Fired Water Heaters

At the time the NOPR analyses were performed, historical shipments data for instantaneous gas-fired water heaters were unavailable. Through a literature review, DOE identified methods to estimate shipments. Table 9.3.3 lists the methods for estimating gas-fired tankless water heater shipments found in the literature.

Table 9.3.3 Estimation Methods for Gas-Fired Tankless Instantaneous Water Heaters

Reference Number	Method of Estimation	Source
1	10% of total commercial water heater market; based on Natural Resources Canada (NRCan) data from 2010.*	Consortium For Energy Efficiency (CEE). *CEE Commercial Water Heating Initiative Description*. 2012.
2	10% of total U.S. gas tankless units shipped to commercial applications; based on conversations with one tankless manufacturer.	CEE. *CEE Commercial Water Heating Initiative Description*. 2012.
3	Approximately two instantaneous gas units shipped for every five gas storage units shipped (did not differentiate between tankless and hot water supply boilers)	DOE. *Screening Analysis for EPACT-Covered Commercial HVAC and Water-Heating Equipment.* 2000.
4	Calculate shipments from total installed base (stock) in 2008, estimated as 600,000 units; 2008 stock based on Commercial Building Energy Consumption Survey (CBECS) data, and includes all instantaneous equipment	Navigant. *Energy Savings Potential and RD&D Opportunities for Commercial Building Appliances.* 2009.

* Based on DOE's review of the CEE document, the 10 percent represents the difference between the total number of commercial shipments and the combined electric and gas storage shipments, which the CEE document refers to as tankless shipments without regard to commercial or residential equipment or type of fuel.

Using the methods outlined in Table 9.3.3, DOE estimated the number of instantaneous gas-fired water heater shipments. Table 9.3.4 summarizes the resulting estimates of instantaneous gas-fired tankless water heaters based on the estimation methods.

Table 9.3.4 Estimated Instantaneous Gas-Fired Water Heater Shipments

Method Number	Year	Intermediate Inputs	Shipments
1	2013	Total Shipments–electric and gas storage: 157,699 Gross-Up: 157,699 ÷ (1–10%) = 175,221	17,522 tankless units, both fuel types 9,838 gas (56%; based on storage shipments)
2a	2010 and 2013	Total Gas Tankless Units: 532,000* (based on 2010 estimate of 399,000 and 10% growth per year) 10% shipped to commercial setting	53,200 (2013) 39,900 (2010)
2b	2010	Total Gas Tankless Units: 315,751**	31,575 (2010)
3	2013	Gas-fired Storage Shipments: 88,539 two instantaneous units/five storage units	35,416
4	2008	Stock, all instantaneous (hot water supply boilers and tankless): 600,000† Used to estimate boiler shipments by subtracting tankless stock and dividing by a life of 25 years	23,582 (2008) 25,696 (2013 with growth as described below)

* Source: Parker, Mike (AO Smith). *Plenary Panel Presentation.* ACEEE Hot Water Forum. 2011. http://aceee.org/conferences/2011/program-hwf
** Source: CEE, *CEE Commercial Water Heating Initiative Description*. 2012.
† Source: Navigant, 2009. The stock includes for all instantaneous units in commercial buildings.

Method 1 results in an estimate of 9,838 gas tankless instantaneous shipments for 2013. Method 2 results in a higher estimate of the number of total instantaneous shipments, but does not distinguish between residential or commercial capacity equipment. Methods 3 and 4 also result in higher estimated instantaneous equipment shipments but, used as stand-alone methods, neither method distinguishes between tankless and HWSB equipment. If the stock value discussed in method 4 is combined with a stock value based on the shipments estimated under method 1 for tankless units, this method results in the lowest estimate of total shipments of all methods listed in Table 9.3.4, and the total is just under 26,000 units in 2013. During the MIA interviews conducted for this Notice of Proposed Rulemaking (NOPR), manufacturers were asked about gas-fired instantaneous shipments. Based on method 3, which estimates that two instantaneous units are shipped for every five gas-fired storage units, the MIA interview guide asked if an estimate of shipments of 35,000 units in 2013 was reasonable. To maintain confidentiality, specific details cannot be made available. However, two summary statements can be used to guide the analysis. Manufacturers indicated that an estimate of 35,000 was too high, and that of the instantaneous shipments, a majority were hot water supply boilers.

Following the two general manufacturer observations, a combination of methods 1 and 4 was used to estimate the two types of instantaneous products' shipments. Method 1 was used to estimate the number of tankless gas-fired water heater shipments, which was translated into an estimated stock. Method 4 was used to estimate total stock and shipments for HWSB equipment. Subtracting tankless stock from the total stock yields HWSB stock, which was then translated into an estimate of shipments.

To split the total stock of instantaneous units (600,000) between tankless and HWSB equipment, DOE used the assumed life of tankless equipment and a Weibull function to identify the stock of commercial gas-fired instantaneous tankless water heaters for the year 2008. To create a historical series for tankless shipments, DOE used import and export data found on a United Nations (UN) website.[b] Using the total of imports and exports, less re-export, DOE constructed a trend in the total trade in tankless gas-fired water heaters, starting at 2013 and going back in time from 2013. While the UN data do not differentiate between residential and commercial sized equipment, it provides one picture of the overall growth in the tankless gas-fired water heater market. The UN trade data are shown in Table 9.3.5. This trade-data growth trend was used with the 2013 shipments of tankless water heaters to estimate shipments for each year from 2012 back to 1990.

Because the 600,000 unit stock value likely includes both commercial-sized and residential-sized tankless units, DOE assumed an equal number of both size categories. The remainder (600,000 minus the commercial gas-fired instantaneous stock multiplied by 2) was assumed to be HWSB stock. DOE divided this stock value by the assumed life of the HWSB equipment, or 25 years, yielding estimated 2008 HWSB shipments of 15,809. The 2008 value was assumed constant for the 25 years prior to 2008 (as opposed to the shipments of commercial gas-fired storage water heaters, which appear to have trended downward over that time), and it was extrapolated forward to 2013 using the year-to-year change in shipments of commercial gas-fired storage water heaters.

[b] Source: http://comtrade.un.org/data/

The resulting shipments of commercial, gas-fired instantaneous tankless, and HWSB units are shown in Table 9.3.6.

Table 9.3.5 United Nations Gas-Fired Tankless Water Heater Trade Statistics for the U.S.

Year	Quantity			Exports Plus Imports net of Re-Export	Growth Rate: Historic Year through 2013
	Exports	Imports	Re-Exports		
1991	151,545	13,273	1,042	163,776	6%
1992	164,435	19,878	562	183,751	6%
1993	134,053	25,558	600	159,011	7%
1994	173,444	48,453	880	221,017	5%
1995	101,401	66,529	330	167,600	7%
1996	73,338	69,188	126	142,400	9%
1997	73,496	40,083	218	113,361	11%
1998	71,515	35,991	214	107,292	12%
1999	60,057	39,387	274	99,170	14%
2000	86,567	30,849	11,132	106,284	14%
2001	75,933	71,449	460	146,922	12%
2002	60,896	151,646	820	211,722	10%
2003	122,304	579,629	11,927	690,006	-2%
2004	174,387	707,700	7,424	874,663	-4%
2005	144,639	427,832	25,613	546,858	1%
2006	139,846	303,618	49,851	393,613	6%
2007	113,305	362,065	19,527	455,843	4%
2008	86,344	403,950	22,609	467,685	5%
2009	83,843	385,295	33,939	435,199	8%
2010	80,525	474,908	36,361	519,072	4%
2011	73,475	498,654	30,468	541,661	5%
2012	100,248	452,579	42,056	510,771	16%
2013	77,826	542,062	27,992	591,896	NA

Source: UN data. http://comtrade.un.org/data/. Last accessed April 24, 2015.

Table 9.3.6 Instantaneous Gas-Fired Water Heater Shipments

Year	Hot Water Supply Boilers *units*	Instantaneous Tankless *units*
1989	15,809	2,422
1990	15,809	2,568
1991	15,809	2,722
1992	15,809	3,054
1993	15,809	2,643
1994	15,809	3,673
1995	15,809	2,786
1996	15,809	2,367
1997	15,809	1,884
1998	15,809	1,783
1999	15,809	1,648
2000	15,809	1,767
2001	15,809	2,442
2002	15,809	3,519
2003	15,809	11,468
2004	15,809	14,537
2005	15,809	9,089
2006	15,809	6,542
2007	15,809	7,576
2008	15,809	7,773
2009	13,520	7,233
2010	14,080	8,627
2011	15,171	9,003
2012	14,416	8,489
2013	15,858	9,838

A fraction of commercial water heaters are shipped to residential buildings; therefore, DOE considered the future shipments of commercial water heaters to residential buildings in this analysis. DOE developed the estimated percentage of shipments of each type of water heater in the LCC analysis discussed in NOPR TSD chapter 8. The consumer-type shipment fractions are shown in Table 9.3.7.

Table 9.3.7 Fraction of Shipments to Commercial and Residential Consumers

Equipment Class	Commercial	Residential
Commercial Gas-Fired Storage Water Heaters	81.0%	19.0%
Residential Duty Gas-Fired Storage Water Heaters	48.0%	52.0%
Gas-Fired Instantaneous Tankless	67.0%	33.0%
Gas-Fired Instantaneous Hot Water Supply Boilers	82.0%	18.0%
Commercial Electric Storage Water Heaters	77.0%	23.0%

9.3.2 Replacement Shipments

DOE determined shipments for replacement of existing stock using the expected lifetimes of each type of equipment, a Weibull distribution, and the historical shipments discussed in section 9.3.1. The retirement distribution was developed at a monthly time scale and aggregated across mid-year-to-mid-year periods to produce cumulative yearly retirement percentages. The expected average equipment lifetimes are shown in Table 9.3.8. Table 9.3.9 shows the Weibull parameters used to develop the Weibull retirement distributions, while the percentage retirements by years from date of purchase, by the expected average lifetimes, are shown in Table 9.3.10.

Table 9.3.8 Equipment Lifetimes by Equipment Class

Equipment Class	Average *years*	Maximum *years*
Commercial Gas-Fired Storage Water Heaters	10	13
Residential Duty Gas-Fired Storage Water Heaters	12	16
Gas-fired instantaneous water heaters and hot water supply boilers		
• Gas-Fired Instantaneous Tankless	17	20
• Gas-Fired Instantaneous Hot Water Supply Boilers	25	28
Commercial Electric Storage Water Heaters	12	16

Table 9.3.9 Weibull Parameters for Developing Percent Retirements

Average Lifetime	Shape	Scale
10-year average lifetime	10.30	10.50
12-year average lifetime	10.00	12.61
17-year average lifetime	18.40	17.50
25-year average lifetime	27.66	25.50

Table 9.3.10 Percent Retirements by Age

Age *years from purchase*	Average Life 10 Years	Average Life 12 Years	Average Life 17 Years	Average Life 25 Years
0	0.00%	0.00%	0.00%	0.00%
1	0.00%	0.00%	0.00%	0.00%
2	0.00%	0.00%	0.00%	0.00%
3	0.00%	0.00%	0.00%	0.00%
4	0.02%	0.00%	0.00%	0.00%
5	0.11%	0.02%	0.00%	0.00%
6	0.59%	0.11%	0.00%	0.00%
7	2.39%	0.42%	0.00%	0.00%
8	7.70%	1.38%	0.00%	0.00%
9	19.32%	3.83%	0.00%	0.00%
10	33.05%	9.12%	0.00%	0.00%
11	28.79%	18.04%	0.04%	0.00%
12	7.74%	27.08%	0.16%	0.00%
13	0.28%	26.03%	0.64%	0.00%
14	–	12.13%	2.28%	0.00%
15	–	1.80%	7.13%	0.00%
16	–	0.04%	18.63%	0.00%
17	–	–	34.32%	0.00%
18	–	–	30.32%	0.01%
19	–	–	6.40%	0.05%
20	–	–	0.08%	0.18%
21	–	–	–	0.66%
22	–	–	–	2.22%
23	–	–	–	6.89%
24	–	–	–	18.31%
25	–	–	–	34.88%
26	–	–	–	30.98%
27	–	–	–	5.78%
28	–	–	–	0.04%
29	–	–	–	–
30	–	–	–	–

Using the historical shipments, lifetimes, and retirement functions, for each equipment type (split between commercial and residential shipments), a stock accounting process was developed to keep track of shipments, stock, replacements, and retirements from the stock.

9.3.3 Shipments to New Construction

DOE determined new commercial building and residential housing construction starts by using recorded data through 2011, and historical data and projections from EIA's *Annual Energy Outlook 2015* (*AEO2015*)[5] for 2012 through 2040. Table 9.3.11 summarizes the EIA's building stock historical data (2013) and projections. For 2041–2048, DOE extrapolated the EIA projections using a growth rate calculated over the years 2030–2040.

Table 9.3.11 Building Stock Projections

Year	Total Commercial Building Stock *million sq. ft.*	Commercial Building Stock Additions *million sq. ft.*	Total Residential Building Stock *millions of units*	Residential Building Additions *millions of units*
2013	81,382	1,451	114.33	0.99
2019	85,888	2,077	119.41	1.67
2020	86,938	2,089	120.51	1.69
2025	92,037	2,027	125.82	1.70
2030	96,380	1,987	131.09	1.66
2035	100,920	2,302	136.04	1.62
2040	106,649	2,408	140.96	1.62
2045	112,186	2,651	146.22	1.73
2048	115,646	2,808	149.48	1.77

Source: EIA *AEO2015*. For 2045 and 2048, EIA projections extrapolated using the growth rate from 2030–2040.

DOE developed new building commercial water heater market saturations from the historical shipments and building stock data. To estimate shipments in new buildings for commercial water heaters, DOE used the average saturations in buildings built prior to 2013 (equipment stocks divided by building stocks).

Table 9.3.12 the projected market saturations of commercial water heaters by building type in year 2019.

Table 9.3.12 Saturations of Commercial Water Heaters in New Construction in 2019

Equipment Class	Residential *CWH units / million bldgs*	Commercial *CWH units / million sq. ft.*
Commercial Gas-Fired Storage Water Heaters	1,405	8.6
Residential Duty Gas-Fired Storage Water Heaters	955	1.3
Gas-fired instantaneous water heaters and hot water supply boilers		
• Gas-Fired Instantaneous Tankless	377	1.1
• Gas-Fired Instantaneous Hot Water Supply Boilers	615	4.0
Commercial Electric Storage Water Heaters	1,548	7.4

9.3.4 Shipments to New Owners

The final component is shipments to new owners, and such shipments can be either positive or negative. This component is composed of two pieces. The first piece is product switching in the replacement market. The second piece is product switching in the new market. In the case of the replacement market, the product switching is real and tangible insofar as a gas-fired storage water heater that currently exists is replaced by an electric storage water heater, or vice versa. In the new market the product switching is less tangible insofar as it is the difference between the number of new units actually installed and the number of units that would be expected, rather than a number that exists and that can be observed. The expected number of shipments is estimated by multiplying a saturation rate by new building starts.

Because DOE has no information about product switching, it is calculated as a residual. The residual value is based on expected levels of shipments for replacement plus the shipments that would otherwise be expected to new buildings. For historical years, the switching into or out of equipment classes is the difference between the shipments that would occur given the expected new and replacement shipments, and the shipments that did occur.

Based on this calculation there is apparent switching away from gas-fired storage units, and because the shipments model links HWSB shipments to the growth in gas-fired storage water heater shipments, there is apparent switching away from the HWSB equipment class as well. Based on the historic data, there is apparent switching toward electric storage water heaters, and a marked shift toward instantaneous tankless equipment. The apparent switching for each equipment class is shown in Table 9.3.13. Also shown are simple ratios to translate shipments into commercial gas-fired storage water heater equivalents based on first hour rating in terms of gallons.

Table 9.3.13 Apparent Switching in Shipments of Commercial Water Heaters

Year	CGSWH	RDGSWH	CITLWH	CIHWSB	CESWH	Total
2013 Shift	-18,586	-4,420	5,429	-6,058	15,998	-7,637
Gas-fired Storage Equivalent	-18,586	-2,077	1,719	-14,237	9,279	-23,903
First Hour Rating (gal)	283	134	268	664	165	NA
Ratio to Gas-fired Storage	1.00	0.47	0.32*	2.34	0.58	NA

* The ratio of the number of installed commercial gas-fired storage water heaters to installed gas-fired tankless water heaters is not directly comparable using only first-hour ratings. The ratio shown reflects in-use delivery capability of the representative gas-fired tankless water heater model relative to the delivery capability of the representative commercial gas-fired storage water heater, and includes an estimated 3-to-1 delivery capability tradeoff in combination with the first-hour rating.

For each equipment class, there are factors that influence the magnitude of the apparent switching, including relative fuel prices, relative equipment, installation and O&M costs, commercial consumer preferences, and outside influences such as ENERGY STAR and utility conservation or marketing programs. For the NOPR shipment projections, DOE used the 2013 switching values adjusted downward by 50 percent. This level of shifting was held constant for all projection years (i.e., 2014–2048). Using the adjusted values continued the observed trends (e.g., electric storage shipments increasing over time) while the adjustment reduced the extent to which the shipment projection shifted the market between fuel types.

For all equipment classes, DOE assumed that the switching is more likely to occur in new installations rather than in the replacement installations. As an example of how DOE modeled this shift, if DOE estimated that in 2013, 20 percent of shipments for an equipment class went to new installations and 80 percent were for replacements in the absence of switching, DOE multiplied the 20 percent multiplied by 2 (40 percent) and added the 80 percent (which equals 120 percent). Both the 40 percent for new and the 80 percent for replacement were then divided by 120 percent to normalize to 100 percent. This is shown in equations 9.10 and 9.11.

$$SwitchFraction_{New} = \left(Fraction_{NS,New} \times 2\right) / \left(Fraction_{NS,New} \times 2 + Fraction_{NS,Replacment}\right)$$

Eq. 9.10

$$SwitchFraction_{Replacement} = \left(Fraction_{NS,Replacement} \times 2\right) / \left(Fraction_{NS,New} \times 2 + Fraction_{NS,Replacment}\right)$$

Eq. 9.11

Where:

$Switch\ Fraction_{New}$ = fraction of the apparent switch applied to new shipments
$Switch\ Fraction_{Replacement}$ = fraction of the apparent switch applied to replacement shipments
$Fraction_{NS,New}$ = fraction of equipment with no switching shipped to new construction
$Fraction_{NS,Replacement}$ = fraction of equipment with no switching shipped to replace existing equipment

9.4 IMPACT OF STANDARDS ON SHIPMENTS

For replacements, commercial consumer purchase decisions are influenced by the purchase price and operating cost of the equipment, and therefore may be different in the no-new-standards case and under standards cases at different efficiency levels (ELs). These decisions can be modeled by estimating the purchase price elasticity for commercial water heaters specifically; however, the data needed are not sufficient enough to do a robust estimation. DOE did a lengthy internet search for information on commercial-type equipment price elasticities, and found no estimates that seemed appropriate to commercial water heaters. DOE was left with a choice of adopting the same assumptions used for residential products and assuming that the purchase price elasticity is similar between residential products and commercial equipment, or with not analyzing price elasticity.

DOE believes that in commercial and in residential buildings, hot water is generally a necessity, not a luxury or a service that the building owners/occupants can do without. Thus, it seems unlikely to DOE that consumers would choose to not install water heating equipment in response to a price change.

Consumers might seek alternative ways to adjust. One adjustment would be to select other water heater products, as discussed in section 9.3.4. Another adjustment would potentially be to attempt to extend the life of equipment beyond the point at which the consumer would otherwise retire the product. In the case of water heaters, DOE believes that to the extent commercial water heaters are repairable, consumers are likely already doing so. When one considers that new commercial water heater products cost thousands of dollars, most repairs costing a few hundreds of dollars are cost effective, and DOE believes consumers likely are already performing such repairs. (This is in contrast to a residential water heater which may only cost a few hundred dollars installed, in which a repair or replace decision is a less clear-cut decision.) For the NOPR, DOE did not include life extension of products as a viable consumer alternative.

9.5 RESULTS

Figure 9.5.1 shows the historic and projected no-new-standards case shipments of commercial water heaters by equipment class. Table 9.5.1 shows the projected shipments of water heaters by type of water heater.

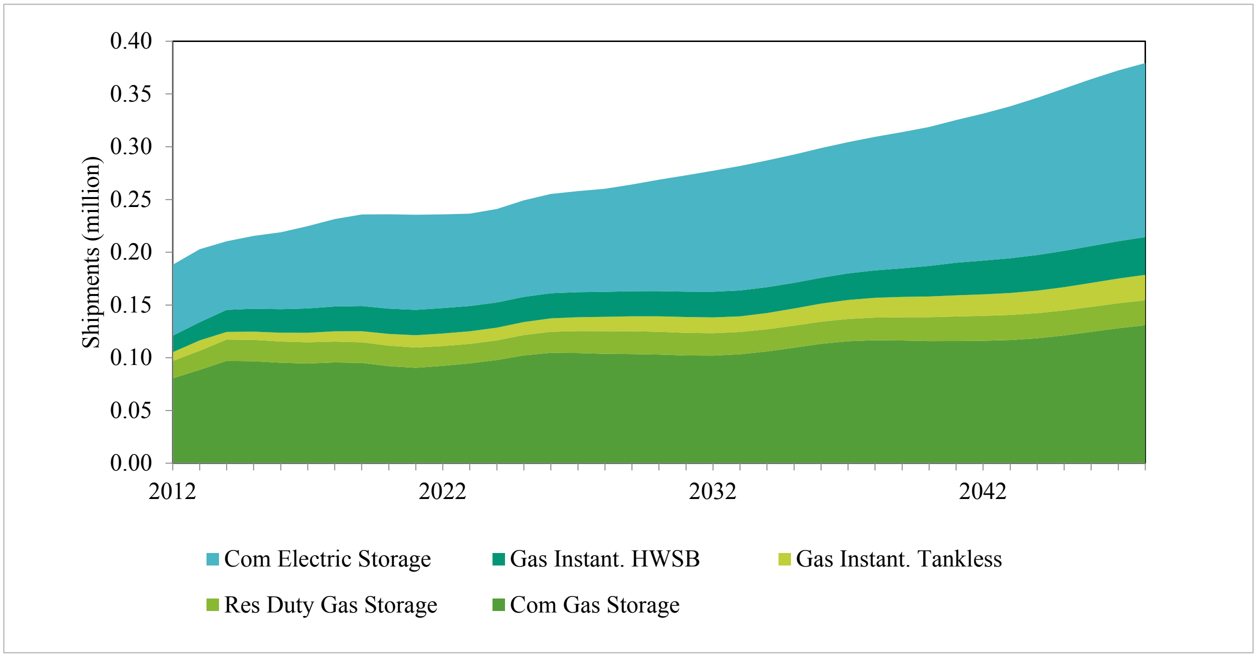

Figure 9.5.1 Historic and Projected No-New-Standards Case Shipments Commercial Water Heaters by Equipment Class

Table 9.5.1 Projected Shipments of Commercial Water Heaters

Year	**Commercial Gas-Fired Storage** ***units***	**Residential Duty Gas-Fired Storage** ***units***	**Gas-Fired Instantaneous Tankless** ***units***	**Gas-Fired Instantaneous Hot Water Supply Boilers** ***units***	**Commercial Electric Storage** ***units***
2013	88,539	18,086	9,838	15,858	69,160
2019	95,145	19,534	8,940	21,959	86,782
2020	92,054	19,402	11,128	22,060	89,390
2025	102,269	19,243	13,323	21,969	91,501
2030	103,025	21,590	14,957	21,957	105,626
2035	109,539	20,911	14,606	22,383	121,567
2040	115,788	22,647	22,817	26,637	131,683
2045	121,163	23,725	22,625	31,671	153,854
2048	130,779	23,726	24,170	32,951	164,934

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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 (DOE) used to conduct a national impact analysis (NIA) of each standard level for commercial water heating (CWH) equipment. DOE evaluated the following impacts: (1) national energy savings (NES) attributable to each possible standard, (2) monetary value of those energy savings to consumers of the considered equipment, (3) increased total installed cost of the equipment because of standards, and (4) net present value (NPV) of energy savings (the difference between the value of energy savings and increased total installed cost).

DOE determined both the NES and NPV for all the efficiency levels (ELs) considered for commercial water heaters. DOE performed all calculations for the considered equipment using a Microsoft Excel spreadsheet model, which is accessible on the Internet at DOE's Commercial Water Heating Equipment web page. The spreadsheet combines the calculations for determining the NES and NPV for each considered equipment class with the shipments model. Details and instructions for using the NIA model are provided in appendix 10A.

Chapter 9 provides a detailed description of the shipments models that DOE used to forecast future purchases of the considered equipment.

In this notice of proposed rulemaking (NOPR), DOE studied four different equipment classes in detail as described in chapter 3, Market and Technology Assessment. For one equipment class, gas-fired instantaneous water heaters, DOE studied tankless and hot water supply boiler (HWSB) types of equipment. (Because standby loss (SL) efficiency levels for two equipment classes were analyzed as separate cost-efficiency curves, for the commercial gas-fired storage water heaters, the NIA model studied three different input sets, and for the residential-duty gas-fired storage water heaters, the NIA model studied four input sets.) To estimate the national impacts of potential standards for the equipment considered in this rulemaking, DOE applied the equipment cost and annual energy consumption (AEC) estimation to each equipment class considered in this analysis.

10.1.1 Alternative Scenarios

The results in this chapter were calculated using selected inputs from the Reference case in the Energy Information Administration's (EIA's) *Annual Energy Outlook 2015* (*AEO2015*).[1] DOE also calculated NIA results using inputs from the high economic growth case and the low economic growth case in *AEO2015.* These results can be viewed in the NIA spreadsheet by selecting the high or low growth economic scenario, and in Appendix 10D.

10.2 FORECASTED EFFICIENCIES FOR NO-NEW-STANDARDS AND STANDARDS CASES

A key factor in estimating NES and NPV is the trend in energy efficiency forecasted for the no-new-standards (previously termed "base") case (without amended standards) and each of the standards cases. In calculating the NES, per-unit AEC is a direct function of equipment efficiency. For the NPV, two inputs depend on efficiency. The first input, the per-unit total installed cost, is an indirect function of efficiency. The per-unit annual operating cost, because it is a function of the per-unit annual consumption, is directly dependent on equipment efficiency. This section describes the method DOE used to forecast the energy efficiency distribution of the considered equipment under the no-new-standards case and each of the potential standards cases.

10.2.1 No-New-Standards Case Efficiencies

The no-new-standards case market share distribution of efficiency levels in the compliance year is discussed in TSD chapter 8, and shown in Table 10.2.1. The distribution by efficiency level is used to disaggregate shipments by efficiency level. The distributions were developed from the database of available CWH equipment discussed in TSD chapter 3. For the gas-fired equipment, thermal efficiency improvement design options were analyzed. For the commercial electric storage water heaters, no thermal efficiency levels were identified for study, but two standby loss efficiency levels were studied. Table 10.2.2 shows the market share distribution for commercial electric storage water heaters. The commercial electric storage water heaters could be modeled with a single efficiency level roll-up, as could the instantaneous gas-fired equipment. In the single efficiency level roll-up, in the no-new-standards case the equipment shipments are distributed across efficiency levels using the distribution shown in Table 10.2.1. Then, as standards are studied at successively higher levels (*e.g.*, EL1), shipments are shifted from levels not meeting the standard being studied (*e.g.*, EL0) to the minimum efficiency level meeting the contemplated standard. For electric storage and gas-fired instantaneous equipment, a single efficiency level roll-up was sufficient to study the efficiency improvements. To accommodate analyses of thermal efficiency and standby losses for the commercial and residential duty gas-fired storage equipment classes, a second roll-up was required. Thus, for commercial gas-fired and residential duty gas-fired storage water heaters, DOE developed two efficiency distributions, one for the distribution of equipment by thermal efficiency level and one for the distribution by standby loss efficiency level. Note that DOE assumed that the distributions shown in Table 10.2.1 (as well as in Table 10.2.2, Table 10.2.3 and Table 10.2.4) would remain the same for all years in the shipments forecast period.

Table 10.2.1 No-New-Standards Case Estimated and Forecast Market Share Distributions by Thermal Efficiency Level

Equipment	Percentage of Shipments by Thermal Efficiency Level (%)					
	EL0	**EL1**	**EL2**	**EL3**	**EL4**	**EL5**
Commercial Gas-Fired Storage Water Heaters	56.7	12.2	0.3	6.4	23.2	1.2
Residential Duty Gas-Fired Storage Water Heaters	65.7	9.0	3.0	16.4	6.0	N/A
Gas-Fired Instantaneous: Tankless	16.0	40.0	28.0	4.0	4.0	8.0
Gas-Fired Instantaneous: HWSB	40.2	23.8	13.8	1.7	7.1	13.4

Table 10.2.2 No-New-Standards Case Estimated and Forecast Market Share Distribution by Standby Loss Efficiency Level for Electric Storage Water Heaters

Equipment	Percentage of Shipments by Standby Loss Efficiency Level (%)	
	SL0	SL1
Commercial Electric Storage Water Heaters*	97.2	2.8

* Shown is the distribution between standby loss level 0 and standby loss level 1. No thermal efficiency options were studied. With only one set of design options, a single efficiency level roll-up sufficed for analyzing this class.

In the case of the commercial gas-fired and residential-duty gas-fired storage water heaters, a second roll-up was needed to study standby loss efficiency levels. In the roll-up based on the distribution shown on Table 10.2.1, equipment efficiencies are studied in the context of thermal efficiency levels. For the two gas-fired storage water heater classes, DOE also studied multiple standby loss efficiency levels. Thus, for two equipment classes, the NIA model needed to do a roll-up by thermal efficiency levels and a roll-up by standby loss levels. Table 10.2.3 shows the percentage of shipments, by thermal efficiency level, for each standby loss level for commercial gas-fired storage water heaters, while Table 10.2.4 shows the distribution for residential-duty gas-fired storage water heaters. For the two gas-fired storage water heater classes, the standby energy usage is partly dependent on the thermal efficiency of the water heater because the standby energy usage is measured as fuel consumption required to reheat stored water that cooled in standby mode. Thus, the distribution of water heaters across the studied standby loss levels differs by thermal efficiency levels. Table 10.2.3 and Table 10.2.4 therefore show distributions across standby loss levels that differ by thermal efficiency level. Final NES and NPV results are relative to the EL0-SL0 efficiency combination. In other words, if $0.5 billion in NPV savings were identified for an EL-SL combination, the savings would be calculated relative to the present value of the EL0-SL0 efficiency combination.

Table 10.2.3 No-New-Standards Case Estimated and Forecast Standby Loss Efficiency Level Market Share Distributions for Commercial Gas-Fired Storage Water Heaters

SL Efficiency Level	Percentage of Shipments by Thermal Efficiency Level					
	EL0	EL1	EL2	EL3	EL4	EL5
SL0*	75.8%	87.5%	0.0%	66.7%	32.9%	75.0%
SL1	19.9%	0.0%	0.0%	19.0%	14.5%	25.0%
SL2	4.3%	12.5%	100.0%	14.3%	52.6%	0.0%

* Standby loss efficiency levels: SL0 is the no-new-standards case, while SL1 and SL2 are standby loss efficiency levels above the no-new-standards case.

Table 10.2.4 No-New-Standards Case Estimated and Forecast Standby Loss Efficiency Level Market Share Distributions for Residential Duty Gas-Fired Storage Water Heaters

SL Efficiency Level	Market Share by Thermal Efficiency Levels %					
	EL0	EL1	EL2	EL3	EL4	EL5
SL0*	81.8%	16.7%	0.0	0.0	0.0	NA
SL1	11.4%	0.0%	100.0	100.0	100.0	NA

SL Efficiency Level	Market Share by Thermal Efficiency Levels %					
	EL0	EL1	EL2	EL3	EL4	EL5
SL2**	4.5%	16.7%	NA	NA	NA	NA
SL3**	2.3%	66.7%	NA	NA	NA	NA

* Standby loss efficiency levels: SL0 is the no-new-standards case, while SL1, SL2, and SL3 are standby loss efficiency levels above the no-new-standards case.
** Standby loss efficiency levels SL2 and SL3 only defined for EL0 and EL1.

10.2.2 Standards Case Efficiencies

Table 10.2.5 through Table 10.2.8 show the efficiency distributions that DOE used for the CWH equipment classes under each standards case. The tables include the thermal efficiency (E_t) level description associated with each standards case. The tables show for each efficiency level how market share is shifted when successively higher standards are considered, making less efficient equipment unavailable. In the absence of other data, DOE assumed that the standards case distribution of efficiency levels remains static in the future.

Table 10.2.5 Commercial Gas-Fired Storage Water Heater Market Share Distributions, by Thermal Efficiency Standards Case

Efficiency Level		No-New-Standards Case EL0	Market Share by Efficiency Level (EL) %				
			EL1	EL2	EL3	EL4	EL5
0	80% E_t - Baseline	56.7					
1	82% E_t	12.2	68.9				
2	90% E_t	0.3	0.3	69.2			
3	92% E_t	6.4	6.4	6.4	75.6		
4	95% E_t	23.2	23.2	23.2	23.2	98.8	
5	99% E_t - Max Tech	1.2	1.2	1.2	1.2	1.2	100.0

Table 10.2.6 Residential Duty Gas-Fired Storage Water Heater Market Share Distributions, by Thermal Efficiency Standards Case

Efficiency Level		No-New-Standards Case EL0	Market Share by Efficiency Level (EL) %				
			EL1	EL2	EL3	EL4	EL5
0	80% E_t - Baseline	65.7					
1	82% E_t	9.0	74.6				
2	90% E_t	3.0	3.0	77.6			
3	95% E_t	16.4	16.4	16.4	94.0		
4	97% E_t - Max Tech	6.0	6.0	6.0	6.0	100.0	

Table 10.2.7 Gas-Fired Tankless Instantaneous Market Share Distributions, by Thermal Efficiency Standards Case

Efficiency Level		No-New-Standards Case EL0	Market Share by Efficiency Level (EL) %				
			EL1	EL2	EL3	EL4	EL5
0	80% E_t - Baseline	16.0					
1	82% E_t	40.0	56.0				
2	84% E_t	28.0	28.0	84.0			

Efficiency Level		No-New-Standards Case EL0	Market Share by Efficiency Level (EL) %				
			EL1	EL2	EL3	EL4	EL5
3	92% E_t	4.0	4.0	4.0	88.0		
4	94% E_t	4.0	4.0	4.0	4.0	92.0	
5	96% E_t - Max Tech	8.0	8.0	8.0	8.0	8.0	100.0

Table 10.2.8 Hot Water Supply Boiler Market Share Distributions, by Thermal Efficiency Standards Case

Efficiency Level		No-New-Standards Case EL0	Market Share by Efficiency Level (EL) %				
			EL1	EL2	EL3	EL4	EL5
0	80% E_t - Baseline	40.2					
1	82% E_t	23.8	64.0				
2	84% E_t	13.8	13.8	77.8			
3	92% E_t	1.7	1.7	1.7	79.5		
4	94% E_t	7.1	7.1	7.1	7.1	86.6	
5	96% E_t - Max Tech	13.4	13.4	13.4	13.4	13.4	100.0

A similar roll-up occurs for the standby loss efficiency levels. The commercial electric storage water heater equipment required a single roll-up to account for standby loss levels as shown in Table 10.2.9. Table 10.2.10 shows the shifting of market share in the analysis of standby loss levels for commercial gas-fired storage water heaters. Table 10.2.11 shows how market share is shifted to study the successively higher standby loss levels for residential duty gas-fired storage water heaters.

Table 10.2.9 Commercial Electric Storage Water Heater Market Share Distributions for Standby Loss Standards Cases

Standby Loss Efficiency Level		No-New-Standards Case SL0	Standby Loss Efficiency Level (SL)				
			SL1	SL2	SL3	SL4	SL5
0	80% E_t - SL0	97.2					
1	80% E_t - SL1	2.8	100.0				

Table 10.2.10 Commercial Gas-Fired Storage Water Heater Market Share Distribution for Standby Loss Standards Cases

Standby Loss Efficiency Level	Percentage of Shipments by Thermal Efficiency Level					
	EL0	EL1	EL2	EL3	EL4	EL5
No-New Standards Case (SL0)						
SL0	75.8	87.5	0.0	66.7	32.9	75.0
SL1	19.9	0.0	0.0	19.0	14.5	25.0
SL2	4.3	12.5	100.0	14.3	52.6	0.0
SL1-Level Standard						
SL0						
SL1	95.7	87.5	0.0	85.7	47.4	100

Standby Loss Efficiency Level	Percentage of Shipments by Thermal Efficiency Level					
	EL0	EL1	EL2	EL3	EL4	EL5
SL2	4.3	12.5	100.0	14.3	52.6	0.0
SL2-Level Standard						
SL0						
SL1						
SL2	100	100	100	100	100	100

Table 10.2.11. Residential-Duty Gas-Fired Storage Water Heater Market Share Distribution for Standby Loss Standards Cases

Standby Loss Efficiency Level	Percentage of Shipments by Thermal Efficiency Level					
	EL0	EL1	EL2	EL3	EL4	EL5
No-New Standards Case (SL0)						
SL0	81.8	16.7	0.0	0.0	0.0	NA
SL1	11.4	0.0	100.0	100.0	100.0	NA
SL2	4.5	16.7	NA	NA	NA	NA
SL3	2.3	66.7	NA	NA	NA	NA
SL1-Level Standard						
SL0						
SL1	93.2	16.7	100.0	100.0	100.0	NA
SL2	4.5	16.7	NA	NA	NA	NA
SL3	2.3	66.7	NA	NA	NA	NA
SL2-Level Standard						
SL0						
SL1						
SL2	97.3	33.3	NA	NA	NA	NA
SL3	2.3	66.7	NA	NA	NA	NA
SL3-Level Standard						
SL0						
SL1						
SL2						
SL3	100.0	100.0	NA	NA	NA	NA

10.3 NATIONAL ENERGY SAVINGS

DOE calculated the NES associated with the difference between the no-new-standards case and the case associated with each potential standard for the CWH equipment considered herein. DOE calculated cumulative energy savings throughout the forecast period, which extends from 2019 through 2048. DOE used full-fuel-cycle (FFC) energy factors to estimate NES; see section 10.3.2.6.

10.3.1 Definition

The following equation shows that DOE calculated annual NES as the difference between two projections: a base case (the no-new standards) and a standards case. Positive values of NES represent energy savings (that is, national AEC under a standard is less than in the no-new standards case).

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

Eq. 10.1

Where:

NES_y = NES in the year y (quadrillion British thermal units (quads)),
AEC_{BASE} = annual national energy consumption in the no-new standards case (quads), and
AEC_{STD} = annual national energy consumption in a standards-case scenario (quads).

Cumulative energy savings are the sum of annual NES throughout the forecast period, which extends over the lifetime of equipment shipped in 2019–2048. Since the analysis includes lifetimes of up to 28 years, the evaluation period for cumulative energy savings spans 2019–2077.

DOE calculated the national annual site energy consumption by multiplying the number or stock of each equipment class (by vintage) by its unit energy consumption (UEC; also by vintage). The calculation of national AEC is represented by the following equation:

$$AEC_y = \sum_V (STOCK_V \times UEC_V) \times ffc\_conv_y$$

Eq. 10.2

Where:

AEC = national annual energy consumption in the year y in quadrillion British thermal units (quads), summed over vintages of the equipment stock, $STOCK_V$,
$STOCK_V$ = stock of equipment (millions of units) of vintage V that survive in the year for which DOE calculated AEC,
UEC_V = AEC of equipment in kilowatt-hours (kWh) or million British thermal units (MMBtu),
ffc_conv_y = time-dependent conversion factors to convert site energy to FFC energy by converting site energy to source energy and adding the energy consumed in extracting, processing, and transporting or distributing primary fuels (calculated as a percent of primary energy),
V = year in which the equipment was purchased as a new unit, and
y = year in the forecast.

The stock of equipment depends on annual shipments and the equipment lifetime. As described in chapter 9, Shipments Analysis, DOE projected shipments under the no-new-standards case and the standards cases.

10.3.2 Inputs

The inputs to the calculation of NES are as follows:

- shipments
- equipment stock ($STOCK_V$)
- AEC per unit (*UEC*)
- national AEC (*AEC*)
- site-to-source conversion factor (*src_conv*).

10.3.2.1 Shipments

DOE forecasted shipments of each considered equipment class under the no-new-standards case and all standards cases. The method DOE used to calculate and generate the shipments forecasts for each considered equipment class is described in detail in chapter 9.

10.3.2.2 Equipment Stock

The equipment stock in a given year is the number of each type of equipment shipped from earlier years that survive in that year. The NIA model tracks the number of units shipped each year. DOE assumes that commercial water heaters have an increasing probability of retiring as they age. The probability of survival as a function of years since purchase is the survival function. Chapter 9 provides additional details on the survival functions that DOE used.

10.3.2.3 Annual Energy Consumption per Unit

DOE used the thermal efficiency levels presented in section 10.2.2 for the no-new-standards case and standards cases, along with the data on AEC presented in chapters 7 and 8, to estimate the shipment-weighted average annual per-unit energy consumption under the no-new-standards and each standards case. The average annual per-unit energy consumption for each equipment category is shown in Table 10.3.1.

Table 10.3.1 Commercial Water Heaters: Shipment-Weighted Average Annual Energy Use for No-New-Standards and Standards Cases

Equipment	No-New-Standards Case	Thermal Efficiency Level*				
		1	2	3	4	5
Commercial Gas-Fired Storage - SL0						
Average Annual Fuel Use (MMBtu/yr)	184	182	170	168	164	157
Average Annual Elec Use (kWh/yr)	79	79	175	172	168	162
Commercial Gas-Fired Storage - SL1						
Average Annual Fuel Use (MMBtu/yr)	183	180	169	166	162	156
Average Annual Elec Use (kWh/yr)	73	73	163	161	157	151
Commercial Gas-Fired Storage - SL2						
Average Annual Fuel Use (MMBtu/yr)	182	179	168	165	161	155
Average Annual Elec Use (kWh/yr)	68	68	154	152	148	143
Res. Duty Gas-Fired Storage - SL0						
Average Annual Fuel Use (MMBtu/yr)	86	84	77	74	72	NA
Average Annual Elec Use (kWh/yr)	36	36	147	142	140	NA
Res. Duty Gas-Fired Storage - SL1						
Average Annual Fuel Use (MMBtu/yr)	84	83	76	73	72	NA

Equipment	No-New-Standards Case	Thermal Efficiency Level*				
		1	2	3	4	5
Average Annual Elec Use (kWh/yr)	68	68	147	142	140	NA
Res. Duty Gas-Fired Storage - SL2						
Average Annual Fuel Use (MMBtu/yr)	84	83	NA	NA	NA	NA
Average Annual Elec Use (kWh/yr)	68	68	NA	NA	NA	NA
Res. Duty Gas-Fired Storage - SL3						
Average Annual Fuel Use (MMBtu/yr)	84	82	NA	NA	NA	NA
Average Annual Elec Use (kWh/yr)	68	68	NA	NA	NA	NA
Gas-Fired Instantaneous: Tankless						
Average Annual Fuel Use (MMBtu/yr)	59	59	58	54	53	52
Average Annual Elec Use (kWh/yr)	115	115	113	107	105	104
Gas-Fired Instantaneous: HWSB						
Average Annual Fuel Use (MMBtu/yr)	357	353	348	324	318	313
Average Annual Elec Use (kWh/yr)	714	708	699	658	649	639
Commercial Electric Storage						
Average Annual Fuel Use (MMBtu/yr)	0	0	NA	NA	NA	NA
Average Annual Elec Use (kWh/yr)	15,431	15,306	NA	NA	NA	NA

* For commercial electric storage equipment, the no-new-standards case and level 1 represent the same thermal efficiency level but differing levels of standby losses.

10.3.2.4 National Annual Energy Consumption

The national AEC is the product of the AEC per unit and the number of units of each vintage. This method of calculation accounts for differences in unit energy consumption from year to year. In determining national AEC, DOE first calculated AEC at the site, and then applied a conversion factor, described in section 10.3.2.5, to calculate primary energy consumption.

10.3.2.5 Site-to-Primary Energy Conversion Factors

In determining national AEC, DOE initially calculated the annual energy consumption at the site (for electricity, the energy in kWh consumed at the establishment). It then used site energy consumption to calculate primary (source) energy consumption by applying a conversion factor to account for losses associated with the generation, transmission, and distribution of electricity. The conversion factor is a multiplicative factor used to convert site energy consumption into primary or source energy consumption, expressed in quads (quadrillion Btu). DOE used annual conversion factors based on the version of the National Energy Modeling System (NEMS)[a] that corresponds to *AEO2015*. The factors are marginal values, which represent the response of the system to an incremental decrease in consumption. For electricity, the

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[a] For more information on NEMS, please refer to the DOE EIA 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 without any modification to code or data. Because this analysis entails some minor code modifications and the model is run under various policy scenarios that are variations on EIA assumptions, DOE refers to the model by the name NEMS-BT (BT is DOE's Building Technologies Program, under whose aegis this work has been performed). NEMS-BT was previously called NEMS-BRS.

conversion factors change over time in response to projected changes in generation sources (*i.e.,* the types of power plants projected to provide electricity to the Nation). The factors also vary between commercial and residential consumer sectors because the pattern of usage varies between sectors. The values derived from the *AEO2015* NEMS end in 2040. DOE assumed that conversion factors remain at the 2040 values throughout the rest of the forecast. Table 10.3.2 shows the site-to-source conversion factors for selected years.

Table 10.3.2 Site-to-Source Conversion Factors for Electricity

	British Thermal Units per kilowatt hour						
	2020	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Residential	10,591	9,840	9,203	8,898	8,984	8,984	8,984
Commercial	10,544	9,792	9,152	8,848	8,926	8,926	8,926

10.3.2.6 Full-Fuel-Cycle Energy Factors

The FFC measures point-of-use (site) energy; the energy losses associated with generation, transmission, and distribution of electricity; and the energy consumed in extracting, processing, and transporting or distributing primary fuels. To calculate the FFC by incorporating the energy consumed in extracting, processing, and transporting or distributing primary fuels, referred to as upstream activities, DOE developed FFC multipliers using the data and projections generated by the NEMS used for *AEO2015*. The *AEO2015* provides extensive information about the energy system, including projections of future oil, natural gas, and coal supplies; energy use for oil and gas field and refinery operations; and fuel consumption and emissions related to electric power production. This information can help define a set of parameters that represents the energy intensity of energy production. Appendix 10D presents a more thorough discussion of the FFC and the energy factors.

10.4 NET PRESENT VALUE

DOE calculated the NPV of the increased product cost and reduced operating cost associated with the difference between the no-new-standards case and each potential standards case for the considered CWH equipment classes.

10.4.1 Definition

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

$$NPV = PVS - PVC$$

Eq. 10.3

Where:

PVS = present value of savings in operating cost, and
PVC = present value of increased total product cost to consumers.

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

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

Eq. 10.4

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

Eq. 10.5

Where:

OCS = total annual savings in operating cost each year summed over vintages of the equipment stock, $STOCK_V$,
TIC = total annual increases in product cost each year summed over years of the equipment shipments, $SHIP_y$,
DF = discount factor in each year, and
y = year in the forecast.

DOE calculated the total annual customer savings in operating cost by multiplying the number or stock of a given equipment class (by vintage) by its per-unit operating cost savings (also by vintage). DOE calculated the total annual increases in customer equipment cost by multiplying the number of shipments of the given equipment class (by vintage) by its per-unit increase in customer equipment cost (also by vintage). The calculation of total annual operating cost savings and total annual equipment cost increases is represented by the following equations.

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

Eq. 10.6

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

Eq. 10.7

Where:

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

DOE determined the total increased equipment cost for each year from the effective date of a potential standard (2019) through 2048. It determined the present value of operating cost savings for each year from the effective date of the standard to the year when all units purchased by 2048 have been retired. DOE calculated costs and savings as the difference between a standards case and a case with no new standards.

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

10.4.2 Inputs

The inputs to calculation of the NPV are as follows:

- average annual equipment cost,
- average annual savings in operating cost,
- total annual increases in equipment cost,
- total annual savings in operating cost,
- discount factor,
- present value of costs, and
- present value of savings.

The increase in total annual equipment cost is equal to the annual change in the average annual equipment cost (difference between no-new-standards case and standards case) multiplied by the shipments forecasted in the standards case.

The total annual savings in operating cost are equal to the change in average annual operating cost (difference between no-new-standards case and standards case) per unit multiplied by the shipments forecasted in the standards case.

10.4.2.1 Average Annual Installed Price

The average annual installed price is directly dependent on efficiency. DOE therefore used the efficiency distributions presented in section 10.2.2 for the no-new-standards case and each standards case, along with the equipment costs at various efficiency levels (presented in chapter 8), to estimate the weighted-average annual installed price under the no-new-standards and standards cases. The average annual installed price for each equipment category is shown in Table 10.4.1.

Table 10.4.1 Commercial Water Heaters: Weighted Average Installed Price (2014$) for No-New-Standards and Standards Cases

Equipment	No-New-Standards Case	Thermal Efficiency Levels*				
		1	2	3	4	5
Com. Gas-Fired Storage - SL0	$4,684	$4,773	$5,384	$5,399	$5,436	$5,521
Com. Gas-Fired Storage - SL1	$4,703	$4,792	$5,404	$5,418	$5,455	$5,535
Com. Gas-Fired Storage - SL2	$4,782	$4,879	$5,488	$5,503	$5,540	$5,627
Res. Duty Gas-Fired Storage - SL0	$2,478	$2,523	$3,399	$3,624	$3,639	NA
Res. Duty Gas-Fired Storage - SL1	$2,606	$2,652	$3,428	$3,653	$3,669	NA
Res. Duty Gas-Fired Storage - SL2	$2,701	$2,748	NA	NA	NA	NA
Res. Duty Gas-Fired Storage - SL3	$2,754	$2,806	NA	NA	NA	NA
Gas-Fired Instantaneous: Tankless	$4,250	$4,257	$4,267	$3,826	$3,852	$3,885

Equipment	No-New-Standards Case	Thermal Efficiency Levels*				
		1	2	3	4	5
Gas-Fired Instantaneous: HWSB	$8,219	$8,285	$8,558	$10,225	$10,480	$10,758
Commercial Electric Storage*	$3,652	$3,743	NA	NA	NA	NA

* For commercial electric storage equipment, the no-new-standards case and level 1 represent the same thermal efficiency level but differing levels of standby losses.

DOE examined historical price data for certain appliances and equipment that have been subject to energy conservation standards. This evaluation indicated that the assumption of constant real prices and costs may, in many cases, overestimate long-term appliance and equipment price trends. For this NOPR, historical price data did not support a declining price trend, so prices are held constant in real terms. The constant price trend is used for the reference, high, and low cases.

As discussed in the Chapter 8 section on installation costs, for replacement units, when the thermal efficiency level reaches the level requiring the installation of condensing equipment, there is a sizable jump in installation costs related to venting. In the NIA model, DOE modeled this as one-time costs. This means that after all equipment existing at the start of the analysis period is replaced one time, the model removes the added cost related to venting rather than making that a permanent cost increase.

10.4.2.2 Repair and Maintenance Costs per Unit

Repair and maintenance costs for storage water heaters are based on a limited number of repairable components, so for non-condensing efficiency levels the costs do not change much within the equipment classes. When the efficiency level reaches the level requiring condensing equipment, repair and maintenance costs change, but the difference is small. Table 10.4.2 shows repair and maintenance costs by equipment class.

Table 10.4.2 Average Annual Repair and Maintenance Costs of Commercial Water Heaters for No-New-Standards and Standards Cases

Equipment	No-New-Standards Case	Thermal Efficiency Levels				
		1	2	3	4	5
Com. Gas-Fired Storage - SL0	$262	$262	$266	$268	$268	$268
Com. Gas-Fired Storage - SL1	$262	$262	$266	$268	$268	$268
Com. Gas-Fired Storage - SL2	$262	$262	$266	$268	$268	$268
Res. Duty Gas-Fired Storage - SL0	$260	$260	$265	$267	$267	NA
Res. Duty Gas-Fired Storage - SL1	$260	$260	$265	$267	$267	NA
Res. Duty Gas-Fired Storage - SL2	$260	$260	NA	NA	NA	NA
Res. Duty Gas-Fired Storage - SL3	$260	$260	NA	NA	NA	NA
Gas-Fired Instantaneous: Tankless	$36	$36	$39	$42	$42	$42
Gas-Fired Instantaneous: HWSB	$53	$53	$58	$94	$95	$97
Commercial Electric Storage*	$44	$44	NA	NA	NA	NA

* For commercial electric storage equipment, the no-new-standards case and level 1 represent the same thermal efficiency level but differing levels of standby losses.

10.4.2.3 Annual Operating Cost Savings per Unit

The average annual operating cost includes the costs for energy, repair, and maintenance. For all the considered equipment, DOE determined the per-unit annual savings in operating cost based on the savings in energy costs attributable to a standard plus repair and maintenance cost savings (negative if repair and maintenance costs increase with efficiency level). DOE determined the per-unit annual savings in operating cost by multiplying the per-unit annual savings in energy consumption developed for each equipment class by the appropriate energy price. As described in chapter 8, DOE forecasted energy prices based on projected average annual price changes in EIA's *AEO2015*.

10.4.2.4 Total Annual Increases in Equipment Cost

The total annual increase in equipment cost for any given standards case is the product of the average cost increase per unit due to the standard and the number of units of each vintage shipped. This method accounts for differences in equipment cost from year to year. The equation for determining the total annual increase in equipment cost for a given standards case, which was shown in section 10.4.1, is repeated here.

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

Eq. 10.8

As with the calculation of the NES, DOE used the standards-case projection of shipments and, in turn, the standards-case stock, to calculate equipment costs.

10.4.2.5 Total Annual Savings in Operating Cost

The total annual savings in operating cost for any given standards case is the product of the annual savings in operating cost per unit attributable to the standard and the number of units of each vintage. This method accounts for differences in annual savings in operating cost from year to year. The equation for determining the total annual savings in operating cost for a given standards case, which was presented in section 10.4.1, is repeated here.

$$OCS = \sum STOCK_V \times UOCS_V$$

Eq. 10.9

10.4.2.6 Discount Factor

DOE multiplied monetary values in future years by a discount factor to determine the present value. The discount factor (DF) is described by this equation:

$$DF = \frac{1}{(1+r)^{(y-yp)}}$$

Eq. 10.10

Where:

r = discount rate,
y = year in which the monetary value exists, and
y_P = year in which the present value is being determined.

Although DOE used customer discount rates to determine the life-cycle cost of commercial water heaters (chapter 8), it used national discount rates to calculate national NPV. DOE estimated NPV using both a 3-percent and a 7-percent real discount rate, in accordance with the Office of Management and Budget's guidance to Federal agencies on the development of regulatory analysis, particularly section E therein: *Identifying and Measuring Benefits and Costs*.[2] DOE defined the present year as 2015.

10.4.2.7 Present Value of Costs

The present value of increased equipment costs is the annual total cost increase in each year (the difference between a standards case and the no-new standards case), discounted to the present, and summed throughout the period in which DOE is considering the installation of equipment (2019 through 2048). DOE calculated annual increases in installed cost as the difference in total equipment cost for new equipment purchased each year, multiplied by the shipments in the standards case.

10.4.2.8 Present Value of Savings

The present value of savings in operating cost 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 effective date to the time when the last unit installed in 2048 is retired from service. Savings are decreases in operating cost associated with the higher energy efficiency of equipment purchased in the standards case compared to the no-new-standards case. Total annual savings in operating cost are the savings per unit multiplied by the number of units of each vintage that survive in a particular year.

10.5 NATIONAL ENERGY SAVINGS AND NET PRESENT VALUE RESULTS

The NIA model produces estimates of the NES and NPV attributable to a given efficiency level. The inputs to the NIA model were discussed in sections 10.3.2 (inputs to NES) and 10.4.2 (inputs to NPV). DOE generated the NES and NPV results using a Microsoft Excel spreadsheet, which is accessible on the Internet at the DOE Commercial Water Heating Equipment web page. Details regarding and instructions for using the spreadsheet are provided in appendix 10A.

10.5.1 Summary of Inputs

Table 10.5.1 summarizes the inputs to the NIA model.

Table 10.5.1 Inputs to Calculation of National Energy Savings and Net Present Value

Input	Description
Shipments	Annual shipments from shipments model (see chapter 9)
Compliance Date of Standard	2019
No-New-Standards Case Forecasted Efficiencies	See section 10.2
Standards-Case Efficiencies	See section 10.2
AEC per Unit	Annual weighted-average values are a function of the efficiency distribution (see section 10.3.2.3)
Total Installed Cost per Unit	Annual weighted-average values are a function of the efficiency distribution (see section 10.4.2.4)
Energy Cost per Unit	Annual weighted-average values are a function of AEC per unit and energy prices (see chapter 8 for energy prices)
Repair and Maintenance Costs per Unit	Repair cost and maintenance costs are a function of the efficiency of the equipment (see chapter 8.)
Forecast of Energy Prices	Energy prices: EIA *AEO2015* forecasts (through 2040) and extrapolation thereafter (see chapter 8)
Site-to-Source Conversion Factor	A time-series conversion factor that includes electric generation, transmission, and distribution losses. The conversion factor, which changes yearly, is generated by DOE-EIA's NEMS* program (see section 10.3.2.5)
Full-Fuel-Cycle Factors	A time-series conversion factor that includes extraction and transportation costs for fuels (see Appendix 10D)
Discount Rates	3% and 7% real
Present Year	Future expenses are discounted to 2015

* Chapter 15, Utility Impact Analysis, provides more detail about NEMS.

10.5.2 Annual Costs and Savings

Figure 10.5.1 illustrates the basic inputs to the calculation of NPV by showing the non-discounted annual increases in equipment cost and annual savings in operating cost at the national level for EL1 (the first efficiency level above the baseline) for gas-fired instantaneous tankless water heaters. The figure also shows the net savings, which is the difference between the savings and costs for each year. The annual increase in equipment cost is the total cost for equipment purchased each year in the forecast period. The annual savings in operating cost applies to equipment operating in each year. The NPV is the difference between the cumulative annual discounted savings and cumulative annual discounted costs. Figure 10.5.1 shows, as an example, non-discounted annual increases in installed cost and savings in operating cost for gas-fired instantaneous tankless water heating equipment at EL1; DOE could create figures like Figure 10.5.1 for each of the considered efficiency levels for each equipment type.

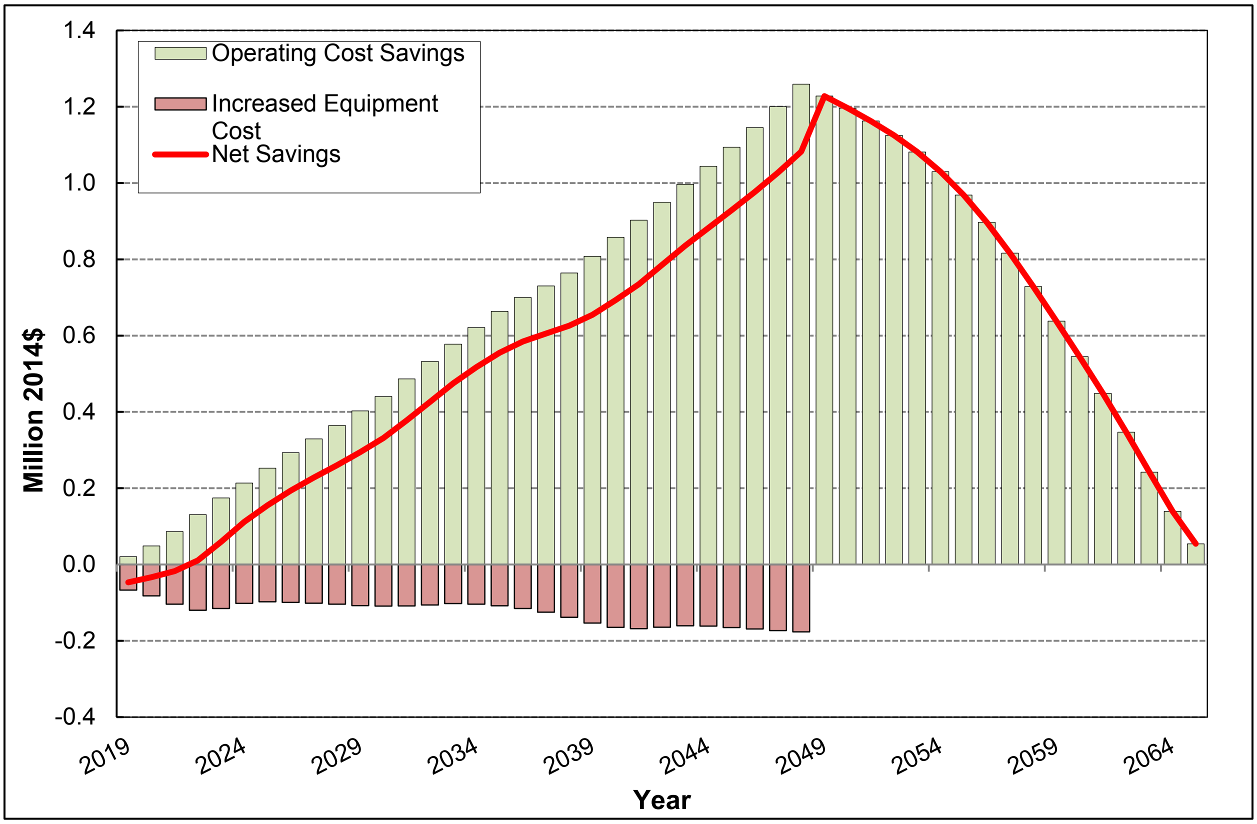

Figure 10.5.1 Non-Discounted Annual Increases in Installed Cost and Savings in Operating Cost for Gas-Fired Instantaneous Tankless Water Heaters at EL 1

10.5.3 National Energy Savings Results by Energy Efficiency Level

This section provides the cumulative NES that DOE calculated for each equipment class analyzed for commercial water heaters. Savings by thermal efficiency and standby loss levels are shown in Table 10.5.2 and Table 10.5.3, and savings by trial standard level (TSL) are on Table 10.5.4 and Table 10.5.5.

For equipment classes with standby loss efficiency options, the NES by EL/SL include the standby loss roll-up with each standby loss/thermal efficiency level being measured relative to EL0/SL0. For commercial and residential duty gas-fired storage water heaters, the non-zero result in the EL0 column indicates that for standby loss efficiency levels above SL0 there are energy savings (and later, NPV impacts) obtained from rolling-up from SL0 to the higher standby loss levels. For commercial electric storage water heaters, the savings (and later NPV impacts) shown are for the standby loss efficiency improvement.

Table 10.5.2 Primary National Energy Savings for CWH Equipment by Efficiency Level (quads)

Equipment	Efficiency Levels*					
	0	1	2	3	4	5
Com. Gas-Fired Storage - SL0**	0.000	0.083	0.505	0.524	0.683	0.854
Com. Gas-Fired Storage - SL1**	0.038	0.126	0.505	0.556	0.699	0.888
Com. Gas-Fired Storage - SL2**	0.075	0.160	0.505	0.588	0.716	0.924
Res. Duty Gas-Fired Storage - SL0	0.000	0.021	0.069	0.091	0.102	NA
Res. Duty Gas-Fired Storage - SL1	0.008	0.022	0.069	0.091	0.102	NA
Res. Duty Gas-Fired Storage - SL2	0.009	0.023	NA	NA	NA	NA
Res. Duty Gas-Fired Storage - SL3	0.014	0.024	NA	NA	NA	NA
Gas-Fired Instantaneous: Tankless	0.000	0.002	0.009	0.048	0.057	0.066
Gas-Fired Instantaneous: HWSB	0.000	0.067	0.169	0.613	0.715	0.822
Commercial Electric Storage†	0.000	0.048	NA	NA	NA	NA

* NA = not analyzed.
** DOE analyzed commercial gas-fired storage water heaters and commercial gas-fired storage-type instantaneous water heaters as one group of equipment rather than analyzing them separately.
† The commercial electric storage savings shown are for the standby loss efficiency improvement.

Table 10.5.3 Full-Fuel-Cycle National Energy Savings for CWH Equipment by Efficiency Level (quads)

Equipment	Efficiency Levels*					
	0	1	2	3	4	5
Com. Gas-Fired Storage - SL0**	0.000	0.093	0.569	0.590	0.769	0.961
Com. Gas-Fired Storage - SL1**	0.043	0.142	0.569	0.626	0.786	0.999
Com. Gas-Fired Storage - SL2**	0.085	0.179	0.569	0.662	0.805	1.038
Res. Duty Gas-Fired Storage - SL0	0.000	0.023	0.078	0.103	0.115	NA
Res. Duty Gas-Fired Storage - SL1	0.009	0.025	0.078	0.103	0.115	NA
Res. Duty Gas-Fired Storage - SL2	0.010	0.025	NA	NA	NA	NA
Res. Duty Gas-Fired Storage - SL3	0.015	0.027	NA	NA	NA	NA
Gas-Fired Instantaneous: Tankless	0.000	0.002	0.011	0.054	0.064	0.074
Gas-Fired Instantaneous: HWSB	0.000	0.075	0.190	0.687	0.801	0.921
Commercial Electric Storage†	0.000	0.050	NA	NA	NA	NA

* NA = not analyzed.
** DOE analyzed commercial gas-fired storage water heaters and commercial gas-fired storage-type instantaneous water heaters as one group of equipment rather than analyzing them separately.
† The commercial electric storage savings shown are for the standby loss efficiency improvement.

Table 10.5.4 Primary National Energy Savings for CWH Equipment by Trial Standard Level (quads)

Equipment	Trial Standard Levels			
	1	2	3	4
Com. Gas-Fired Storage Water Heaters*	0.160	0.505	0.716	0.924
Res. Duty Gas-Fired Storage Water Heaters	0.024	0.069	0.069	0.102
Gas-fired instantaneous water heaters and hot water supply boilers	0.179	0.661	0.772	0.888
Tankless Water Heaters	0.009	0.048	0.057	0.066
Hot Water Supply Boilers	0.169	0.613	0.715	0.822
Com. Electric Storage Water Heaters	0.048	0.048	0.048	0.048
Total	**0.410**	**1.282**	**1.604**	**1.961**

* DOE analyzed commercial gas-fired storage water heaters and commercial gas-fired storage-type instantaneous water heaters as one group of equipment rather than analyzing them separately.

Table 10.5.5 Full-Fuel-Cycle National Energy Savings for CWH Equipment by Trial Standard Level (quads)

Equipment	Trial Standard Levels			
	1	2	3	4
Com. Gas-Fired Storage Water Heaters*	0.179	0.569	0.805	1.038
Res. Duty Gas-Fired Storage Water Heaters	0.027	0.078	0.078	0.115
Gas-fired instantaneous water heaters and hot water supply boilers	0.200	0.741	0.865	0.996
Tankless Water Heaters	0.011	0.054	0.064	0.074
Hot Water Supply Boilers	0.190	0.687	0.801	0.921
Com. Electric Storage Water Heaters	0.050	0.050	0.050	0.050
Total	**0.457**	**1.438**	**1.798**	**2.199**

* DOE analyzed commercial gas-fired storage water heaters and commercial gas-fired storage-type instantaneous water heaters as one group of equipment rather than analyzing them separately.

10.5.4 Customer Net Present Value Results by Energy Efficiency Level

Table 10.5.6 through Table 10.5.7 show the cumulative NPV associated with each of the considered efficiency levels for each CWH equipment class. Table 10.5.8 and Table 10.5.9 show the cumulative NPV associated with each of the considered TSLs for each CWH equipment class. Results in Table 10.5.6 and Table 10.5.8 are shown as the discounted dollar values using a 3-percent discount rate, and results in Table 10.5.7 and Table 10.5.9 are shown as the discounted dollar value of the net savings using a 7-percent discount rate.

Table 10.5.6 Net Present Value, Discounted at 3 Percent, for CWH Equipment by Efficiency Level (billion 2014$)

Equipment	Efficiency Levels*					
	0	1	2	3	4	5
Com. Gas-Fired Storage - SL0**	0.000	0.341	1.958	2.169	3.033	4.053
Com. Gas-Fired Storage - SL1**	0.215	0.586	1.958	2.350	3.120	4.251
Com. Gas-Fired Storage - SL2**	0.307	0.654	1.958	2.416	3.154	4.302
Res. Duty Gas-Fired Storage - SL0	0.000	0.045	0.163	0.220	0.282	NA
Res. Duty Gas-Fired Storage - SL1	0.010	0.046	0.163	0.220	0.282	NA
Res. Duty Gas-Fired Storage - SL2	-0.016	0.042	NA	NA	NA	NA

Equipment	Efficiency Levels*					
	0	1	2	3	4	5
Res. Duty Gas-Fired Storage - SL3	-0.006	0.044	NA	NA	NA	NA
Gas-Fired Instantaneous: Tankless	0.000	0.011	0.038	0.340	0.387	0.433
Gas-Fired Instantaneous: HWSB	0.000	0.362	0.804	2.438	2.909	3.399
Commercial Electric Storage†	0.000	0.138	NA	NA	NA	NA

* NA = not analyzed.
** DOE analyzed commercial gas-fired storage water heaters and commercial gas-fired storage-type instantaneous water heaters as one group of equipment rather than analyzing them separately.
† The commercial electric storage savings shown are for the standby loss efficiency improvement.

Table 10.5.7 Net Present Value, Discounted at 7 Percent, for CWH Equipment by Efficiency Level (billion 2014$)

Equipment	Trial Standard Levels*					
	0	1	2	3	4	5
Com. Gas-Fired Storage - SL0**	0.000	0.134	0.708	0.814	1.186	1.635
Com. Gas-Fired Storage - SL1**	0.093	0.240	0.708	0.893	1.224	1.721
Com. Gas-Fired Storage - SL2**	0.120	0.256	0.708	0.908	1.231	1.727
Res. Duty Gas-Fired Storage - SL0	0.000	0.008	0.026	0.041	0.067	NA
Res. Duty Gas-Fired Storage - SL1	(0.001)	0.008	0.026	0.041	0.067	NA
Res. Duty Gas-Fired Storage - SL2	(0.016)	0.006	NA	NA	NA	NA
Res. Duty Gas-Fired Storage - SL3	(0.014)	0.006	NA	NA	NA	NA
Gas-Fired Instantaneous: Tankless	0.000	0.004	0.013	0.130	0.147	0.163
Gas-Fired Instantaneous: HWSB	(0.000)	0.121	0.251	0.674	0.817	0.964
Commercial Electric Storage†	0.000	0.042	NA	NA	NA	NA

* Numbers in parentheses are negative numbers. NA = not analyzed.
** DOE analyzed commercial gas-fired storage water heaters and commercial gas-fired storage-type instantaneous water heaters as one group of equipment rather than analyzing them separately.
† The commercial electric storage savings shown are for the standby loss efficiency improvement.

Table 10.5.8 Net Present Value, Discounted at 3 Percent, for CWH Equipment by Trial Standard Level (billion 2014$)

Equipment	Trial Standard Levels			
	1	2	3	4
Com. Gas-Fired Storage Water Heaters*	0.65	1.96	3.15	4.30
Res. Duty Gas-Fired Storage Water Heaters	0.04	0.16	0.16	0.28
Gas-fired instantaneous water heaters and hot water supply boilers	0.84	2.78	3.30	3.83
Tankless Water Heaters	0.04	0.34	0.39	0.43
Hot Water Supply Boilers	0.80	2.44	2.91	3.40
Com. Electric Storage Water Heaters	0.14	0.14	0.14	0.14
Total	**1.68**	**5.04**	**6.75**	**8.55**

* DOE analyzed commercial gas-fired storage water heaters and commercial gas-fired storage-type instantaneous water heaters as one group of equipment rather than analyzing them separately.

Table 10.5.9 Net Present Value, Discounted at 7 Percent, for CWH Equipment by TSL (billion 2014$)

Equipment	Trial Standard Levels			
	1	**2**	**3**	**4**
Com. Gas-Fired Storage Water Heaters*	0.26	0.71	1.23	1.73
Res. Duty Gas-Fired Storage Water Heaters	0.006	0.03	0.03	0.07
Gas-fired instantaneous water heaters and hot water supply boilers	0.26	0.80	0.96	1.13
Tankless Water Heaters	0.01	0.13	0.15	0.16
Hot Water Supply Boilers	0.25	0.67	0.82	0.96
Com. Electric Storage Water Heaters	0.04	0.04	0.04	0.04
Total	**0.57**	**1.58**	**2.26**	**2.96**

* DOE analyzed commercial gas-fired storage water heaters and commercial gas-fired storage-type instantaneous water heaters as one group of equipment rather than analyzing them separately.

REFERENCES

1. U.S. Energy Information Administration. *Annual Energy Outlook 2015 with Projections to 2040*. 2015. U.S. Department of Energy: Washington, DC. DOE/EIA-0383(2015). www.eia.gov/forecasts/aeo/

2. Office of Management and Budget. *OMB Circular A-4, Regulatory Analysis*. 2003. OMB: Washington, D.C. September 17, 2003. www.whitehouse.gov/omb/assets/omb/circulars/a004/a-4.pdf.

APPENDIX 10A. USER INSTRUCTIONS FOR NATIONAL IMPACT ANALYSES SPREADSHEET MODEL

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APPENDIX 10A. USER INSTRUCTIONS FOR NATIONAL IMPACT ANALYSES SPREADSHEET MODEL

10A.1 USER INSTRUCTIONS

The results obtained in this analysis can be examined and reproduced using the Microsoft Excel® spreadsheet accessible on the Internet from the U.S. Department of Energy's (DOE's) commercial water heating (CWH) equipment rulemaking page: https://www1.eere.energy.gov/buildings/appliance_standards/standards.aspx?productid=36. From that page, follow the links to the notice of proposed rulemaking (NOPR) phase of the rulemaking and then to the analytical tools.

10A.2 STARTUP

The National Impact Analyses (NIA) spreadsheet enables the user to examine selected national impacts attributable to each efficiency level considered for CWH equipment. To use the spreadsheet the user will need access to a personal computer with a hardware configuration capable of running Windows 7 and Microsoft Excel® 2010, or a later version.

10A.3 DESCRIPTION OF NATIONAL IMPACT ANALYSES WORKSHEETS

The NIA spreadsheet performs calculations to project the change in national energy use and in the net present value of financial impacts due to revised energy efficiency standards for each analyzed CWH equipment class. The energy use and associated costs for a given potential energy efficiency standard level are determined by calculating the shipments and then calculating the energy use and costs for all CWH equipment shipped within that analyzed equipment class under that potential standard. The differences between the standards and no-new-standards cases then can be compared, and the overall energy savings and net present values determined. The NIA spreadsheet consists of the following worksheets:

Flow Chart	Contains an introduction to each worksheet and a flow chart of spreadsheet inputs and outputs
NIA Summary	Contains the national energy savings (NES) results tables; net present value (NPV) results tables; and other tables such as shipments, equipment cost, and energy use in 2019 for each equipment class
Summary Results	Contains interim summaries of disaggregated NPV and NES results for all equipment classes; used as an intermediate stage for storing input for downstream analyses and for creation of a graph used in the TSD
Matrix	Contains the unique calculations for the two equipment classes with multiple standby loss and thermal efficiency improvement levels (the calculations for a standby loss level roll-up are not

	needed for classes without multiple standby loss improvement levels and multiple thermal efficiency improvement levels)
Labels	Contains labels and definitions used throughout the spreadsheet; also contains tables where the thermal efficiency (E_t) and standby loss (SL) efficiency levels (ELs) used in the analysis are defined
TSL Mapping	Contains the mapping of Trial Standard Levels (TSLs) to E_t and SL efficiency levels, and a TSL-to-EL mapping that allows the model to be run to analyze ELs rather than TSLs
CGSWH_SL0	Contains NIA calculations for commercial gas-fired storage water heaters analyzed in this NOPR at baseline standby loss efficiency level
CGSWH_SL1	Contains NIA calculations for commercial gas-fired storage water heaters analyzed in this NOPR at standby loss efficiency level 1
CGSWH_SL2	Contains NIA calculations for commercial gas-fired storage water heaters analyzed in this NOPR at standby loss efficiency level 2
RDGSWH_SL0	Contains NIA calculations for residential-duty gas-fired storage water heaters analyzed in this NOPR at baseline standby loss efficiency level
RDGSWH_SL1	Contains NIA calculations for residential-duty gas-fired storage water heaters analyzed in this NOPR at standby loss efficiency level 1
RDGSWH_SL2	Contains NIA calculations for residential-duty gas-fired storage water heaters analyzed in this NOPR at standby loss efficiency level 2
RDGSWH_SL3	Contains NIA calculations for residential-duty gas-fired storage water heaters analyzed in this NOPR at standby loss efficiency level 3
CGITLWH	Contains NIA calculations for commercial gas-fired instantaneous tankless water heaters analyzed in this NOPR
CGIHWSB	Contains NIA calculations for commercial gas-fired instantaneous hot water supply boilers analyzed in this NOPR
CESWH	Contains NIA calculations for commercial electric storage water heaters analyzed in this NOPR

Intermed. for NIAplus	Intermediate worksheet preparing commercial and residential consumer results stored on the forNIAplusRes and on the forNIAplusCom worksheets
Eqp Price Trend	Includes the learning multipliers to adjust the manufacturer's cost over the entire analysis period
Price Elasticity	Includes the price elasticity to account for the change in the percentage of commercial consumers acquiring a water heater divided by a change in the relative price
Energy Use Trend	Contains look-up tables for factors to adjust energy usage for identified changes expected during the analysis period (all adjustments are set to reflect the lack of expected changes)
Fuel Prices	Contains energy prices for each equipment class by year
AEO Housing Forecast	Includes *Annual Energy Outlook* (*AEO*) forecasts of building stocks and starts for both commercial and residential buildings
New Saturation	Contains market saturation data for each equipment class
Lifetime	Includes the lifetime and the retirement function for each equipment class
LCC Output	Contains energy use, electricity use, total installed price, annual repair and maintenance costs, and 2019 fuel and electricity prices for each equipment class, from the LCC model
Historical Shipments	Includes historical shipments data for each equipment class
Shipments	Includes historical shipment and the annual shipment forecast results for document tables and graphics, and tables for results macros to store intermediate results
TSD Tables	Stores tables for use in the Technical Support Document

The following are worksheets, primarily for use in the development of downstream analysis inputs. These worksheets are normally hidden because they are generally not edited during production.

For NIAplus	Includes the inputs for the downstream emissions analyses
For NIAplus Res	Stores residential consumer results used in the downstream emissions analyses, and in generating summary tables for the NIA Summary worksheet

For NIAplus Com	Stores commercial consumer results used in the downstream emissions analyses, and in generating summary tables for the NIA Summary worksheet
matrixOutput	Stores data for downstream analyses developed in the matrix analysis of the EL/SL efficiency levels
Output Data	Stores raw data for the employment downstream analysis initially captured in the Summary Results worksheet
For MIA	Stores shipments data for export to the Manufacturer Impact Analysis
For ImSET	Stores final inputs for the employment downstream analysis

10A.4 BASIC INSTRUCTIONS FOR OPERATING THE NATIONAL IMPACT ANALYSES SPREADSHEET

Basic instructions for operating the NIA spreadsheet are as follows:

1) Once the NIA spreadsheet file has been downloaded from the DOE website, open the file using MS Excel. Click "Enable Macro" when prompted and then click on the tab for the worksheet "NIA Summary."

2) Use MS Excel's view/zoom commands at the top menu bar to change the size of the display to make it fit your monitor.

3) Change the default parameters in the sheet "NIA Summary" as follows (see Figure 10A.4.1):

    a) Year Standards in Effect: Set to 2019. To change the value, click on cell D7 and change to the desired year.

    b) Analysis Period: Set to 30. To change the value, click on cell D6 and change to the desired analysis period. The year that analysis ends (cell D9) is automatically calculated based on the year the standard is in effect and analysis period.

    c) Discount Rates: Set to 7%. To change the value, click on cell D51 in "Labels" and change to the desired value (7% or 3%).

    d) Discount Year: Set to 2015. To change the value, click on cell D13 in "NIA Summary" and change to the desired year.

    e) Economic Growth Scenario: Set to "AEO2015 Reference." To change the value, click on the pull down menu next to cell C23 "Economic Growth Scenario" and change to the desired scenario.

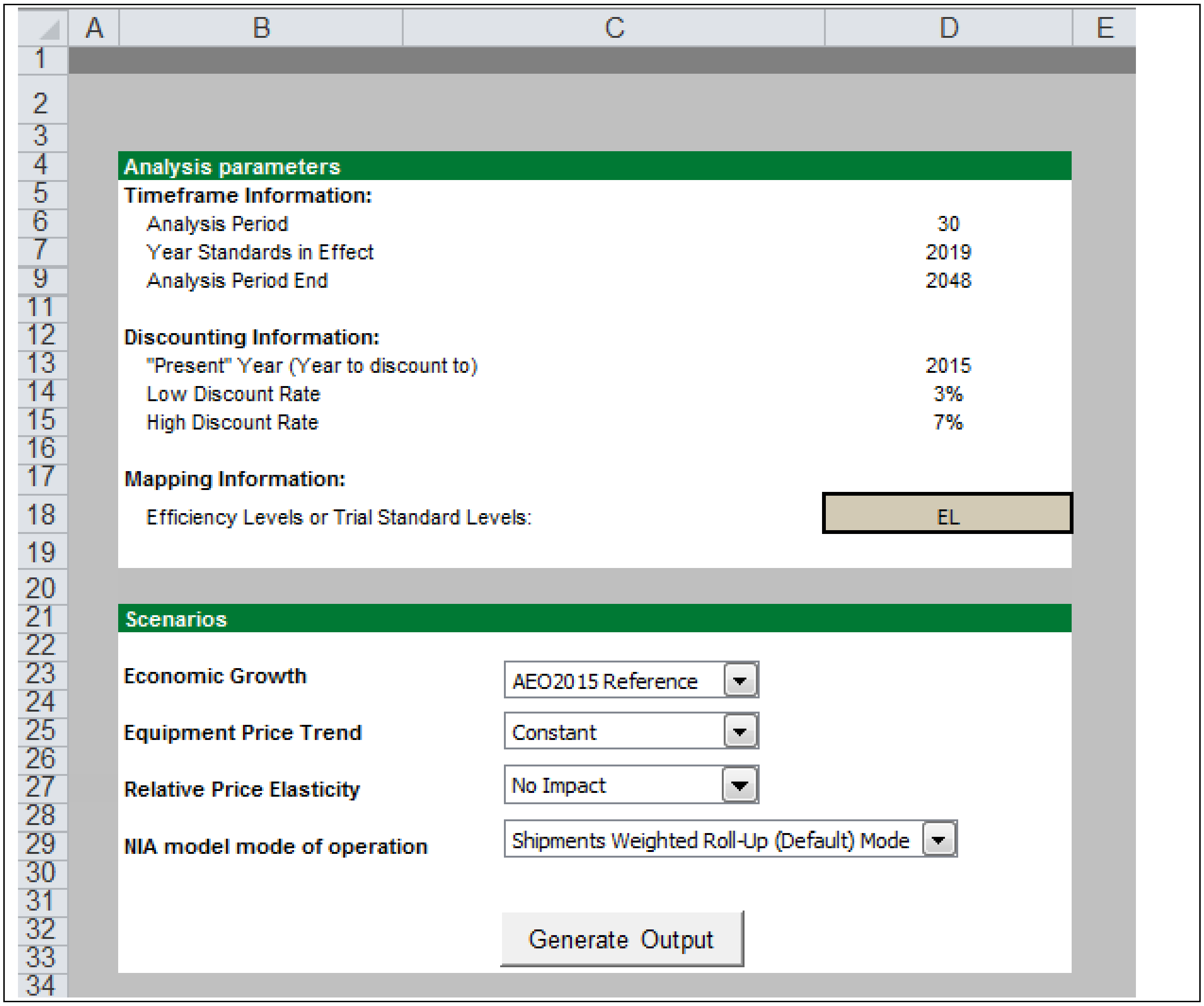

Figure 10A.4.1 Default User Input Parameters

f) Equipment Price Trend Scenario: Set to "Constant." To change the value, click on the pull down menu next to cell C25 "Equipment Price Trend" and change to the desired scenario. Note that currently, low, reference, and high price trends are all set to zero, so analyzing alternative trends will require specification of alternative trends by the user.

g) Relative Price Elasticity: Set to No Impact. Not currently enabled.

h) Mapping Information: Cell D18 should be set to EL. The model when run will generate results by EL and TSL. The TSL mapping setting is useful primarily in the generation of inputs for downstream analyses.

i) NIA model mode of operation: Set to "Shipments Weighted Roll-Up (Default) Mode." The Generate Output macro will adjust this for purposes of generating inputs for the matrix analysis for the SL-EL roll-up, but otherwise, this control should not be of interest to users.

4) Use the button "Generate Output" to update the analysis results based on user inputs: national energy savings by efficiency level in cells H7 to O22 and net present values by efficiency level in cells H29 to O66.

5) Select current application sector: because commercial water heaters are used for both commercial and residential applications, users could select the application sector by selecting sectors on the pull down menu in the "Application Sector" table next to cell D22 in "Labels." The annual shipment, unit energy use, equipment cost, etc. of CWH equipment at no-new-standards case and higher efficiency levels under the selected application sector can be seen in the accounting worksheets named by equipment classes, namely "CGSWH_SL0," "CGSWH_SL1," "CGSWH_SL2," "RDGSWH_SL0," "RDGSWH_SL1," "RDGSWH_SL2," "RDGSWH_SL3," "CGITLWH," "CGIHWSB," and "CESWH." It should be mentioned that all the results in the "NIA Summary" worksheet are aggregated from both commercial and residential applications.

Note: Make sure that the spreadsheet is in automatic calculation mode. The calculation mode could be changed using the following steps (shown in Figure 10A.4.2):

1) In Excel 2010 and later versions, go to the tab "Formulas" in the Office ribbon.

2) Click on the button "Calculation Options" and select "Automatic."

The results are automatically updated and are reported in the source energy savings matrix, net present value matrix, and summary table for each equipment class.

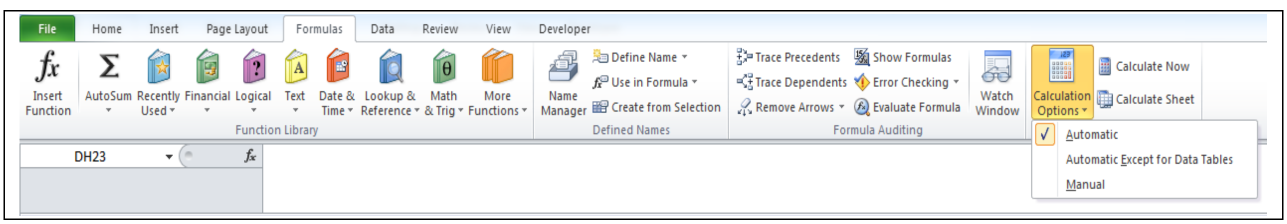

Figure 10A.4.2 Set the Spreadsheet to Automatic Calculation Mode

APPENDIX 10B. NATIONAL NET PRESENT VALUE USING ALTERNATIVE SENSITIVITY ANALYSES

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APPENDIX 10B. NATIONAL NET PRESENT VALUE USING ALTERNATIVE PRICE FORECASTS

10B.1 NET PRESENT VALUE SENSITIVITY ANALYSES USING ALTERNATIVE ECONOMIC GROWTH SCENARIOS

For the net present value (NPV) sensitivity analysis, the U.S. Department of Energy (DOE) considered projections from alternative economic growth scenarios. These scenarios are based on the High Economic Growth case and the Low Economic Growth case from the Energy Information Administration's (EIA) *Annual Energy Outlook 2015* (*AEO2015*).[1]

Tables in this appendix provide estimates of impacts arising from thermal efficiency and standby loss efficiency improvements. Chapter 5 discusses the specific design options underlying these efficiency improvements while chapter 10 discusses the improvements in the context of the national impact analysis (NIA). Thermal efficiency levels are denoted on tables with the efficiency level (EL) abbreviations while standby loss efficiency levels are denoted with the standby loss (SL) abbreviations. Tables also provide results by trial standard level (TSL) in which DOE tests alternative levels of potential standards defined by specific criteria (*e.g.*, EL/SL combinations providing the highest NPV results at a 7-percent discount rate). TSL definitions are provided in appendix 10C.

10B.1.1 Description of High and Low Economic Growth Scenarios

To generate NIA results reported in chapter 10, DOE uses the Reference case energy price and building stock and construction projection from *AEO2015*. The Reference case is a business-as-usual estimate, given known market, demographic, and technological trends. For *AEO2015*, EIA explored the impacts of alternative assumptions in other scenarios with different macroeconomic growth rates, world oil prices, rates of technology progress, and policy changes.

To reflect uncertainty in the projection of U.S. economic growth, EIA's *AEO2015* uses High and Low Economic Growth scenarios to project the possible impacts of alternative economic growth assumptions on energy markets.

Energy prices are higher in the High Economic Growth scenario and lower in the Low Economic Growth scenario, except for electricity prices for the period between 2012 and 2017. For the residential sector, the High Economic Growth scenario exhibits the lowest prices of the three scenarios until 2017, with the high-growth scenario prices exceeding the low-growth scenario electricity prices beginning in 2018 and exceeding the reference scenario beginning in 2019. For the commercial sector, high-growth scenario prices exceed low-growth scenario electricity prices, and high-growth scenario prices exceed reference prices in some but not all years until 2017, after which high-growth scenario prices are projected to be higher in all years. Figure 10B.1.1 shows the residential sector fuel price projections for the different *AEO2015* scenarios, and Figure 10B.1.2 shows commercial sector fuel price projections based on the *AEO2015* scenarios.

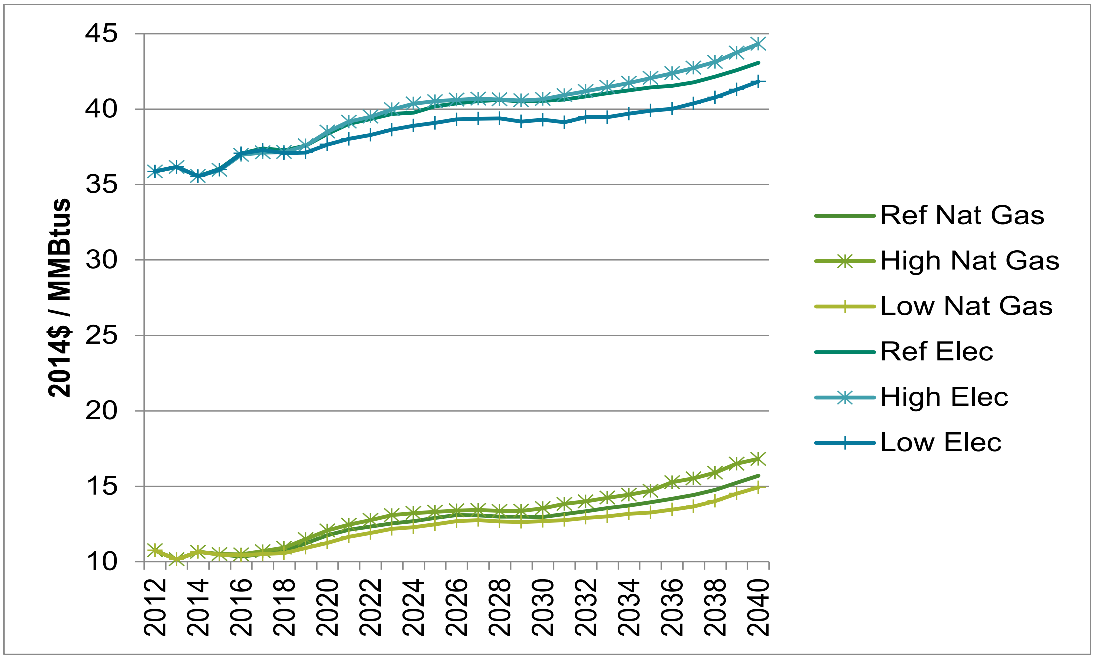

Figure 10B.1.1 Residential Sector Fuel Price Projections from *AEO2015*

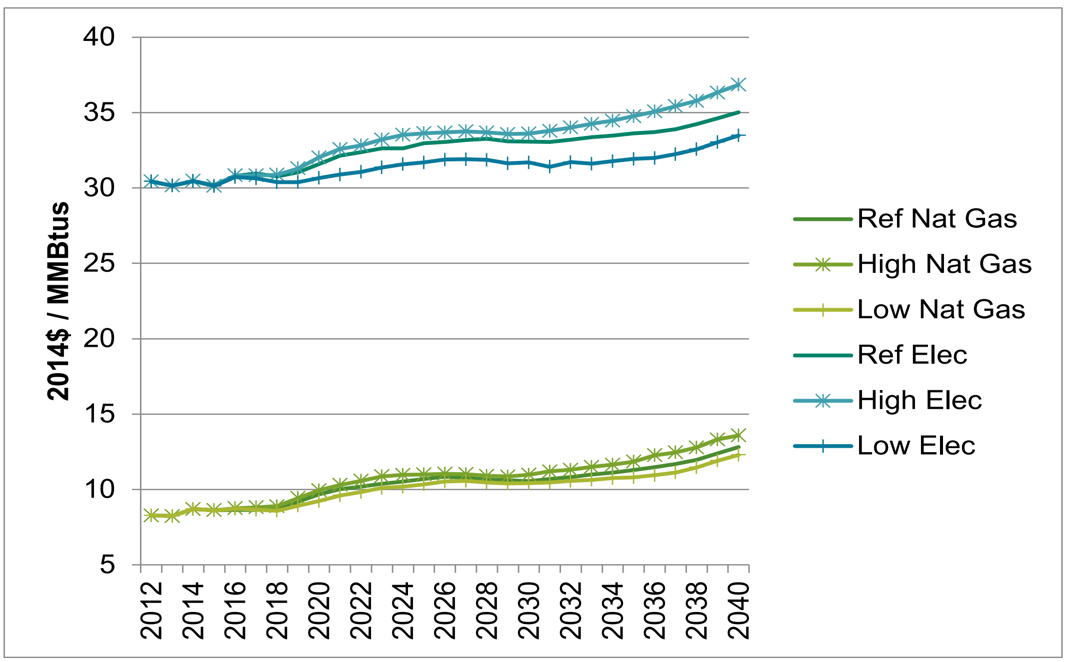

Figure 10B.1.2 Commercial Sector Fuel Price Projections from *AEO2015*

The High and Low Economic Growth scenarios also provide different building additions and stock projections that affect the commercial water heater (CWH) shipments projections. Table 10B.1.1 shows the total building stock, by year, for commercial and residential consumer sectors, and for the Low Economic Growth, Reference, and High Economic Growth *AEO2015* cases.

Table 10B.1.1 Building Stock Projections from *AEO2015*

Year	Commercial Building Stock			Residential Building Stock		
	Low Econ*	Reference	High Econ	Low Econ	Reference	High Econ
	million sq. ft.	*million sq. ft.*	*million sq. ft.*	*million units*	*million units*	*million units*
2013	81,382	81,382	81,382	114	114	114
2014	81,879	81,879	81,879	115	115	115
2015	82,459	82,459	82,459	115	116	116
2016	83,154	83,161	83,168	116	116	117
2017	83,922	83,958	84,021	117	117	119
2018	84,796	84,888	85,055	117	118	120
2019	85,697	85,888	86,143	118	119	122
2020	86,625	86,938	87,262	118	121	124
2021	87,547	87,989	88,421	119	122	125
2022	88,475	89,046	89,609	120	123	127
2023	89,392	90,090	90,801	120	124	129
2024	90,276	91,087	91,955	121	125	131
2025	91,113	92,037	93,055	121	126	132
2026	91,924	92,963	94,125	122	127	134
2027	92,704	93,857	95,146	122	128	136
2028	93,453	94,718	96,125	123	129	138
2029	94,180	95,552	97,073	123	130	140
2030	94,898	96,380	98,009	124	131	141
2031	95,606	97,205	98,944	124	132	143
2032	96,322	98,048	99,899	125	133	145
2033	97,098	98,954	100,916	125	134	146
2034	97,924	99,912	101,992	126	135	148
2035	98,798	100,920	103,131	126	136	150
2036	99,743	101,997	104,362	126	137	151
2037	100,763	103,150	105,679	127	138	153
2038	101,796	104,323	107,027	127	139	155
2039	102,820	105,497	108,386	128	140	157
2040	103,811	106,649	109,731	128	141	158
2041	104,747	107,734	110,977	128	142	160
2042	105,692	108,830	112,238	129	143	162
2043	106,645	109,938	113,513	129	144	164
2044	107,606	111,056	114,803	130	145	166
2045	108,577	112,186	116,107	130	146	168
2046	109,556	113,328	117,427	131	147	170
2047	110,544	114,481	118,761	131	148	172
2048	111,540	115,646	120,110	131	149	174

Source: EIA. *AEO2015*, for 2013–2040. Growth after 2040 projected by extrapolating the *AEO2015* growth over the last 10 years of the *AEO* projections.
* Low Econ = Low Economic Growth scenario; Reference = Reference case; High Econ = High Economic Growth scenario

10B.2 SENSITIVITY ANALYSIS RESULTS

For convenience in the following tables of results, some CWH equipment class names have been abbreviated as follows:

- com. gas-fired storage = commercial gas-fired storage
- res.-duty gas-fired storage = residential-duty gas-fired storage
- gas-fired instantaneous: HWSB = gas-fired instantaneous hot water supply boiler

10B.2.1 High Economic Growth Scenarios

Table 10B.2.1 through Table 10B.2.8 show scenarios involving High Economic Growth case energy prices and building stock growth.

Table 10B.2.1 CWH Equipment: Primary National Energy Savings by EL (quads) – High Economic Growth Scenario

Equipment Class	Thermal Efficiency Levels*					
	0	1	2	3	4	5
Com. gas-fired storage - SL0**	0.000	0.087	0.529	0.549	0.716	0.895
Com. gas-fired storage - SL1**	0.040	0.132	0.529	0.582	0.732	0.931
Com. gas-fired storage - SL2**	0.079	0.167	0.529	0.616	0.750	0.967
Res.-duty gas-fired storage - SL0	0.000	0.022	0.074	0.099	0.110	NA
Res.-duty gas-fired storage - SL1	0.009	0.024	0.074	0.099	0.110	NA
Res.-duty gas-fired storage - SL2	0.010	0.024	NA	NA	NA	NA
Res.-duty gas-fired storage - SL3	0.015	0.026	NA	NA	NA	NA
Gas-fired instantaneous: tankless	0.000	0.002	0.010	0.050	0.060	0.069
Gas-fired instantaneous: HWSB	0.000	0.072	0.181	0.656	0.766	0.880
Commercial electric storage†	0.000	0.050	NA	NA	NA	NA

* NA = not analyzed.
** DOE analyzed commercial gas-fired storage water heaters and commercial gas-fired storage-type instantaneous water heaters as one group of equipment rather than analyzing them separately.
† Commercial electric storage savings shown are for the standby loss efficiency improvement.

Table 10B.2.2 CWH Equipment: Full-Fuel-Cycle National Energy Savings by EL (quads) – High Economic Growth Scenario

Equipment Class	Thermal Efficiency Levels*					
	0	1	2	3	4	5
Com. gas-fired storage - SL0**	0.000	0.097	0.596	0.618	0.805	1.007
Com. gas-fired storage - SL1**	0.045	0.148	0.596	0.656	0.823	1.047
Com. gas-fired storage - SL2**	0.088	0.188	0.596	0.693	0.844	1.088
Res.-duty gas-fired storage - SL0	0.000	0.025	0.084	0.111	0.124	NA
Res.-duty gas-fired storage - SL1	0.010	0.027	0.084	0.111	0.124	NA
Res.-duty gas-fired storage - SL2	0.011	0.027	NA	NA	NA	NA
Res.-duty gas-fired storage - SL3	0.017	0.029	NA	NA	NA	NA
Gas-fired instantaneous: tankless	0.000	0.003	0.011	0.057	0.067	0.078
Gas-fired instantaneous: HWSB	0.000	0.081	0.204	0.736	0.859	0.987
Commercial electric storage†	0.000	0.052	NA	NA	NA	NA

* NA = not analyzed.
** DOE analyzed commercial gas-fired storage water heaters and commercial gas-fired storage-type instantaneous water heaters as one group of equipment rather than analyzing them separately.
† Commercial electric storage savings shown are for the standby loss efficiency improvement.

Table 10B.2.3 CWH Equipment: Net Present Value in Billions (2014$) at a 3-Percent Discount Rate by EL – High Economic Growth Scenario

Equipment Class	Thermal Efficiency Levels*					
	0	1	2	3	4	5
Com. gas-fired storage - SL0**	0.000	0.391	2.274	2.504	3.473	4.611
Com. gas-fired storage - SL1**	0.241	0.664	2.274	2.706	3.570	4.832
Com. gas-fired storage - SL2**	0.351	0.749	2.274	2.787	3.612	4.899
Res.-duty gas-fired storage - SL0	0.000	0.058	0.215	0.287	0.358	NA
Res.-duty gas-fired storage - SL1	0.015	0.061	0.215	0.287	0.358	NA
Res.-duty gas-fired storage - SL2	-0.013	0.056	NA	NA	NA	NA
Res.-duty gas-fired storage - SL3	0.000	0.059	NA	NA	NA	NA
Gas-fired instantaneous: tankless	0.000	0.013	0.044	0.397	0.451	0.503
Gas-fired instantaneous: HWSB	0.000	0.422	0.947	2.970	3.526	4.105
Commercial electric storage†	0.000	0.160	NA	NA	NA	NA

* NA = not analyzed.
** DOE analyzed commercial gas-fired storage water heaters and commercial gas-fired storage-type instantaneous water heaters as one group of equipment rather than analyzing them separately.
† Commercial electric storage savings shown are for the standby loss efficiency improvement.

Table 10B.2.4 CWH Equipment: Net Present Value in Billions (2014$) at a 7-Percent Discount Rate by EL – High Economic Growth Scenario

Equipment Class	Thermal Efficiency Levels*					
	0	1	2	3	4	5
Com. gas-fired storage - SL0**	0.000	0.152	0.827	0.942	1.354	1.849
Com. gas-fired storage - SL1**	0.103	0.270	0.827	1.028	1.396	1.944
Com. gas-fired storage - SL2**	0.136	0.292	0.827	1.049	1.406	1.955
Res.-duty gas-fired storage - SL0	0.000	0.013	0.044	0.063	0.093	NA
Res.-duty gas-fired storage - SL1	0.001	0.013	0.044	0.063	0.093	NA
Res.-duty gas-fired storage - SL2	(0.015)	0.010	NA	NA	NA	NA
Res.-duty gas-fired storage - SL3	(0.012)	0.010	NA	NA	NA	NA
Gas-fired instantaneous: tankless	0.000	0.004	0.016	0.154	0.173	0.191
Gas-fired instantaneous: HWSB	(0.000)	0.139	0.293	0.836	1.003	1.177
Commercial electric storage†	(0.000)	0.048	NA	NA	NA	NA

* Numbers in parenthesis are negative numbers. NA = not analyzed.
** DOE analyzed commercial gas-fired storage water heaters and commercial gas-fired storage-type instantaneous water heaters as one group of equipment rather than analyzing them separately.
† Commercial electric storage savings shown are for the standby loss efficiency improvement.

Table 10B.2.5 CWH Equipment: Primary National Energy Savings by TSL (quads) – High Economic Growth Scenario

Equipment Class	Trial Standard Levels			
	1	**2**	**3**	**4**
Com. gas-fired storage water heaters*	0.167	0.529	0.750	0.967
Res.-duty gas-fired storage water heaters	0.026	0.074	0.074	0.110
Gas-fired instantaneous water heaters and hot water supply boilers	0.191	0.707	0.826	0.950
Tankless water heaters	0.010	0.050	0.060	0.069
Hot water supply boilers	0.181	0.656	0.766	0.880
Com. electric storage water heaters	0.050	0.050	0.050	0.050
Total	**0.435**	**1.360**	**1.700**	**2.077**

* DOE analyzed commercial gas-fired storage water heaters and commercial gas-fired storage-type instantaneous water heaters as one group of equipment rather than analyzing them separately.

Table 10B.2.6 CWH Equipment: Full-Fuel-Cycle National Energy Savings by TSL (quads) – High Economic Growth Scenario

Equipment Class	Trial Standard Levels			
	1	**2**	**3**	**4**
Com. gas-fired storage water heaters*	0.188	0.596	0.844	1.088
Res.-duty gas-fired storage water heaters	0.029	0.084	0.084	0.124
Gas-fired instantaneous water heaters and hot water supply boilers	0.215	0.793	0.926	1.065
Tankless water heaters	0.011	0.057	0.067	0.078
Hot water supply boilers	0.204	0.736	0.859	0.987
Com. electric storage water heaters	0.052	0.052	0.052	0.052
Total	**0.484**	**1.525**	**1.906**	**2.329**

* DOE analyzed commercial gas-fired storage water heaters and commercial gas-fired storage-type instantaneous water heaters as one group of equipment rather than analyzing them separately.

Table 10B.2.7 CWH Equipment: Net Present Value in Billions (2014$) at a 3-Percent Discount Rate by TSL – High Economic Growth Scenario

Equipment Class	Trial Standard Levels			
	1	**2**	**3**	**4**
Com. gas-fired storage water heaters*	0.75	2.27	3.61	4.90
Res.-duty gas-fired storage water heaters	0.06	0.21	0.21	0.36
Gas-fired instantaneous water heaters and hot water supply boilers	0.99	3.37	3.98	4.61
Tankless water heaters	0.04	0.40	0.45	0.50
Hot water supply boilers	0.95	2.97	3.53	4.11
Com. electric storage water heaters	0.16	0.16	0.16	0.16
Total	**1.96**	**6.02**	**7.96**	**10.03**

* DOE analyzed commercial gas-fired storage water heaters and commercial gas-fired storage-type instantaneous water heaters as one group of equipment rather than analyzing them separately.

Table 10B.2.8 CWH Equipment: Net Present Value in Billions (2014$) at a 7-Percent Discount Rate by TSL – High Economic Growth Scenario

Equipment Class	Trial Standard Levels			
	1	2	3	4
Com. gas-fired storage water heaters*	0.29	0.83	1.41	1.96
Res.-duty gas-fired storage water heaters	0.010	0.04	0.04	0.09
Gas-fired instantaneous water heaters and hot water supply boilers	0.31	0.99	1.18	1.37
Tankless water heaters	0.02	0.15	0.17	0.19
Hot water supply boilers	0.29	0.84	1.00	1.18
Com. electric storage water heaters	0.05	0.05	0.05	0.05
Total	**0.66**	**1.91**	**2.67**	**3.46**

* DOE analyzed commercial gas-fired storage water heaters and commercial gas-fired storage-type instantaneous water heaters as one group of equipment rather than analyzing them separately.

10B.2.2 Low Economic Growth Scenarios

Table 10B.2.9 through Table 10B.2.16 show scenarios involving Low Economic Growth case energy prices.

Table 10B.2.9 CWH Equipment: Primary National Energy Savings by EL (quads) – Low Economic Growth Scenario

Equipment Class	Thermal Efficiency Levels*					
	0	1	2	3	4	5
Com. gas-fired storage - SL0**	0.000	0.079	0.486	0.504	0.657	0.821
Com. gas-fired storage - SL1**	0.037	0.121	0.486	0.535	0.672	0.854
Com. gas-fired storage - SL2**	0.073	0.154	0.486	0.565	0.688	0.888
Res.-duty gas-fired storage - SL0	0.000	0.019	0.065	0.086	0.095	NA
Res.-duty gas-fired storage - SL1	0.007	0.021	0.065	0.086	0.095	NA
Res.-duty gas-fired storage - SL2	0.008	0.021	NA	NA	NA	NA
Res.-duty gas-fired storage - SL3	0.013	0.023	NA	NA	NA	NA
Gas-fired instantaneous: tankless	0.000	0.002	0.009	0.046	0.055	0.063
Gas-fired instantaneous: HWSB	0.000	0.063	0.160	0.578	0.674	0.775
Commercial electric storage†	0.000	0.046	NA	NA	NA	NA

* NA = not analyzed.
** DOE analyzed commercial gas-fired storage water heaters and commercial gas-fired storage-type instantaneous water heaters as one group of equipment rather than analyzing them separately.
† Commercial electric storage savings shown are for the standby loss efficiency improvement.

Table 10B.2.10 CWH Equipment: Full-Fuel-Cycle National Energy Savings by EL (quads) – Low Economic Growth Scenario

Equipment Class	Thermal Efficiency Levels*					
	0	1	2	3	4	5
Com. gas-fired storage - SL0**	0.000	0.089	0.547	0.567	0.739	0.924
Com. gas-fired storage - SL1**	0.041	0.136	0.547	0.602	0.756	0.961
Com. gas-fired storage - SL2**	0.081	0.172	0.547	0.636	0.774	0.999
Res.-duty gas-fired storage - SL0	0.000	0.022	0.073	0.097	0.108	NA
Res.-duty gas-fired storage - SL1	0.009	0.024	0.073	0.097	0.108	NA
Res.-duty gas-fired storage - SL2	0.010	0.024	NA	NA	NA	NA
Res.-duty gas-fired storage - SL3	0.014	0.025	NA	NA	NA	NA
Gas-fired instantaneous: tankless	0.000	0.002	0.010	0.052	0.061	0.071
Gas-fired instantaneous: HWSB	0.000	0.071	0.179	0.648	0.756	0.870
Commercial electric storage†	0.000	0.048	NA	NA	NA	NA

* NA = not analyzed.
** DOE analyzed commercial gas-fired storage water heaters and commercial gas-fired storage-type instantaneous water heaters as one group of equipment rather than analyzing them separately.
† Commercial electric storage savings shown are for the standby loss efficiency improvement.

Table 10B.2.11 CWH Equipment: Net Present Value in Billions (2014$) at a 3-Percent Discount Rate by EL – Low Economic Growth Scenario

Equipment Class	Thermal Efficiency Levels*					
	0	1	2	3	4	5
Com. gas-fired storage - SL0**	0.000	0.305	1.732	1.929	2.716	3.650
Com. gas-fired storage - SL1**	0.197	0.529	1.732	2.094	2.796	3.830
Com. gas-fired storage - SL2**	0.275	0.586	1.732	2.149	2.824	3.870
Res.-duty gas-fired storage - SL0	0.000	0.036	0.128	0.175	0.230	NA
Res.-duty gas-fired storage - SL1	0.007	0.037	0.128	0.175	0.230	NA
Res.-duty gas-fired storage - SL2	-0.018	0.033	NA	NA	NA	NA
Res.-duty gas-fired storage - SL3	-0.009	0.035	NA	NA	NA	NA
Gas-fired instantaneous: tankless	0.000	0.010	0.034	0.296	0.338	0.379
Gas-fired instantaneous: HWSB	0.000	0.319	0.700	2.051	2.460	2.886
Commercial electric storage†	0.000	0.121	NA	NA	NA	NA

* Numbers in parenthesis are negative numbers. NA = not analyzed.
** DOE analyzed commercial gas-fired storage water heaters and commercial gas-fired storage-type instantaneous water heaters as one group of equipment rather than analyzing them separately.
† Commercial electric storage savings shown are for the standby loss efficiency improvement.

Table 10B.2.12 CWH Equipment: Net Present Value in Billions (2014$) at a 7-Percent Discount Rate by EL – Low Economic Growth Scenario

Equipment Class	Thermal Efficiency Levels*					
	0	1	2	3	4	5
Com. gas-fired storage - SL0**	0.000	0.120	0.621	0.722	1.064	1.479
Com. gas-fired storage - SL1**	0.086	0.218	0.621	0.795	1.099	1.559
Com. gas-fired storage - SL2**	0.108	0.230	0.621	0.806	1.104	1.561
Res.-duty gas-fired storage - SL0	0.000	0.006	0.014	0.026	0.049	NA
Res.-duty gas-fired storage - SL1	(0.001)	0.006	0.014	0.026	0.049	NA
Res.-duty gas-fired storage - SL2	(0.016)	0.003	NA	NA	NA	NA
Res.-duty gas-fired storage - SL3	(0.014)	0.003	NA	NA	NA	NA
Gas-fired instantaneous: tankless	0.000	0.004	0.012	0.113	0.128	0.142
Gas-fired instantaneous: HWSB	(0.000)	0.108	0.221	0.557	0.681	0.810
Commercial electric storage†	0.000	0.035	NA	NA	NA	NA

* Numbers in parenthesis are negative numbers. NA = not analyzed.
** DOE analyzed commercial gas-fired storage water heaters and commercial gas-fired storage-type instantaneous water heaters as one group of equipment rather than analyzing them separately.
† Commercial electric storage savings shown are for the standby loss efficiency improvement.

Table 10B.2.13 CWH Equipment: Primary National Energy Savings by TSL (quads) – Low Economic Growth Scenario

Equipment Class	Trial Standard Levels			
	1	2	3	4
Com. gas-fired storage water heaters*	0.154	0.486	0.688	0.888
Res.-duty gas-fired storage water heaters	0.023	0.065	0.065	0.095
Gas-fired instantaneous water heaters and hot water supply boilers	0.169	0.624	0.729	0.839
Tankless water heaters	0.009	0.046	0.055	0.063
Hot water supply boilers	0.160	0.578	0.674	0.775
Com. electric storage water heaters	0.046	0.046	0.046	0.046
Total	**0.391**	**1.221**	**1.528**	**1.868**

* DOE analyzed commercial gas-fired storage water heaters and commercial gas-fired storage-type instantaneous water heaters as one group of equipment rather than analyzing them separately.

Table 10B.2.14 CWH Equipment: Full-Fuel-Cycle National Energy Savings by TSL (quads) – Low Economic Growth Scenario

Equipment Class	Trial Standard Levels			
	1	2	3	4
Com. gas-fired storage water heaters*	0.172	0.547	0.774	0.999
Res.-duty gas-fired storage water heaters	0.025	0.073	0.073	0.108
Gas-fired instantaneous water heaters and hot water supply boilers	0.189	0.700	0.818	0.941
Tankless water heaters	0.010	0.052	0.061	0.071
Hot water supply boilers	0.179	0.648	0.756	0.870
Com. electric storage water heaters	0.048	0.048	0.048	0.048
Total	**0.435**	**1.369**	**1.713**	**2.095**

* DOE analyzed commercial gas-fired storage water heaters and commercial gas-fired storage-type instantaneous water heaters as one group of equipment rather than analyzing them separately.

Table 10B.2.15 CWH Equipment: Net Present Value in Billions (2014$) at a 3-Percent Discount Rate by TSL – Low Economic Growth Scenario

Equipment Class	Trial Standard Levels			
	1	2	3	4
Com. gas-fired storage water heaters*	0.59	1.73	2.82	3.87
Res.-duty gas-fired storage water heaters	0.03	0.13	0.13	0.23
Gas-fired instantaneous water heaters and hot water supply boilers	0.73	2.35	2.80	3.26
Tankless water heaters	0.03	0.30	0.34	0.38
Hot water supply boilers	0.70	2.05	2.46	2.89
Com. electric storage water heaters	0.12	0.12	0.12	0.12
Total	**1.47**	**4.33**	**5.87**	**7.49**

* DOE analyzed commercial gas-fired storage water heaters and commercial gas-fired storage-type instantaneous water heaters as one group of equipment rather than analyzing them separately.

Table 10B.2.16 CWH Equipment: Net Present Value in Billions (2014$) at a 7-Percent Discount Rate by TSL – Low Economic Growth Scenario

Equipment Class	Trial Standard Levels			
	1	2	3	4
Com. gas-fired storage water heaters*	0.23	0.62	1.10	1.56
Res.-duty gas-fired storage water heaters	0.003	0.01	0.01	0.05
Gas-fired instantaneous water heaters and hot water supply boilers	0.23	0.67	0.81	0.95
Tankless water heaters	0.01	0.11	0.13	0.14
Hot water supply boilers	0.22	0.56	0.68	0.81
Com. electric storage water heaters	0.03	0.03	0.03	0.03
Total	**0.50**	**1.34**	**1.96**	**2.60**

* DOE analyzed commercial gas-fired storage water heaters and commercial gas-fired storage-type instantaneous water heaters as one group of equipment rather than analyzing them separately.

10B.3 PRICE TREND SENSITIVITY ANALYSES

The net present value results presented in chapter 10 of this technical support document reflect constant real prices for CWH equipment. In analyses of price trends in manufacturing costs, DOE analyzes the producer price index (PPI) that includes relevant equipment (in this case CWH equipment). CWH equipment was included in PPI 333319, Other Commercial and Service Industry Machinery, and in particular 333319A, Miscellaneous Machinery Products, Except Electrical, for 1982–2007, before the PPI was discontinued. CWH equipment is now covered by a different PPI. With the discontinuity, DOE could not extend a consistent historical series beyond 2007. DOE analyzed the 333319A data series, and found that the inflation-adjusted historical price index showed no clear trend between 1982 and 2007. Given that the observed data did not provide a firm basis for projecting future cost trends for commercial water heaters, DOE used a constant price assumption as the default price trend for commercial water heaters. Because the data did not support an analysis yielding a reference trend, DOE did not perform analyses to identify high and low price trends and, instead, used the default trend in all sensitivities. Thus, no price learning sensitivity analyses are presented herein.

10B.3.1 9-Year Sensitivity Analysis

For this rulemaking, DOE undertook a sensitivity analysis using 9 years rather than 30 years of equipment shipments. The choice of a 9-year period is a proxy for the timeline in Energy Policy and Conservation Act of 1975 (EPCA) for the review of certain energy conservation standards and potential revision of and compliance with such revised standards.[a] This timeframe may not be statistically relevant with regard to the product lifetime, product manufacturing cycles, or other factors specific to commercial gas-fired water heaters. Thus, this information is presented for informational purposes only and is not indicative of any change in DOE's analytical methodology. The energy savings and NPV results based on a 9-year analysis period are shown in Table 10B.3.1 through Table 10B.3.8. The impacts are counted over the lifetime of equipment purchased in 2018–2026.

Table 10B.3.1 CWH Equipment: Primary National Energy Savings by EL (quads) for 9-Year Analysis Period for Equipment Purchased in 2019–2027

Equipment Class	Thermal Efficiency Levels*					
	0	1	2	3	4	5
Com. gas-fired storage - SL0**	0.000	0.022	0.135	0.140	0.183	0.229
Com. gas-fired storage - SL1**	0.010	0.034	0.135	0.149	0.187	0.238
Com. gas-fired storage - SL2**	0.020	0.043	0.135	0.158	0.192	0.248
Res.-duty gas-fired storage - SL0	0.000	0.006	0.019	0.025	0.027	NA
Res.-duty gas-fired storage - SL1	0.002	0.006	0.019	0.025	0.027	NA
Res.-duty gas-fired storage - SL2	0.002	0.006	NA	NA	NA	NA
Res.-duty gas-fired storage - SL3	0.004	0.006	NA	NA	NA	NA
Gas-fired instantaneous: tankless	0.000	0.001	0.002	0.011	0.013	0.016
Gas-fired instantaneous: HWSB	0.000	0.018	0.045	0.164	0.191	0.220
Commercial electric storage†	0.000	0.011	NA	NA	NA	NA

* NA = not analyzed.
** DOE analyzed commercial gas-fired storage water heaters and commercial gas-fired storage-type instantaneous water heaters as one group of equipment rather than analyzing them separately.
† Commercial electric storage savings shown are for the standby loss efficiency improvement.

[a] For CWH equipment, EPCA requires DOE to review its standards at least once every 6 years, and requires a 3-year period after any new standard is promulgated before compliance is required, except that in no case may any new standards be required within 6 years of the compliance date of the previous standards. (42 U.S.C. 6313(a)(6)(C)) While adding a 6-year review to the 3-year compliance period adds up to 9 years, DOE notes that it may undertake reviews at any time within the 6-year period and that the 3-year compliance date may yield to the 6-year backstop. A 9-year analysis period may not be appropriate given the variability that occurs in the timing of standards reviews and the fact that for some consumer products, the compliance period is 5 years rather than 3 years.

Table 10B.3.2 CWH Equipment: Full-Fuel-Cycle National Energy Savings by EL (quads) for 9-Year Analysis Period for Equipment Purchased in 2019–2027

Equipment Class	Thermal Efficiency Levels*					
	0	1	2	3	4	5
Com. gas-fired storage - SL0**	0.000	0.025	0.153	0.158	0.206	0.258
Com. gas-fired storage - SL1**	0.012	0.038	0.153	0.168	0.211	0.268
Com. gas-fired storage - SL2**	0.023	0.048	0.153	0.178	0.216	0.279
Res.-duty gas-fired storage - SL0	0.000	0.006	0.021	0.028	0.031	NA
Res.-duty gas-fired storage - SL1	0.002	0.007	0.021	0.028	0.031	NA
Res.-duty gas-fired storage - SL2	0.003	0.007	NA	NA	NA	NA
Res.-duty gas-fired storage - SL3	0.004	0.007	NA	NA	NA	NA
Gas-fired instantaneous: tankless	0.000	0.001	0.002	0.013	0.015	0.017
Gas-fired instantaneous: HWSB	0.000	0.020	0.051	0.184	0.215	0.247
Commercial electric storage†	0.000	0.012	NA	NA	NA	NA

* NA = not analyzed.
** DOE analyzed commercial gas-fired storage water heaters and commercial gas-fired storage-type instantaneous water heaters as one group of equipment rather than analyzing them separately.
† Commercial electric storage savings shown are for the standby loss efficiency improvement.

Table 10B.3.3 CWH Equipment: Net Present Value in Billions (2014$) at a 3-Percent Discount Rate by EL for 9-Year Analysis Period for Equipment Purchased in 2019–2027

Equipment Class	Thermal Efficiency Levels*					
	0	1	2	3	4	5
Com. gas-fired storage - SL0**	0.000	0.098	0.408	0.478	0.744	1.061
Com. gas-fired storage - SL1**	0.067	0.174	0.408	0.534	0.771	1.123
Com. gas-fired storage - SL2**	0.089	0.189	0.408	0.549	0.778	1.131
Res.-duty gas-fired storage - SL0	0.000	0.009	0.004	0.018	0.037	NA
Res.-duty gas-fired storage - SL1	0.001	0.009	0.004	0.018	0.037	NA
Res.-duty gas-fired storage - SL2	-0.009	0.007	NA	NA	NA	NA
Res.-duty gas-fired storage - SL3	-0.007	0.008	NA	NA	NA	NA
Gas-fired instantaneous: tankless	0.000	0.003	0.009	0.075	0.087	0.099
Gas-fired instantaneous: HWSB	0.000	0.110	0.237	0.667	0.804	0.947
Commercial electric storage†	0.000	0.039	NA	NA	NA	NA

* Numbers in parenthesis are negative numbers. NA = not analyzed.
** DOE analyzed commercial gas-fired storage water heaters and commercial gas-fired storage-type instantaneous water heaters as one group of equipment rather than analyzing them separately.
† Commercial electric storage savings shown are for the standby loss efficiency improvement.

Table 10B.3.4 CWH Equipment: Net Present Value in Billions (2014$) at a 7-Percent Discount Rate by EL for 9-Year Analysis Period for Equipment Purchased in 2019–2027

Equipment Class	Thermal Efficiency Levels*					
	0	1	2	3	4	5
Com. gas-fired storage - SL0**	0.000	0.055	0.197	0.246	0.408	0.606
Com. gas-fired storage - SL1**	0.041	0.101	0.197	0.281	0.425	0.645
Com. gas-fired storage - SL2**	0.049	0.105	0.197	0.285	0.426	0.643
Res.-duty gas-fired storage - SL0	0.000	0.001	(0.014)	(0.010)	0.001	NA
Res.-duty gas-fired storage - SL1	(0.002)	0.001	(0.014)	(0.010)	0.001	NA
Res.-duty gas-fired storage - SL2	(0.009)	(0.001)	NA	NA	NA	NA
Res.-duty gas-fired storage - SL3	(0.009)	(0.001)	NA	NA	NA	NA
Gas-fired instantaneous: tankless	0.000	0.002	0.005	0.043	0.050	0.056
Gas-fired instantaneous: HWSB	0.000	0.053	0.106	0.258	0.318	0.379
Commercial electric storage†	0.000	0.016	NA	NA	NA	NA

* Numbers in parenthesis are negative numbers. NA = not analyzed.
** DOE analyzed commercial gas-fired storage water heaters and commercial gas-fired storage-type instantaneous water heaters as one group of equipment rather than analyzing them separately.
† Commercial electric storage savings shown are for the standby loss efficiency improvement.

Table 10B.3.5 CWH Equipment: Primary National Energy Savings by TSL (quads) for 9-Year Analysis Period for Equipment Purchased in 2019–2027

Equipment Class	Trial Standard Levels			
	1	2	3	4
Com. gas-fired storage water heaters*	0.043	0.135	0.192	0.248
Res.-duty gas-fired storage water heaters	0.006	0.019	0.019	0.027
Gas-fired instantaneous water heaters and hot water supply boilers	0.048	0.175	0.205	0.236
Tankless water heaters	0.002	0.011	0.013	0.016
Hot water supply boilers	0.045	0.164	0.191	0.220
Com. electric storage water heaters	0.011	0.011	0.011	0.011
Total	**0.108**	**0.341**	**0.427**	**0.522**

* DOE analyzed commercial gas-fired storage water heaters and commercial gas-fired storage-type instantaneous water heaters as one group of equipment rather than analyzing them separately.

Table 10B.3.6 CWH Equipment: Full-Fuel-Cycle National Energy Savings by TSL (quads) for 9-Year Analysis Period for Equipment Purchased in 2019–2027

Equipment Class	Trial Standard Levels			
	1	2	3	4
Com. gas-fired storage water heaters*	0.048	0.153	0.216	0.279
Res.-duty gas-fired storage water heaters	0.007	0.021	0.021	0.031
Gas-fired instantaneous water heaters and hot water supply boilers	0.053	0.197	0.230	0.264
Tankless water heaters	0.002	0.013	0.015	0.017
Hot water supply boilers	0.051	0.184	0.215	0.247
Com. electric storage water heaters	0.012	0.012	0.012	0.012
Total	**0.121**	**0.382**	**0.479**	**0.586**

* DOE analyzed commercial gas-fired storage water heaters and commercial gas-fired storage-type instantaneous water heaters as one group of equipment rather than analyzing them separately.

Table 10B.3.7 CWH Equipment: Net Present Value in Billions (2014$) at a 3-Percent Discount Rate by TSL for 9-Year Analysis Period for Equipment Purchased in 2019–2027

Equipment Class	Trial Standard Levels*			
	1	2	3	4
Com. gas-fired storage water heaters*	0.19	0.41	0.78	1.13
Res.-duty gas-fired storage water heaters	0.01	0.00	0.00	0.04
Gas-fired instantaneous water heaters and hot water supply boilers	0.25	0.74	0.89	1.05
Tankless water heaters	0.01	0.07	0.09	0.10
Hot water supply boilers	0.24	0.67	0.80	0.95
Com. electric storage water heaters	0.04	0.04	0.04	0.04
Total	**0.48**	**1.19**	**1.71**	**2.25**

* A value in parentheses is a negative number.
** DOE analyzed commercial gas-fired storage water heaters and commercial gas-fired storage-type instantaneous water heaters as one group of equipment rather than analyzing them separately.

Table 10B.3.8 CWH Equipment: Net Present Value in Billions (2014$) at a 7-Percent Discount Rate by TSL for 9-Year Analysis Period for Equipment Purchased in 2019–2027

Equipment Class	Trial Standard Levels*			
	1	2	3	4
Com. gas-fired storage water heaters*	0.10	0.20	0.43	0.64
Res.-duty gas-fired storage water heaters	-0.001	-0.01	-0.01	0.00
Gas-fired instantaneous water heaters and hot water supply boilers	0.11	0.30	0.37	0.43
Tankless water heaters	0.00	0.04	0.05	0.06
Hot water supply boilers	0.11	0.26	0.32	0.38
Com. electric storage water heaters	0.02	0.02	0.02	0.02
Total	**0.23**	**0.50**	**0.80**	**1.10**

* A value in parentheses is a negative number.
** DOE analyzed commercial gas-fired storage water heaters and commercial gas-fired storage-type instantaneous water heaters as one group of equipment rather than analyzing them separately.

REFERENCES

1. U.S. Energy Information Administration. *Annual Energy Outlook 2015 with Projections to 2040*. 2015. DOE/EIA-0383(2015). www.eia.gov/forecasts/aeo/.

APPENDIX 10C. TRIAL STANDARD LEVELS AND STANDARDS EQUATIONS

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APPENDIX 10C. TRIAL STANDARD LEVELS AND STANDARDS EQUATIONS

10C.1 INTRODUCTION

The U.S. Department of Energy (DOE) carried out the life-cycle cost (LCC) analysis and national impact analysis (NIA) by defining a baseline efficiency level and up to five higher thermal efficiency levels within each equipment class of commercial water heating (CWH) equipment, including separately conducting LCC and NIA analyses for commercial gas-fired tankless water heaters and hot water supply boilers (HWSB) as described in chapters 5–10 of this notice of proposed rulemaking (NOPR) technical support document (TSD). For commercial electric storage water heaters, DOE did not identify thermal efficiency improvements but did identify and study one more-stringent level of standby loss. In addition, for gas-fired storage water heaters and residential-duty gas-fired storage water heaters, DOE analyzed a baseline and up to three more-stringent standby loss levels at each thermal efficiency level. Because of the dependency of standby loss on thermal efficiency, the standby loss, in physical units of energy consumption, varied at each standby loss level as a function of thermal efficiency.

Subsequently, DOE identified trial standard levels (TSLs) as possible standard proposals that reflect combined efficiency levels across all classes of analyzed CWH equipment. DOE developed TSLs so that each TSL is composed of efficiency levels from each equipment class that exhibit similar characteristics. For example, one of the TSLs consists of the maximum technologically available (max-tech) efficiency levels for each equipment class considered for this rulemaking. DOE attempted to limit the number of TSLs considered for the NOPR analysis by eliminating efficiency levels that do not exhibit significantly different economic and/or engineering characteristics from the efficiency levels already selected as a TSL. In addition, DOE developed TSLs that include efficiency levels for both thermal efficiency and standby loss because standby loss is dependent upon thermal efficiency. This dependence of standby loss on thermal efficiency is discussed in detail in chapter 5 of this TSD.

This appendix describes DOE's method for selecting TSLs for CWH equipment. The following sections describe the criteria used for TSL selection and standard level equations associated with each TSL.

10C.2 TRIAL STANDARD LEVEL SELECTION CRITERIA

DOE selected four TSLs for this rulemaking based on the following criteria:

- TSL 4 was set at the max-tech level for each equipment class. The efficiency levels in TSL 4 also provide the highest net present value (NPV) of aggregated national consumer impacts.

- TSL 3 consists of intermediate condensing efficiency levels for each gas-fired equipment class with the exception of the residential-duty gas-fired storage water heaters class, which has a minimum condensing efficiency level. For TSL 3, DOE selected thermal efficiency levels closest to the current ENERGY STAR® level for commercial gas-fired storage water heaters, and gas-fired instantaneous tankless water heaters and hot water supply boilers. DOE also selected the standby loss levels that maximize energy savings and have positive NPV impacts at a 7-percent discount rate.

- TSL 2 consists of minimum condensing thermal efficiency levels for each gas-fired equipment class. For this TSL, all selected standby loss levels maximize both energy savings and NPV using a 7-percent discount rate.

- TSL 1 consists of maximum non-condensing thermal efficiency levels for each gas-fired equipment class. For this TSL, all selected standby loss levels maximize energy savings and have a positive NPV using a 7-percent discount rate.

Table 10C.2.1 presents the efficiency levels within each equipment class that belong to the TSL groupings. Table 10C.2.2 presents the thermal efficiency and standby loss reduction factor for each equipment class in each TSL that DOE considered.

Table 10C.2.1 TSL and Efficiency Levels Mapping

Equipment Class		Trial Standard Level*,**							
		1		2		3		4	
		E_t	SL	E_t	SL	E_t	SL	E_t	SL
Commercial gas-fired storage water heaters and storage-type instantaneous water heaters		1	2	2	2	4	2	5	2
Residential-duty gas-fired storage water heaters		1	3	2	1	2	1	4	1
Gas-fired instantaneous water heaters and hot water supply boilers	Tankless water heaters	2	-	3	-	4	-	5	-
	Hot water supply boilers	2	-	3	-	4	-	5	-
Electric storage water heaters		-	1	-	1	-	1	-	1

* E_t stands for thermal efficiency and SL stands for standby loss.
** DOE did not analyze amended energy conservations standards for standby loss of instantaneous water heaters and hot water supply boilers or for thermal efficiency of electric storage water heaters.

Table 10C.2.2 Trial Standard Levels for CWH Equipment by Thermal Efficiency and Standby Loss Reduction Factor

Equipment Class		Trial Standard Level*,**							
		1		2		3		4	
		E_t	SL Factor	E_t	SL Factor	E_t	SL Factor	E_t	SL Factor
Commercial gas-fired storage water heaters and storage-type instantaneous water heaters		82%	0.72	90%	0.67	95%	0.63	99%	0.61
Residential-duty gas-fired storage water heaters		82%	0.66	90%	0.48	90%	0.48	97%	0.48
Gas-fired instantaneous water heaters and hot water supply boilers	Tankless water heaters	84%	-	92%	-	94%	-	96%	-
Gas-fired instantaneous water heaters and hot water supply boilers	Hot water supply boilers	84%	-	92%	-	94%	-	96%	-
Electric storage water heaters		-	0.84	-	0.84	-	0.84	-	0.84

* E_t stands for thermal efficiency and SL stands for standby loss
** DOE did not analyze amended energy conservations standards for standby loss of instantaneous water heaters and hot water supply boilers or for thermal efficiency of electric storage water heaters.

10C.3 TRIAL STANDARD LEVEL EQUATIONS

For all but the residential-duty gas-fired equipment, the metrics used in the NOPR analyses translate directly through to standards. Trial standards for all equipment except residential-duty equipment are shown on Table 10C.3.1.

For the NOPR, DOE analyzed residential-duty gas-fired water heaters in terms of the thermal efficiency and standby loss metrics. However, in a July 11, 2014 final rule, DOE established that residential-duty water heaters would be covered by the new uniform energy factor (UEF) metric.[1] 79 FR 40542, 40586. Further, DOE proposed a method for converting the thermal efficiency and standby loss ratings to UEF in the April 14, 2015 NOPR.[2] 80 FR 20116. In this NOPR, DOE converted its proposed standards for residential-duty gas-fired water heaters from thermal efficiency and standby loss to UEF using the conversion factors as proposed in the April 14, 2015 NOPR. Table 10C.3.2 shows the UEF for residential-duty commercial gas-fired storage water heaters by TSL, for the high draw pattern as outlined in the April 14, 2015 NOPR.

Table 10C.3.1 Trial Standard Levels for Equipment Classes Except Residential-Duty Gas-Fired Storage

Equipment / Specifications		TSL	Energy Conservation Standards*	
			Minimum Thermal Efficiency	Maximum Standby Loss
Electric storage water heaters				
	All	TSL 1	N/A	$0.84 \times [0.30 + 27/V_r]$ (*%/h*)
	All	TSL 2	N/A	$0.84 \times [0.30 + 27/V_r]$ (*%/h*)
	All	TSL 3	N/A	$0.84 \times [0.30 + 27/V_r]$ (*%/h*)
	All	TSL 4	N/A	$0.84 \times [0.30 + 27/V_r]$ (*%/h*)
Gas-fired storage water heaters				
	>105 kBtu/h or >120 gal**	TSL 1	82%	$0.72 \times [Q/800 + 110(V_r)^{1/2}]$ (*Btu/h*)
	>105 kBtu/h or >120 gal**	TSL 2	90%	$0.67 \times [Q/800 + 110(V_r)^{1/2}]$ (*Btu/h*)
	>105 kBtu/h or >120 gal**	TSL 3	95%	$0.63 \times [Q/800 + 110(V_r)^{1/2}]$ (*Btu/h*)
	>105 kBtu/h or >120 gal**	TSL 4	99%	$0.61 \times [Q/800 + 110(V_r)^{1/2}]$ (*Btu/h*)
Gas-fired instantaneous water heaters and hot water supply boilers				
Instantaneous water heaters (other than storage-type) and hot water supply boilers	<10 gal	TSL 1	84%	N/A
	<10 gal	TSL 2	92%	N/A
	<10 gal	TSL 3	94%	N/A
	<10 gal	TSL 4	96%	N/A
Instantaneous water heaters (other than storage-type) and hot water supply boilers	≥10 gal	TSL 1	84%	$Q/800 + 110(V_r)^{1/2}$ (*Btu/h*)
	≥10 gal	TSL 2	92%	$Q/800 + 110(V_r)^{1/2}$ (*Btu/h*)
	≥10 gal	TSL 3	94%	$Q/800 + 110(V_r)^{1/2}$ (*Btu/h*)
	≥10 gal	TSL 4	96%	$Q/800 + 110(V_r)^{1/2}$ (*Btu/h*)
Storage-type instantaneous water heaters†	≥10 gal	TSL 1	82%	$0.72 \times [Q/800 + 110(V_r)^{1/2}]$ (*Btu/h*)
	≥10 gal	TSL 2	90%	$0.67 \times [Q/800 + 110(V_r)^{1/2}]$ (*Btu/h*)
	≥10 gal	TSL 3	95%	$0.63 \times [Q/800 + 110(V_r)^{1/2}]$ (*Btu/h*)
	≥10 gal	TSL 4	99%	$0.61 \times [Q/800 + 110(V_r)^{1/2}]$ (*Btu/h*)

* V_r is the rated volume in gallons. Q is the nameplate input rate in Btu/h.
** To be classified as a residential-duty water heater, a commercial water heater must, if requiring electricity, use single-phase external power supply and not be designed to heat water at temperatures greater than 180 °F. 79 FR 40542, 40586 (July 11, 2014).
† DOE proposes a new equipment class for storage-type instantaneous water heaters. This class of equipment is similar to storage water heaters in design, cost, and application. However, it has a ratio of input capacity to storage volume greater than or equal to 4,000 Btu/h per gallon of water stored; therefore, it is properly classified as an instantaneous water heater by EPCA's definition at 42 U.S.C. 6311(12)(B). Because of its similarities with storage water heaters, DOE grouped these two equipment classes together in its analyses for this NOPR. Storage-type instantaneous water heaters are further discussed in the NOPR.

Table 10C.3.2 Trial Standard Levels by UEF for Residential-Duty Gas-Fired Storage Water Heaters

Equipment	TSL 1	TSL 2	TSL 3	TSL 4
Gas-Fired Storage*	$0.6646 - (0.0006 \times V_r)$	$0.7311 - (0.0006 \times V_r)$	$0.7311 - (0.0006 \times V_r)$	$0.7718 - (0.0006 \times V_r)$

* This table shows the UEF standard equations corresponding to each TSL for the high draw pattern. The thermal efficiency and standby loss levels corresponding to the proposed TSL were converted to UEF equations for all four draw patterns (high, medium, low, very small). V_r is the rated volume in gallons.

REFERENCES

1. U.S. Department of Energy–Office of Energy Efficiency and Renewable Energy. Energy Conservation Program for Consumer Products and Certain Commercial and Industrial Equipment: Test Procedures for Residential and Commercial Water Heaters. *Federal Register*. July 11, 2014. Vol. 79, no. 133: pp. 40542–40588.

2. U.S. Department of Energy–Office of Energy Efficiency and Renewable Energy. Energy Conservation Program for Consumer Products and Certain Commercial and Industrial Equipment: Test Procedures for Consumer and Commercial Water Heaters. *Federal Register*. April 14, 2015. Vol. 80, no. 71: pp. 20116–20147.

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APPENDIX 10D. FULL FUEL CYCLE

10D.1 INTRODUCTION

This appendix summarizes the methods the U.S. Department of Energy (DOE) used to calculate the full-fuel-cycle (FFC) energy savings estimated from potential standards for commercial water heating equipment. The FFC measure includes point-of-use (site) energy; the energy losses associated with generation, transmission, and distribution of electricity; and the energy consumed in extracting, processing, and transporting or distributing primary fuels. DOE's method of analysis previously encompassed only site energy and the energy lost through generation, transmission, and distribution of electricity. In 2011, DOE announced its intention, based on recommendations from the National Academy of Sciences, to use FFC measures of energy use and emissions when analyzing proposed energy conservation standards.[1] This appendix summarizes the methods DOE used to incorporate impacts of the full fuel cycle into the analysis.

This analysis uses several terms to describe aspects of energy use. The physical sources of energy are primary fuels such as coal, natural gas, or liquid fuel. Primary energy is equal to the heat content (British thermal units (Btu)) of the primary fuel used to produce an end-use service. Site energy use is defined as the energy consumed at the point of use in a house or establishment. When natural gas or petroleum fuels are consumed at the site (*e.g.*, in an on-site furnace), site energy is identical to primary energy, with both equal to the heat content of the primary fuel consumed.

For electricity generated by an off-site power plant, site energy is measured in kilowatt-hours (kWh). In such a case, the primary energy is equal to the quads (quadrillion Btu) of primary energy required to generate and deliver electricity to the site. For the FFC analysis, upstream energy use is defined as the energy consumed in extracting, processing, and transporting or distributing primary fuels. FFC energy use is the sum of primary plus upstream energy use.

Both primary fuels and electricity are used in upstream activities. The treatment of electricity in full-fuel-cycle analysis must distinguish between electricity generated by fossil fuels and uranium and electricity generated from renewable sources (wind, solar, and hydro). For the former, the upstream fuel cycle relates to the amount of fuel consumed at the power plant. There is no upstream component for the latter, because no fuel per se is used.

10D.2 METHODOLOGY

The methods used to calculate FFC energy use are summarized here. The mathematical approach to determining FFC is discussed in Coughlin 2012.[2] Details on analyzing the fuel production chain are presented in Coughlin 2013.[3]

When all energy quantities are normalized to the same units, FFC energy use can be represented as the product of the primary energy use and an FFC multiplier. Mathematically, the FFC multiplier is a function of a set of parameters that represent the energy intensity and material losses at each stage of energy production. Those parameters depend only on physical data, so the calculations require no assumptions about prices or other economic factors. Although the parameter values often differ by geographic region, this analysis utilizes national averages.

The fuel cycle parameters are defined as follows.

- a_x is the quantity of fuel *x* burned per unit of electricity produced, on average, for grid electricity. The calculation of a_x includes a factor to account for losses incurred through the transmission and distribution systems.
- b_y is the amount of grid electricity used in producing fuel *y*, in MWh per physical unit of fuel *y*.
- c_{xy} is the amount of fuel *x* consumed in producing one unit of fuel *y*.
- q_x is the heat content of fuel *x* (Million Btu/physical unit).
- $z_x(s)$ is the emissions intensity for fuel *x* (mass of pollutant s per physical unit of *x* produced).

All the parameters are calculated as functions of an annual time step; hence, when evaluating the effects of potential new standards, a time series of annual values is used to estimate the FFC energy and emissions savings in each year of the analysis period and cumulatively.

The FFC multiplier is denoted μ (mu). A separate multiplier is calculated for each fuel used on site. Also calculated is a multiplier for electricity that reflects the fuel mix used in its generation. The multipliers are dimensionless numbers applied to primary energy savings to obtain the FFC energy savings. The upstream component of the energy savings is proportional to (μ-1). The fuel type is denoted by a subscript on the multiplier μ.

When DOE estimates energy savings attributable to appliance standards, the method for performing the full-fuel-cycle analysis utilizes data and projections published in the *Annual Energy Outlook* (*AEO*); in the case of this rulemaking, the *AEO2015*.[4] Table 10D.2.1 summarizes the *AEO2015* 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 10D.2.1 Dependence of FFC Parameters on *AEO* Inputs

Parameter(s)	Fuel(s)	*AEO* Table	Variables
q_x	All	Conversion factors	MMBtu per physical unit
a_x	All	Electricity supply, disposition, prices, and emissions 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

Parameter(s)	Fuel(s)	*AEO* Table	Variables
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 *AEO2015* does not provide all the information needed to estimate total energy use in the fuel production chain. Coughlin 2013[3] describes the additional data sources needed to complete the analysis. The time dependence in the FFC multipliers for commercial water heating equipment, however, arises exclusively from variables taken from the *AEO*.

10D.3 ENERGY MULTIPLIERS FOR THE FULL FUEL CYCLE

FFC energy multipliers for selected years are presented in Table 10D.3.1. The 2040 value was held constant for the analysis period beyond 2040, which is the last year in the *AEO2015* projection. The multiplier for electricity reflects the shares of various primary fuels in total electricity generation throughout the forecast period.

Table 10D.3.1 Energy Multipliers for the Full Fuel Cycle (Based on AEO2014)

	2020	2025	2030	2035	2040	2045	2050
Electricity	1.044	1.045	1.046	1.045	1.045	1.045	1.045
Natural Gas	1.123	1.124	1.123	1.122	1.123	1.123	1.123

REFERENCES

1. U.S. Department of Energy–Office of Energy Efficiency and Renewable Energy. Energy Conservation Program for Consumer Products and Certain Commercial and Industrial Equipment. Statement of Policy for Adopting Full Fuel Cycle Analyses into Energy Conservation Standards Program. *Federal Register.* August 18, 2011. Vol. 76, no. 160*:* pp. 51281–51289.

2. Coughlin, K. A Mathematical Analysis of Full Fuel Cycle Energy Use*. Energy.* 2012. 37(1): pp. 698–708. Last accessed August 31, 2015. www.sciencedirect.com/science/article/pii/S0360544211006803.

3. Coughlin, K. *Projections of Full-Fuel-Cycle Energy and Emissions Metrics*. 2013. Lawrence Berkeley National Laboratory. Report No. LBNL-6025E.

4. U.S. Department of Energy–Energy Information Administration. *Annual Energy Outlook 2015 with Projections to 2040*. 2015. Washington, DC. DOE/EIA-0383(2015). Available at www.eia.gov/forecasts/aeo/.

CHAPTER 11. COMMERCIAL CONSUMER SUBGROUP ANALYSIS

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11.1 METHODOLOGY

The commercial consumer subgroup analysis evaluates impacts on any identifiable groups or commercial consumers who may be disproportionately affected by a national energy conservation standard. DOE will conduct this analysis as one of the analyses for the notice of proposed rulemaking. DOE will accomplish this, in part, by analyzing the life-cycle costs (LCCs) and payback periods (PBPs) for those commercial consumers that fall into any identifiable groups. DOE plans to evaluate variations in regional energy prices, variations in energy use, and variations in installation costs that might affect the net present value of a standard to commercial consumer subpopulations. To the extent possible, DOE will obtain estimates of each input parameter's variability and will consider this variability in its calculation of commercial consumer impacts.

DOE will determine the impact on commercial consumer subgroups using the LCC Spreadsheet Model, which allows for different data inputs. The standard LCC analysis (described in chapter 8 of this technical support document) focuses on the commercial consumers that use commercial water heating equipment. 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 PBP.)

11.2 SUBGROUP ANALYSIS FOR RESIDENTIAL APPLICATIONS

In general, consumers in the lower income groups tend to discount future stream of benefits at a higher rate when compared to consumers in higher income brackets. Residential Energy Consumption Survey (RECS) divides the samples into 24 bins of gross annual household income. Additionally, the survey of consumer finances divides the residential population into six different income bins (with income bin 1 representing 0–20% income percentile). Hence, to analyze the influence of a national standard on low-income group population, DOE conducted a (residential) subgroup analysis where only the 0–20% income percentile samples were included for the entire simulation run. After integrating gross annual household income with income bins from the Federal Reserve Board's Survey of Consumer Finances (SCF) (Table 11.3.1), DOE conducted a subgroup analysis for the low-income population. Subsequently, the results of the subgroup analysis are compared to the results from all customers.

11.3 SUBGROUP FOR COMMERCIAL APPLICATIONS

DOE identified small businesses within Commercial Buildings Energy Consumption Survey (CBECS) database by using threshold levels for maximum number of employees within each building type (such as Assembly, Education, Food Service, Office, Retail, and Warehouse). Subsequently, in addition to the discount rate chosen for each "small business" sample, a premium of 1.9 percent was added to evaluate future benefit and cost streams.[1] In general, smaller businesses tend to discount future stream of monetary flows at higher rates. DOE conducted a subgroup analysis for small businesses, and subsequently the results of the subgroup analysis were compared to the results from all customers.

Table 11.3.1 Integration of MONEYPY Indicator in RECS, with Income Bins in Survey of Consumer Finances

RECS Income (MONEYPY)	SCF Income Bin
1	1
2	1
3	1
4	1
5	1
6	1
7	2
8	2
9	2
10	3
11	3
12	3
13	3
14	4
15	4
16	4
17	4
18	4
19	4
20	4
21	5
22	5
23	5
24	6

11.4 RESULTS FOR SUBGROUPS ANALYSIS

Table 11.4.1 through Table 11.4.6 summarize the results of the subgroups analysis. For the CWH equipment, the low-income residential subgroup in general had a slightly higher LCC savings when compared to the general commercial consumer population, due in part to greater hot water use than the average commercial consumer for all equipment classes with the exception of residential-duty. For both residential-duty gas-fired commercial storage water heaters and for tankless water heating equipment, the low-income residential subgroup analyzed had somewhat lower hot water usage than the average commercial consumer of this equipment, which contributed to lower LCC savings for some TSLs. The LCC savings for the small business subgroups were consistently lower than those of the average commercial consumer.

Table 11.4.1 Comparison of Impacts for Commercial Consumer Subgroups with All Commercial Consumers, Commercial Gas-Fired Storage Water Heaters

TSL	Thermal Efficiency (E_t)	Standby Loss (SL) Factor	LCC Savings *2014$**			Simple Payback Period *years*		
			Residential Low-Income	Commercial Small Business	All	Residential Low-Income	Commercial Small Business	All
1	82%	0.72	345	179	219	3.2	3.8	3.8
2	90%	0.67	731	243	317	4.7	5.5	5.7
3	95%	0.63	1,399	679	794	3.5	4.2	4.3
4	99%	0.61	2,046	1,093	1,252	3.1	3.7	3.8

* Parentheses indicate negative values.

Table 11.4.2 Comparison of Impacts for Commercial Consumer Subgroups with All Commercial Consumers, Residential-Duty Gas-Fired Storage Water Heaters

TSL	UEF	LCC Savings *2014$**			Simple Payback Period *years*		
		Residential Low-Income	Commercial Small Business	All	Residential Low-Income	Commercial Small Business	All
1	0.62	587	467	537	9.8	10.5	10.5
2, 3	0.69	(17)	48	14	12.4	10.1	11.9
4	0.73	251	250	241	10.4	8.7	10.2

* Parentheses indicate negative values.

Table 11.4.3 Comparison of Impacts for Commercial Consumer Subgroups with All Commercial Consumers, Gas-Fired Tankless Water Heaters

TSL	Thermal Efficiency (E_t)	LCC Savings *2014$**			Simple Payback Period *years*		
		Residential Low-Income	Commercial Small Business	All	Residential Low-Income	Commercial Small Business	All
1	84%	94	62	86	2.9	3.1	2.9
2	92%	748	1,036	1,009	Immediate	Immediate	Immediate
3	94%	869	1,121	1,119	Immediate	Immediate	Immediate
4	96%	985	1,199	1,224	Immediate	Immediate	Immediate

* Parentheses indicate negative values.
Note: Immediate payback can result from a decrease in installation cost that is greater than the incremental increase in equipment cost.

Table 11.4.4 Comparison of Impacts for Commercial Consumer Subgroups with All Commercial Consumers, Gas-Fired Hot Water Supply Boilers

TSL	Thermal Efficiency (E_t)	LCC Savings *2014$**			Simple Payback Period *years*		
		Residential Low-Income	Commercial Small Business	All	Residential Low-Income	Commercial Small Business	All
1	84%	2,937	401	1,245	2.1	6.4	3.6
2	92%	9,568	761	3,794	4.1	12.2	6.7
3	94%	11,302	979	4,528	4.0	11.7	6.4
4	96%	13,101	1,192	5,285	3.8	11.4	6.3

* Parentheses indicate negative values.

Table 11.4.5 Comparison of Impacts for Commercial Consumer Subgroups with All Commercial Consumers, Gas-Fired Instantaneous Water Heaters and Hot Water Supply Boilers*

TSL	Thermal Efficiency (E_t)	LCC Savings *2014$**			Simple Payback Period *years*		
		Residential Low-Income	Commercial Small Business	All	Residential Low-Income	Commercial Small Business	All
1	84%	2,070	298	891	2.1	6.1	3.6
2	92%	6,878	845	2,944	3.9	9.7	5.8
3	94%	8,120	1,022	3,488	3.8	9.5	5.6
4	96%	9,406	1,195	4,046	3.7	9.3	5.6

* This table shows results for the gas-fired instantaneous water heaters and hot water supply boilers equipment class (i.e., both tankless water heaters and hot water supply boilers), and reflects a weighted average result of Tables V.18 and V.19.
** Parentheses indicate negative values.

Table 11.4.6 Comparison of Impacts for Commercial Consumer Subgroups with All Commercial Consumers, Electric Storage Water Heaters

TSL	Standby Loss (SL) Factor	LCC Savings *2014$**			Simple Payback Period *years*		
		Residential Low-Income	Commercial Small Business	All	Residential Low-Income	Commercial Small Business	All
1,2,3,4	0.84	87	26	47	5.5	6.9	6.5

* Parentheses indicate negative values.

REFERENCES

1. U.S. Small Business Administration. *The Small Business Economy*: Introduction and Data Summary 2012. www.sba.gov/advocacy/small-business-economy.

CHAPTER 12. MANUFACTURER IMPACT ANALYSIS

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APPENDIX 12. MANUFACTURER IMPACT ANALYSIS

12.1 INTRODUCTION

In determining whether a standard is economically justified, the U.S. Department of Energy (DOE) is required to consider the economic impact of the standard on the manufacturers and consumers of equipment subject to such a standard. (42 U.S.C. 6313(a)(6)(B)(i)) The law also calls for an assessment of the impact of any lessening of competition as determined in writing by the Attorney General. *Id*. DOE conducted a manufacturer impact analysis (MIA) to estimate the financial impact of amended energy conservation standards on manufacturers of commercial water heating (CWH) equipment, and assessed the impact of such standards on direct employment and manufacturing capacity.

The MIA has both quantitative and qualitative aspects. The quantitative part of the MIA primarily relies on the Government Regulatory Impact Model (GRIM), an industry cash-flow model adapted for the equipment in this rulemaking. The GRIM inputs include information on industry cost structure, shipments, and pricing strategies. The GRIM's key output is the industry net present value (INPV). The model estimates the financial impact of more stringent energy conservation standards for each equipment class by comparing changes in INPV between a no-new-standards case and the various trial standard levels (TSLs) in the standards case. The qualitative part of the MIA addresses product characteristics, manufacturer characteristics, and market and product trends, as well as the impact of standards on subgroups of manufacturers.

12.2 METHODOLOGY

DOE conducted the MIA in three phases. Phase I, "Industry Profile," consisted of preparing an industry characterization for the CWH equipment industry. This characterization included data on sales volumes, pricing, employment, and financial structure. In phase II, "Industry Cash Flow Analysis and Interview Guide," DOE used the GRIM to assess the potential impacts of amended energy conservation standards on manufacturers. DOE also reached out to a wide range of CWH equipment manufacturers to invite them to participate in an MIA interview. DOE developed an interview guide that was distributed to participating manufacturers prior to the interviews. DOE used this guide to help steer conversations with manufacturers about potential impacts of amended standards. In phase III, "Subgroup Impact Analysis," DOE interviewed manufacturers that account for approximately 88 percent of CWH equipment sales. DOE used the information gathered in these interviews to refine the GRIM analysis and to develop additional analyses for subgroups that may be affected in various ways. DOE also incorporated qualitative data from interviews into its analysis. Each phase of the MIA is described in greater detail in the following sections.

12.2.1 Phase I: Industry Profile

In phase I of the MIA, DOE prepared a profile of the CWH equipment industry that built on the market and technology assessment (MTA) prepared for this rulemaking. The MTA is explained in detail in chapter 3 of this notice of proposed rulemaking (NOPR) technical support document (TSD). Before initiating detailed impact analyses, DOE collected information on past and present market characteristics of the CWH equipment industry. This information included shipment data, manufacturer markups, manufacturer market shares, and consolidation trends. As part its industry profile research, DOE also collected information on industry financial parameters, such as net plant, property, and equipment (PPE); selling, general and administrative (SG&A) expenses; research and development (R&D) expenses, depreciation, revenue, cost of goods sold, etc. These parameters allowed DOE to derive preliminary industry financial inputs for the GRIM as discussed in section 12.4.4.

DOE used public information to develop its initial characterization of the industry, including Securities and Exchange Commission (SEC) 10-K reports,[1] Standard & Poor's (S&P) stock reports,[2] market research tools (*i.e.*, Hoover's[3]), corporate annual reports, and the U.S. Census Bureau's 2013 Annual Survey of Manufacturers.[4] DOE also used information from its engineering analysis and the life-cycle cost analysis to enhance its industry profile.

12.2.2 Phase II: Industry Cash-Flow Analysis and Interview Guide

Phase II focused on the financial impacts of amended energy conservation standards on manufacturers of CWH equipment. More stringent energy conservation standards can affect manufacturer cash flows in three distinct ways. These include: (1) creating a need for increased investment; (2) raising production costs per unit; and (3) altering revenue due to higher per-unit prices and/or possible changes in sales volumes. To quantify these impacts, DOE used the GRIM to perform a cash-flow analysis for the CWH equipment industry. DOE used the financial values derived during phase I and the shipment scenarios used in the national impact analysis (NIA) to perform these analyses. The GRIM modeled impacts from the energy conservation standards for both thermal efficiency and standby loss. The GRIM results for the standards for both metrics were analyzed together because the examined trial standard levels (TSLs) include both thermal efficiency and standby loss levels. In phase II, DOE also prepared written guides for manufacturer interviews.

12.2.2.1 Industry Cash-Flow Analysis

The GRIM is designed to take into account several factors while calculating a series of annual cash flows from the announcement year of amended energy conservation standards until 30 years after the compliance date. These factors include annual expected revenues, costs of goods sold, SG&A, taxes, and capital expenditures related to the amended standards. DOE developed these financial parameters using publicly available manufacturer data and revised them with information submitted confidentially during manufacturer interviews. DOE also used estimates developed in other analyses as inputs to the GRIM including manufacturer production costs (MPCs), markup assumptions, and shipments forecasts. DOE derived the MPCs from the engineering analysis and information provided by the industry. DOE estimated typical manufacturer markups from publicly available financial reports and interviews with manufacturers. DOE developed alternative markup scenarios for the GRIM based on discussions with manufacturers. DOE's shipments analysis, presented in chapter 9 of the TSD, provided the basis for the shipment projections in the GRIM. Once the GRIM was complete, DOE compared the results at various TSLs to no-new-standards-case projections for the industry. The difference between the discounted annual cash flows in the no-new-standards case and standards case at each TSL represents the financial impact of amended standards on the industry.

12.2.2.2 Interview Guides

During phase II of the MIA, DOE developed an interview guide to help gather information on the effects of amended energy conservation standards on revenues and finances, direct employment, capital assets, and industry competitiveness. DOE distributed the interview guide to the companies that agreed to participate well before the interviews to give companies time to prepare responses. DOE used the interview guide to structure its conversation with manufacturers and to procure information about important manufacturing issues relevant to this rulemaking. DOE also sought to identify potential impacts that could result from amended energy conservation standards on individual manufacturers or subgroups of manufacturers. Information received from these meetings is protected by nondisclosure agreements and is stored securely by DOE's contractors. The MIA interview topics included: (1) key issues; (2) engineering; (3) component parts, material costs, and factory parameter assumptions; (4) manufacturer production costs; (5) company overview and organizational characteristics; (6) markups and profitability; (7) financial parameters; (8) shipment projections and market shares; (9) product mix; (10) distribution channels; (11) conversion costs; (12) cumulative regulatory burden; (13) direct employment impact assessment; (14) capacity, outsourcing, and foreign competition; (15) consolidation; and (16) impacts on small business.

12.2.3 Phase III: Subgroup Analysis

In phase III of its analysis, DOE interviewed a wide range of CWH equipment manufacturers in order to better inform its analyses and to identify any subgroups of manufacturers that may be affected in different ways by amended standards. DOE identified small manufacturers as a subgroup that could be disproportionately affected by amended standards, and as a result, DOE conducted a separate analysis for small businesses in the industry.

12.2.3.1 Manufacturer Interviews

The information gathered in phase I and the cash-flow analysis performed in phase II are supplemented with information gathered from manufacturer interviews in phase III of the MIA. The interview process provides an opportunity for interested parties to express their views on important issues confidentially, allowing sensitive information to be considered in the rulemaking process. DOE sought to understand manufacturers' key issues and concerns with this rulemaking and asked for feedback on its GRIM inputs and assumptions.

DOE used the information gained in these interviews to tailor the GRIM to more accurately reflect financial characteristics unique to the CWH equipment industry. Interviews were scheduled well in advance to provide every opportunity for key individuals to be available for comment. DOE accepted written responses to the interview guide, however, made every effort to schedule interactive interviews, which helped to clarify responses and identify additional issues.

12.2.3.2 Revised Industry Cash-Flow Analysis

In phase II of the MIA, DOE provided manufacturers with preliminary financial figures for the GRIM analysis for their review and evaluation. During the interviews, DOE requested comments on the values it had calculated for the GRIM. DOE revised its industry cash-flow model based on manufacturer feedback. Section 12.4.4 provides more information on how DOE calculated these parameters.

12.2.3.3 Manufacturer Subgroup Analysis

DOE acknowledges that using average cost assumptions to develop industry cash-flow estimates may not adequately assess different impacts of amended energy conservation standards on manufacturer subgroups. For example, small manufacturers, niche players, or manufacturers exhibiting a cost structure that largely differs from the industry average, could be more negatively affected. DOE included a series of questions about the subgroups it had identified in its interview guide. DOE asked manufacturers and other interested parties to suggest what subgroups or characteristics are the most appropriate to analyze. DOE also asked manufacturers to comment on a list of companies that DOE believed comprised each subgroup.

DOE presents the industry impacts on CWH equipment manufacturers as a whole in this NOPR because most of the equipment classes represent the same market served by the same manufacturers. However, DOE identified one manufacturer subgroup in the CWH equipment industry that warranted a separate impact analysis: small manufacturers. More information on DOE's small business impact analysis is detailed below.

Small business manufacturer subgroup. DOE first investigated whether small business manufacturers should be analyzed as a manufacturer subgroup. DOE used the U.S. Small Business Administration (SBA) small business size standards, effective January 22, 2014, as amended, and the North American Industry Classification System (NAICS) code, presented in Table 12.2.1, to determine whether any small entities would be affected by the rulemaking.[5] For the equipment classes under review, the SBA bases its small business definition on a company's total number of employees. This includes its subsidiaries and its parent companies. An aggregated business entity with fewer employees than the listed limit is considered a small business.

Table 12.2.1 SBA and NAICS Classification of Small Businesses Potentially Affected by This Rulemaking

Industry Description	Revenue Limit	Employee Limit	NAICS
Other Commercial and Service Industry Machinery Manufacturing	N/A	1,000	333318

DOE used publicly available and proprietary information to identify potential small manufacturers. DOE's research involved industry trade association membership directories (*e.g.,* American Heating and Refrigeration Institute (AHRI) Directory of Certified Product Performance[6]), public databases *(e.g.,* California Energy Commission (CEC) Appliance Efficiency Database[7]), individual company websites, market research tools (*e.g.*, Hoover's reports), and DOE's Certification Compliance Database. DOE used information from these sources to create a list of companies that manufacture or sell equipment covered by this rulemaking. During manufacturer interviews and at previous DOE public meetings, DOE also asked stakeholders and industry representatives if they were aware of any other small manufacturers. DOE screened out companies that did not offer equipment covered by this rulemaking, did not meet the definition of a small business, or are foreign owned and operated.

Based on this analysis, DOE identified 13 companies in the CWH equipment industry that qualify as domestic small businesses. DOE made an effort to contact all identified small businesses to solicit feedback on the potential impacts of energy conservation standards. Two of the small businesses agreed to be interviewed. DOE solicited data on different impacts these companies might experience as a result of amended energy conservation standards. DOE obtained further information on small business impacts in interviews with large manufacturers. DOE reports the results of its analysis on the potential impacts of this rulemaking on small manufacturers in section 12.6.

12.2.3.4 Manufacturing Capacity Impact

Amended energy conservation standards could result in the obsolescence of existing manufacturing assets, including tooling and capital investments. The manufacturer interview guide includes a series of questions to help identify impacts of amended standards on manufacturing capacity. Specifically, questions address: capacity utilization and plant location decisions in the United States and North America, with and without amended standards; the ability of manufacturers to upgrade or remodel existing facilities to accommodate the new efficiency requirements; the nature and value of any stranded assets that might result from amended standards; and estimates for any one-time changes to existing PPE that be necessitated by amended standards. DOE's estimates of the one-time capital changes and stranded assets affect the cash flow estimates in the GRIM. These estimates can be found in section 12.4.8. DOE's discussion of the manufacturing capacity impact can be found in section 12.7.2.

12.2.3.5 Employment Impact

The impact of amended energy conservation standards on employment is an important consideration in the rulemaking process. During manufacturer interviews, DOE solicited information about current employment trends in the CWH equipment industry, as well as manufacturers' views on how amended standards might change employment patterns. In the employment impacts section of the interview guide, DOE asked manufacturers about current employment levels at their production facilities and expected future employment levels with and without amended energy conservation standards. DOE also inquired about any different workforce skills or employee retraining that might be necessary if standards were amended. The employment impacts are reported in section 12.7.1.

12.2.3.6 Cumulative Regulatory Burden

DOE seeks to mitigate the overlapping effects on manufacturers due to amended energy conservation standards and other regulatory actions affecting the same products. DOE analyzed the impact on manufacturers of multiple, product-specific regulatory actions. Based on its own research and discussions with manufacturers, DOE identified regulations relevant to CWH equipment manufacturers, including other federal regulations that affect other products made by the same manufacturers. Discussion of the cumulative regulatory burden can be found in section 12.7.3.

12.3 MANUFACTURER IMPACT ANALYSIS KEY ISSUES

Each MIA interview starts by asking: "What are the key issues for your company regarding this energy conservation standard rulemaking?" This question prompts manufacturers to identify the issues they want DOE to explore and discuss further during the interview. The following sections describe the most significant issues identified by CWH equipment manufacturers. These summaries report aggregated information to protect manufacturer confidentiality.

12.3.1 Magnitude of Conversion Costs

Manufacturers stated in interviews that an increase in the stringency of energy conservation standards may cause them to face significant capital and product conversion costs to bring their equipment into compliance if DOE were to propose a standard that necessitates condensing technology. While all major CWH manufacturers currently produce condensing equipment, most also offer a wide range of non-condensing equipment that they stated is important in serving the replacement market. Manufacturers stated that eliminating non-condensing equipment would strand production assets and could result in manufacturers having to make capital investments in machinery and tooling to increase their condensing equipment production capacity.

Manufacturers also stated that shifting their entire product line to condensing equipment would require significant product conversion costs for R&D and testing. Most manufacturers currently offer a less diverse product line of condensing equipment compared to their non-condensing equipment offerings. Several stated that in order to serve the replacement market and remain competitive, they would need to develop a range of sizes and capacities of condensing equipment that they currently only offer at non-condensing thermal efficiency levels. Manufacturers stated that this would require a substantial engineering effort.

12.3.2 Complexity and Cost of Retrofits

In interviews, several manufacturers pointed out that approximately 85 percent of CWH equipment sales are conducted in the replacement channel, rather than the new construction channel. They stated that the majority of the CWH market is structured around the legacy venting infrastructure designed for non-condensing equipment. Manufacturers stated that these venting systems are not designed to handle the acidic condensate that develops in condensing equipment. Manufacturers were concerned that commercial consumers would have to make expensive retrofits to install condensing equipment. According to manufacturers, this may result in commercial consumers repairing water heaters, rather than replacing them, which manufacturers argued would not save energy.

12.3.3 Impacts on Innovation

Manufacturers expressed concern that more stringent energy conservation standards may stifle innovation in the industry by causing manufacturers to spend funds set aside for product innovation on compliance efforts instead. Several manufacturers pointed out that it is important for them to continually develop unique and innovative products in order to differentiate their brands in the market. They pointed out that it is difficult to accomplish this when engineering resources are diverted to focus on compliance with amended DOE standards. Manufacturers stated that this concern is particularly important for small manufacturers' ability to compete in the market. Small manufacturers generally have fewer resources to devote to compliance, and so may be at a disadvantage if DOE amends energy conservation standards.

12.4 GRIM INPUTS AND ASSUMPTIONS

The Government Regulatory Impact Model serves as the main tool for assessing the impacts on industry due to amended energy conservation standards. DOE relies on several sources to obtain inputs for the GRIM. DOE then feeds data and assumptions from these sources into an accounting model that calculates the industry cash flow both with and without amended energy conservation standards.

12.4.1 Overview of the Government Regulatory Impact Model

The basic structure of the GRIM, illustrated in Figure 12.4.1, is an annual cash-flow analysis that uses manufacturer prices, manufacturing costs, shipments, and industry financial information as inputs, and accepts a set of regulatory conditions such as changes in costs, investments, and associated margins. The GRIM spreadsheet uses these and other inputs to calculate a series of annual cash flows, beginning with the reference year of the analysis, 2015, and continuing to 2048. The model calculates the INPV by summing the stream of annual discounted cash flows during this period and adding a discounted terminal value.[8]

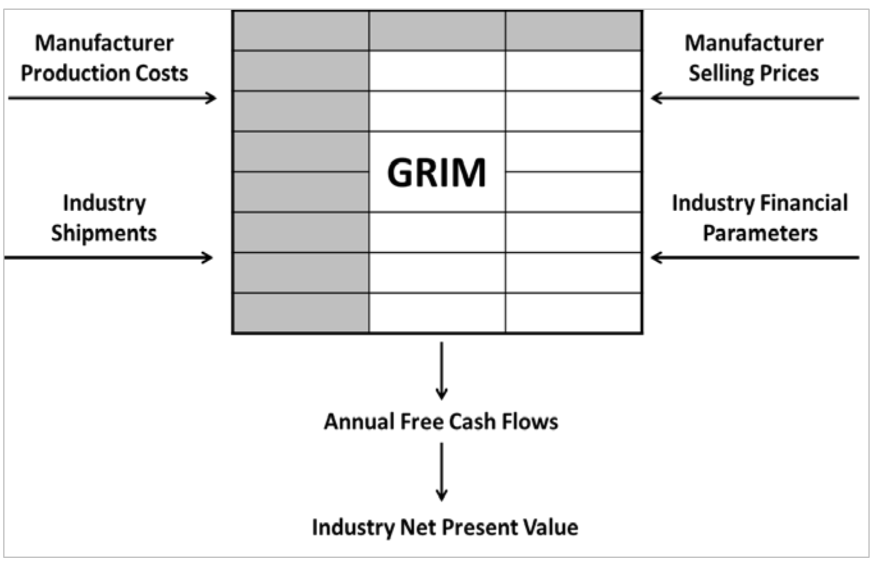

Figure 12.4.1 Using the GRIM to Calculate Cash Flow

The GRIM projects cash flows using standard accounting principles and compares changes in INPV between the no-new-standards-case scenario and the standards-case scenario induced by amended energy conservation standards. The difference in INPV between the no-new-standards case and the standards case(s) represents the estimated financial impact of amended energy conservation standards on manufacturers. Appendix 12A provides more technical details and user information for the GRIM.

12.4.2 Sources for GRIM Inputs

The GRIM uses several different sources for data inputs in determining industry cash flow. These sources include corporate annual reports, company profiles, census data, credit ratings, the shipments model, the engineering analysis, and manufacturer interviews.

12.4.2.1 Corporate Annual Reports

Corporate annual reports to the SEC (SEC 10-Ks) provided many of the initial financial inputs to the GRIM. These reports exist for publicly held companies and are available to the general public. DOE developed initial financial inputs to the GRIM by examining the annual SEC 10-K reports filed by publicly traded CWH equipment manufacturers. DOE generally has to use parent-company-level financial data to develop its initial financial parameter estimates for the GRIM, as these companies do not usually provide detailed financial information about their individual product lines in their 10-K reports. These estimates were later revised using feedback from interviews to make them more representative of CWH equipment manufacturing. DOE used corporate annual reports to derive the following initial inputs to the GRIM:

- tax rate
- working capital
- SG&A
- R&D
- depreciation
- capital expenditures
- net PPE

12.4.2.2 Standard and Poor Credit Ratings

S&P provides independent credit ratings, research, and financial information. DOE relied on S&P reports to determine the industry's average cost of debt when calculating the cost of capital.

12.4.2.3 Shipment Model

DOE used shipment projections derived from DOE's shipments model in the NIA in the GRIM analysis. Chapter 9 of the TSD describes the methodology and analytical model DOE used to forecast shipments.

12.4.2.4 Engineering Analysis

The engineering analysis develops the relationship between manufacturer selling price (MSP) and energy efficiency for the products analyzed in this rulemaking. This relationship serves as the basis for the cost-benefit calculations for commercial consumers, manufacturers, and the nation. In determining the cost-efficiency relationship, DOE estimates the increase in manufacturing costs associated with increasing the efficiency of equipment above the baseline up to the maximum technologically feasible (max-tech) efficiency level for each equipment class.

DOE analyzed thermal efficiency and standby loss levels in the engineering analysis using a combination of the efficiency-level approach and reverse-engineering approach.[a] DOE identified representative equipment for analysis, thermal efficiency levels based on market data, and standby loss levels based on market data and commonly used technology options. DOE then conducted a teardown analysis, based upon physical and catalog teardowns of selected units. Based on estimates for production costs of materials, labor, depreciation, and overhead developed from teardowns, DOE developed MPC estimates for each equipment class and efficiency level. See chapter 5 of the TSD for a more detailed discussion of the engineering analysis.

12.4.2.5 Manufacturer Interviews

During the course of the MIA, DOE interviewed manufacturers representing approximately 88 percent of the industry by revenue. The information gathered during these interviews enabled DOE to tailor the GRIM to reflect the unique financial characteristics of the CWH equipment industry. In interviews, DOE asked manufacturers to describe their major concerns about this rulemaking. Key topics discussed during the interviews and reflected in the GRIM include:

- capital conversion costs;
- product conversion costs;
- financial parameters;
- markups; and
- possible profitability impacts.

12.4.3 Trial Standard Levels

DOE developed a number of efficiency levels for each equipment class. TSLs were then developed by selecting groupings of efficiency levels for all equipment types as part of this rulemaking. Table 12.4.1 presents the TSLs examined as part of this rulemaking.

[a] DOE has identified three basic methods for generating manufacturing costs: (1) the design-option approach, which provides the incremental costs of adding to a baseline model design options that will improve its efficiency (*i.e.*, lower its energy use); (2) the efficiency-level approach, which provides the incremental costs of moving to higher energy efficiency levels, without regard to the particular design option(s) used to achieve such increases; and (3) the reverse-engineering (or cost-assessment) approach, which provides "bottom-up" manufacturing cost assessments for achieving various levels of increased efficiency based on teardown analyses (or physical teardowns) that provides detailed data on costs for parts and material, labor, shipping/packaging, and investment for models that operate at particular efficiency levels.

Table 12.4.1 Summary of TSLs for the CWH Industry

Equipment Class	TSL 1		TSL 2		TSL 3		TSL 4	
	E_t EL	SL EL	E_t EL	SL EL	E_t EL	SL EL	E_t EL	SL EL
Commercial Gas-Fired Storage Water Heaters	1	2	2	2	4	2	5	2
Residential-Duty Gas-Fired Water Heaters	1	3	2	1	2	1	4	1
Gas-Fired Tankless Water Heaters	2	-	3	-	4	-	5	-
Gas-Fired Hot Water Supply Boilers	2	-	3	-	4	-	5	-
Commercial Electric Storage Water Heaters	-	1	-	1	-	1	-	1

12.4.4 Financial Parameters

As part of the MIA, DOE estimated eight key financial parameters for use in the GRIM. DOE developed its initial estimates of industry financial parameters based on a review of SEC public filings, corporate annual reports, company profiles, and credit ratings. DOE used these parameters as a starting point for its industry cash flow analysis and presented them to manufacturers for review and comment during interviews. Based on manufacturer feedback, DOE then revised its initial estimates to better reflect the current CWH industry.

Table 12.4.2 presents both the initial estimates and the revised financial parameters used as inputs to the GRIM.

Table 12.4.2 Financial Parameters for the CWH Industry

Financial Parameter	Initial Estimate %	Revised Estimate %
Tax Rate (% of taxable income)	31.0	36.6
Discount Rate	9.0	9.1
Working Capital (% of Revenue)	9.3	8.5
Net Property, Plant, and Equipment (% of Revenue)	20.3	17.5
SG&A (% of Revenue)	21.6	20.6
R&D (% of Revenue)	2.4	2.5
Depreciation (% of Revenue)	2.7	2.8
Capital Expenditures (% of Revenue)	3.3	3.1

12.4.5 Manufacturer Markup

DOE also used publicly available financial data to estimate an average manufacturer markup for the CWH equipment industry. DOE initially estimated this markup—which captures all non-production costs, including SG&A expenses, R&D expenses, interest, and profit—to be 1.43 for all CWH equipment classes. During interviews, DOE presented manufacturers with this average markup estimate. DOE then revised its estimate to reflect manufacturer feedback. Table 12.4.3 presents the revised manufacturer markups used as inputs to the GRIM.

Table 12.4.3 Baseline Manufacturer Markups

Equipment Class	Markup
Commercial Gas-Fired Storage Water Heaters	1.45
Residential-Duty Gas-Fired Water Heaters	1.45
Gas-Fired Tankless Water Heaters	1.43
Gas-Fired Hot Water Supply Boilers	1.43
Commercial Electric Storage Water Heaters	1.41

12.4.6 Shipment Forecasts

The GRIM estimates manufacturer revenues based on total unit shipment forecasts and the distribution of these values by efficiency level. Changes in sales volumes and efficiency mix over time can significantly affect manufacturer finances. For this analysis, the GRIM uses the NIA's annual shipment forecasts derived from the shipments analysis from 2015 (the reference year) through 2048 (the end year of the analysis period). The shipments model divides the shipments of CWH equipment into specific market segments. The model starts from a historical reference year and calculates retirements and shipments by market segment for each year of the analysis period. This approach produces an estimate of the total equipment stock, broken down by age or vintage, in each year of the analysis period. In addition, the equipment stock efficiency distribution is calculated for the no-new-standards case and for each standards case for each equipment class. The NIA shipments forecasts are, in part, based on a roll-up scenario. The forecast assumes that equipment in the no-new-standards case that does not meet the standard under consideration would "roll up" to meet the amended standard beginning in the compliance year of 2019. See chapter 9 of the TSD for more information on the standards-case shipment forecasts.

12.4.7 Manufacturer Production Costs

Manufacturing higher efficiency equipment is typically more expensive than manufacturing baseline equipment due to the use of more complex components, which are typically more costly than baseline components. The changes in the MPCs of the analyzed equipment can affect the revenues, gross margins, and cash flow of the industry, making these product cost data key GRIM inputs for DOE's analysis.

In the MIA, DOE used the MPCs calculated in the engineering analysis for each examined combination of thermal efficiency and standby loss levels. In addition, DOE used information from its teardown analysis to disaggregate the MPCs into material, labor, depreciation, and overhead costs. DOE validated and revised these cost breakdowns and equipment markups with manufacturers during manufacturer interviews. See chapter 5 of this TSD for more information on the derivation of MPCs for each equipment class.

After calculating MPCs, DOE applied a manufacturer markup to arrive at the total manufacturer selling price (MSP) for each equipment class at each efficiency level. DOE applied an average no-new-standards case markup of 1.45 for commercial gas-fired storage water heaters and residential-duty gas-fired storage water heaters, 1.43 for gas-fired tankless water heaters and gas-fired hot water supply boilers, and 1.41 for electric storage water heaters. As discussed in section 12.4.9, DOE varied this markup under a set of markup scenarios to analyze a range of potential financial impacts on the industry resulting from amended efficiency standards.

Table 12.4.4 through Table 12.4.13 present the MPC breakdown, and MSP for each equipment class at each efficiency level analyzed.

Table 12.4.4 Manufacturer Production Cost Breakdown (2014$) for Commercial Gas-Fired Storage Water Heaters at SL EL0

Thermal Efficiency Level	Material *$*	Labor *$*	Depre-ciation *$*	Overhead *$*	MPC *$*	Shipping *$*	Markup	MSP *$*
Baseline	$753.55	$78.02	$41.85	$150.16	$1,023.59	$55.34	1.45	$1,539.55
1	$773.66	$79.45	$42.78	$150.25	$1,046.14	$59.03	1.45	$1,575.94
2	$965.57	$85.00	$51.26	$151.74	$1,253.56	$52.09	1.45	$1,869.75
3	$974.91	$85.60	$51.68	$151.73	$1,263.93	$52.09	1.45	$1,884.78
4	$995.79	$86.95	$52.67	$152.64	$1,288.05	$52.09	1.45	$1,919.77
5	$1,033.56	$89.34	$54.43	$153.76	$1,331.09	$52.09	1.45	$1,982.17

Table 12.4.5 Manufacturer Production Cost Breakdown (2014$) for Commercial Gas-Fired Storage Water Heaters at SL EL1

Thermal Efficiency Level	Material *$*	Labor *$*	Depre-ciation *$*	Overhead *$*	MPC *$*	Shipping *$*	Markup	MSP *$*
Baseline	$756.54	$79.52	$42.10	$151.53	$1,029.70	$55.34	1.45	$1,548.40
1	$776.71	$80.96	$43.03	$151.62	$1,052.31	$59.03	1.45	$1,584.89
2	$968.51	$86.79	$51.52	$153.15	$1,259.97	$52.09	1.45	$1,879.04
3	$977.86	$87.40	$51.94	$153.14	$1,270.35	$52.09	1.45	$1,894.09
4	$998.77	$88.76	$52.93	$154.05	$1,294.51	$52.09	1.45	$1,929.13
5	$1,034.17	$91.04	$54.59	$155.20	$1,335.00	$52.09	1.45	$1,987.84

Table 12.4.6 Manufacturer Production Cost Breakdown (2014$) for Commercial Gas-Fired Storage Water Heaters at SL EL2

Thermal Efficiency Level	Material *$*	Labor *$*	Depre-ciation *$*	Overhead *$*	MPC *$*	Shipping *$*	Markup	MSP *$*
Baseline	$775.87	$80.81	$42.98	$151.53	$1,051.20	$59.03	1.45	$1,583.27
1	$796.29	$82.27	$43.92	$151.62	$1,074.10	$59.03	1.45	$1,616.48
2	$988.12	$88.36	$52.43	$153.29	$1,282.19	$55.34	1.45	$1,914.53
3	$997.53	$88.97	$52.86	$153.28	$1,292.63	$55.34	1.45	$1,929.66
4	$1,018.57	$90.34	$53.85	$154.19	$1,316.95	$55.34	1.45	$1,964.93
5	$1,056.93	$92.80	$55.64	$155.30	$1,360.66	$55.34	1.45	$2,028.30

Table 12.4.7 Manufacturer Production Cost Breakdown (2014$) for Residential-Duty Gas-Fired Storage Water Heaters at SL EL0

Thermal Efficiency Level	Material $	Labor $	Depre-ciation $	Overhead $	MPC $	Shipping $	Markup	MSP $
Baseline	$257.74	$45.45	$14.47	$36.33	$354.00	$26.83	1.45	$540.13
1	$262.71	$45.64	$14.69	$36.33	$359.37	$26.83	1.45	$547.91
2	$546.32	$55.75	$27.30	$38.39	$667.75	$23.61	1.45	$991.86
3	$680.16	$61.62	$33.13	$35.41	$810.33	$24.60	1.45	$1,199.58
4	$687.07	$62.33	$33.47	$35.72	$818.60	$24.60	1.45	$1,211.57

Table 12.4.8 Manufacturer Production Cost Breakdown (2014$) for Residential-Duty Gas-Fired Storage Water Heaters at SL EL1

Thermal Efficiency Level	Material $	Labor $	Depre-ciation $	Overhead $	MPC $	Shipping $	Markup	MSP $
Baseline	$302.14	$46.32	$16.41	$36.49	$401.35	$28.11	1.45	$610.07
1	$307.34	$46.56	$16.64	$36.51	$407.06	$29.52	1.45	$619.76
2	$562.11	$57.05	$28.04	$38.47	$685.67	$25.67	1.45	$1,019.88
3	$695.80	$62.95	$33.86	$35.53	$828.15	$25.67	1.45	$1,226.48
4	$702.72	$63.66	$34.20	$35.84	$836.43	$25.67	1.45	$1,238.49

Table 12.4.9 Manufacturer Production Cost Breakdown (2014$) for Residential-Duty Gas-Fired Storage Water Heaters at SL EL2

Thermal Efficiency Level	Material $	Labor $	Depre-ciation $	Overhead $	MPC $	Shipping $	Markup	MSP $
Baseline	$342.56	$44.98	$18.07	$36.34	$441.95	$28.11	1.45	$668.94
1	$347.91	$45.27	$18.31	$36.39	$447.89	$29.52	1.45	$678.96
2	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
3	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
4	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

Table 12.4.10 Manufacturer Production Cost Breakdown (2014$) for Residential-Duty Gas-Fired Storage Water Heaters at SL EL3

Thermal Efficiency Level	Material $	Labor $	Depre-ciation $	Overhead $	MPC $	Shipping $	Markup	MSP $
Baseline	$359.89	$45.69	$18.90	$37.67	$462.14	$31.07	1.45	$701.17
1	$365.33	$45.99	$19.14	$37.72	$468.18	$31.07	1.45	$709.94
2	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
3	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
4	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

Table 12.4.11 Manufacturer Production Cost Breakdown (2014$) for Gas-Fired Tankless Water Heaters

Thermal Efficiency Level	Material $	Labor $	Depre-ciation $	Overhead $	MPC $	Shipping $	Markup	MSP $
Baseline	$540.88	$57.93	$25.39	$5.46	$629.67	$13.38	1.43	$913.81
1	$548.58	$58.75	$25.75	$5.54	$638.62	$14.72	1.43	$927.95
2	$556.10	$59.56	$26.11	$5.62	$647.38	$15.50	1.43	$941.25
3	$683.74	$69.56	$31.88	$5.28	$790.45	$19.08	1.43	$1,149.43
4	$697.82	$69.22	$32.46	$5.37	$804.87	$19.08	1.43	$1,170.05
5	$716.45	$69.25	$33.25	$5.50	$824.45	$22.90	1.43	$1,201.86

Table 12.4.12 Manufacturer Production Cost Breakdown (2014$) for Gas-Fired Hot Water Supply Boilers

Thermal Efficiency Level	Material $	Labor $	Depre-ciation $	Overhead $	MPC $	Shipping $	Markup	MSP $
Baseline	$1,027.16	$54.37	$47.67	$52.80	$1,182.00	$52.09	1.43	$1,742.35
1	$1,047.64	$55.46	$48.62	$53.86	$1,205.56	$55.34	1.43	$1,779.30
2	$1,246.06	$57.86	$56.91	$50.34	$1,411.17	$55.34	1.43	$2,073.31
3	$2,490.17	$66.80	$107.75	$7.14	$2,671.86	$42.17	1.43	$3,862.92
4	$2,640.32	$65.02	$114.00	$7.56	$2,826.90	$42.17	1.43	$4,084.63
5	$2,791.09	$65.60	$120.25	$4.99	$2,981.94	$42.17	1.43	$4,306.34

Table 12.4.13 Manufacturer Production Cost Breakdown (2014$) for Electric Storage Water Heaters

Standby Loss Efficiency Level	Material $	Labor $	Depre-ciation $	Overhead $	MPC $	Shipping $	Markup	MSP $
Baseline	$619.96	$76.62	$33.97	$123.70	$854.25	$55.34	1.41	$1,259.83
1	$645.69	$78.91	$35.13	$123.67	$883.40	$59.03	1.41	$1,304.62

12.4.8 Conversion Costs

Energy conservation standards typically cause manufacturers to incur upfront conversion costs to bring their production facilities and product designs into compliance with new regulations. For the MIA, DOE classified these upfront conversion costs into two major groups: capital conversion costs and product conversion costs. Capital conversion costs are one-time investments in plant, property, and equipment required to adapt or change existing production facilities in order to fabricate and assemble new product designs that comply with amended energy conservation standards. Product conversion costs are upfront investments in research, development, testing, marketing, and other costs to make product designs comply with amended energy conservation standards. DOE based its estimates of the conversion costs for each efficiency level on information obtained from manufacturer interviews and the design pathways analyzed in the engineering analysis.

12.4.8.1 Capital Conversion Costs

To evaluate the level of capital conversion costs manufacturers would likely incur to comply with amended thermal efficiency standards for all analyzed gas-fired CWH equipment classes, DOE estimated capital expenditure requirements to achieve each efficiency level using the equipment teardowns and engineering analysis described in chapter 5 of the NOPR TSD. DOE used these analyses to determine equipment investments that would be necessary to achieve higher ELs. Specifically, the results from the engineering analysis allowed DOE to identify how manufacturer investment costs for equipment, tooling, building space, and conveyor systems would increase for each incremental thermal efficiency level. As a baseline, DOE used the current distribution of non-condensing and condensing equipment on the market, and then considered the additional investment costs that would be needed to manufacture only condensing equipment, as would be required by a condensing standard. DOE also estimated capital expenditures manufacturers may have to make on upgrades to their R&D and testing facilities. For hot water supply boilers, DOE only considered capital conversion costs for increased space requirements, because DOE believes that most manufacturers would source the condensing heat exchangers that would be required at condensing thermal efficiency levels. DOE's estimated capital conversion costs are shown below by thermal efficiency level in Table 12.4.14 through Table 12.4.17.

Table 12.4.14 Industry Capital Conversion Costs by Thermal Efficiency Level for Commercial Gas-Fired Storage Water Heaters

TE EL	Thermal Efficiency	Industry Capital Conversion Costs *2014$*		
		Investment Costs for Production Equipment	Investment Costs for R&D and Testing Facilities	Total
1	82%	$26,440	-	$26,440
2	90%	$3,659,074	-	$3,659,074
3	92%	$3,659,074	-	$3,659,074
4	95%	$3,996,231	$2,969,043	$6,965,274
5	99%	$6,411,718	$8,907,129	$15,318,847

Table 12.4.15 Industry Capital Conversion Costs by Thermal Efficiency Level for Residential-Duty Gas-Fired Storage Water Heaters

TE EL	Thermal Efficiency	Industry Capital Conversion Costs *2014$*		
		Investment Costs for Production Equipment	Investment Costs for R&D and Testing Facilities	Total
1	82%	$26,440	-	$26,440
2	90%	$431,403	-	$431,403
3	95%	$810,595	-	$810,595
4	97%	$946,876	$742,261	$1,689,137

Table 12.4.16 Industry Capital Conversion Costs by Thermal Efficiency Level for Gas-Fired Tankless Water Heaters

TE EL	Thermal Efficiency	Total Capital Conversion Costs *2014$*
1	82%	-
2	90%	-
3	92%	$528,162
4	95%	$528,162
5	99%	$528,162

Table 12.4.17 Industry Capital Conversion Costs by Thermal Efficiency Level for Gas-Fired Hot Water Supply Boilers

TE EL	Thermal Efficiency	Total Capital Conversion Costs *2014$*
1	82%	-
2	90%	-
3	92%	$1,649,468
4	95%	$1,649,468
5	99%	$1,649,468

To evaluate the level of capital conversion costs manufacturers would likely incur to comply with amended standby loss standards, DOE relied on manufacturer feedback obtained during interviews as well as data derived from the engineering analysis. DOE estimated that manufacturers would incur approximately $1.1 million in capital conversion costs at all standby loss levels above baseline for commercial gas-fired storage water heaters and electric storage water heaters. This estimate reflects the additional press dies that may need to be purchased to produce the tank jacket lids, because the diameter of the jacket would need to expand to accommodate a thicker layer of tank insulation. DOE assumed that no capital conversion costs would be needed at the standby loss levels above baseline for residential-duty gas-fired water heaters because DOE believes that manufacturers already possess the machinery and tooling necessary to achieve those levels as part of their current production capabilities for either residential or residential-duty commercial water heaters.

Table 12.4.18 presents estimated capital conversion costs by TSL for the CWH industry resulting from amended energy conservation standards.

Table 12.4.18 Industry Cumulative Capital Conversion Costs by TSL

TSL	Capital Conversion Costs *million 2014$*
Baseline	0.0
1	2.2
2	8.4
3	11.7
4	21.3

12.4.8.2 Product Conversion Costs

To evaluate the level of product conversion costs manufacturers would likely incur to comply with amended thermal efficiency standards, DOE estimated the number of manufacturing platforms that would need to be modified per manufacturer to move their product lines to each incremental thermal efficiency level. These assumptions about the number of platforms that would need to be modified were based on the variation of units by input capacity offered by each manufacturer, because different input capacity models often have different heat exchanger sizes. For each platform, DOE estimated a number of engineers and lab technicians that would need to work to redesign a product, as well as a length of time this work would take. DOE's estimates for the number of platforms as well as average labor and time requirements are shown by efficiency level in Table 12.4.19 through Table 12.4.22. In its calculations, DOE used labor costs of $150,000 per year and $100,000 per year for engineers and lab technicians, respectively.

Table 12.4.19 Industry Product Conversion Cost Inputs and Results by Thermal Efficiency Level for Commercial Gas-Fired Storage Water Heaters

TE EL	Thermal Efficiency	Number of Platforms	Per Platform			Total Industry Product Conversion Cost *2014$*
			Average Time Required *Months*	Number of Engineers	Number of Lab Technicians	
1	82%	12	6	1	1	$1,484,522
2	90%	6	12	3	2	$4,453,565
3	92%	6	12	3	3	$4,453,565
4	95%	9	18	3	3	$10,020,521
5	99%	24	24	3	3	$35,628,518

Table 12.4.20 Industry Product Conversion Cost Inputs and Results by Thermal Efficiency Level for Residential-Duty Gas-Fired Storage Water Heaters

TE EL	Thermal Efficiency	Number of Platforms	Per Platform			Total Product Conversion Cost *2014$*
			Average Time Required *Months*	Number of Engineers	Number of Lab Technicians	
1	82%	3	6	1	1	$371,130
2	90%	3	9	1	1	$865,971
3	95%	3	12	2	2	$1,484,522
4	97%	3	15	2	2	$2,350,492

Table 12.4.21 Industry Product Conversion Cost Inputs and Results by Thermal Efficiency Level for Gas-Fired Tankless Water Heaters

TE EL	Thermal Efficiency	Number of Platforms	Per Platform			Total Product Conversion Cost *2014$*
			Average Time Required *Months*	Number of Engineers	Number of Lab Technicians	
1	82%	2	6	1	1	$247,420
2	84%	2	9	1	1	$494,841
3	92%	4	12	1	1	$989,681
4	94%	4	12	1	1	$989,681
5	96%	4	12	1	1	$989,681

Table 12.4.22 Industry Product Conversion Cost Inputs and Results by Thermal Efficiency Level for Gas-Fired Hot Water Supply Boilers

TE EL	Thermal Efficiency	Number of Platforms	Per Platform			Total Product Conversion Cost *2014$*
			Average Time Required *Months*	Number of Engineers	Number of Lab Technicians	
1	82%	5	6	2	2	$1,237,101
2	84%	5	7	2	2	$1,237,101
3	92%	9	15	2	2	$6,185,507
4	94%	9	15	2	2	$6,185,507
5	96%	18	14	2	2	$9,278,260

For standby loss levels above baseline, DOE does not expect manufacturers to incur any product conversion costs, as no substantial redesign work would be necessary to achieve the standby loss levels evaluated in the engineering analysis and discussed in chapter 5 of the NOPR TSD.

Table 12.4.23 presents estimated product conversion costs by TSL for the CWH industry resulting from amended energy conservation standards.

Table 12.4.23 Industry Cumulative Product Conversion Costs by TSL

TSL	Product Conversion Costs *million 2014$*
Baseline	0.0
1	3.6
2	12.5
3	18.1
4	48.2

12.4.9 Markup Scenarios

DOE modeled two markup scenarios to capture uncertainty regarding potential impacts on prices and profitability following implementation of amended energy conservation standards: (1) a preservation of gross margin percentage markup scenario and (2) a preservation of per-unit operating profit markup scenario. These scenarios lead to different markup values that, when applied to MPCs, result in varying revenue and cash flow impacts.

12.4.9.1 Preservation of Gross Margin Percentage Scenario

Under the preservation of gross margin percentage scenario, DOE applied a single uniform "gross margin percentage" markup across all efficiency levels. This assumes manufacturers would be able to maintain the same amount of profit, as a percentage of revenues, at all efficiency levels within a product class. As production costs and sales prices increase with more stringent efficiency levels, this scenario implies that the absolute dollar markup will increase as well. The manufacturer, in this case, will see more profit in absolute terms on a per-unit basis. The no-new-standards-case manufacturer markups used in the GRIM are displayed in Table 12.4.3. Because this markup scenario implies manufacturers would be able to maintain their gross margin percentage markups as production costs increase in response to amended energy conservation standards, DOE assumes this scenario represents an upper bound to industry profitability under amended standards.

12.4.9.2 Preservation of Per Unit Operating Profit Scenario

DOE decided to include the preservation of per unit operating profit scenario in its analysis because manufacturers stated that they do not expect to be able to mark up the full cost of production in the standards case, given the highly competitive nature of the CWH equipment market. In this scenario, manufacturer markups are set so that operating profit one year after the compliance date of amended energy conservation standards is the same as in the no-new-standards case on a per unit basis. In other words, manufacturers are not able to yield additional operating profit from the higher production costs and the investments that are required to comply with the proposed standards; however, they are able to maintain the same operating profit in the standards case that was earned in the no-new-standards case. Therefore, operating margin in percentage terms is reduced between the no-new-standards case and standards case. DOE adjusted the manufacturer markups in the GRIM at each TSL to yield approximately the same earnings before interest and taxes in the standards case as in the no-new-standards case. The preservation of per unit operating profit markup scenario represents the lower bound of industry profitability in the standards case. This is because manufacturers are not able to fully pass through to consumers the additional costs necessitated by CWH equipment standards, as they are able to do in the preservation of gross margin percentage markup scenario.

12.5 INDUSTRY FINANCIAL IMPACTS

Using the inputs and scenarios described in previous sections, DOE estimated financial impacts on the CWH equipment industry resulting from amended energy conservation standards. The following sections address two key financial metrics analyzed in the MIA: industry net present value and annual cash flows.

12.5.1 Impacts on Industry Net Present Value

The INPV measures the industry value and is used in the MIA to compare the economic impacts of different TSLs. The INPV is different from DOE's net present value, which is applied to the U.S. economy. The INPV is the sum of all net cash flows discounted at the industry's cost of capital or discount rate. The GRIM for this rulemaking estimates cash flows from 2015 to 2048. This timeframe models both the short-term impacts on the industry from the reference year of the analysis until the compliance date (2015–2029) and the long-term impacts over the 30-year analysis period used in the NIA (2019–2048).

In the MIA, DOE compares the INPV in the no-new-standards case to the INPVs that result at each TSL in the standards case. The difference between these estimates represents the economic impacts implementing a particular TSL would have on the industry. For the CWH equipment industry, DOE examined the two markup scenarios described in section 12.4.9, which result in a range of INPV impacts at each TSL. Table 12.5.1 and Table 12.5.2 show the estimated INPV impacts under the two scenarios.

Table 12.5.1 Change in INPV under the Preservation of Gross Margin Percentage Scenario

	Units	No-New-Standards Case	Trial Standard Level			
			1	2	3	4
INPV	*million 2014$*	176.2	177.4	187.8	185.0	166.6
Change in INPV*	*million 2014$*	-	1.2	11.6	8.8	-9.7
	%	-	0.7	6.6	5.0	(5.5)
Total Conversion Costs	*million 2014$*	-	5.8	20.9	29.8	69.6
Shipment Weighted Average Price Per Unit (2019)	*2014$*	1,475	1,541	1,783	1,816	1,875

Note: Parentheses indicate negative values.

Table 12.5.2 Change in INPV under the Preservation of Per-Unit Operating Profit Scenario

	Units	No-New-Standards Case	Trial Standard Level			
			1	2	3	4
INPV	*million 2014$*	176.2	171.5	158.8	152.8	128.6
Change in INPV	*million 2014$*	-	(4.7)	(17.4)	(23.4)	(47.6)
	%	-	(2.7)	(9.9)	(13.3)	(27.0)
Total Conversion Costs	*million 2014$*	-	5.8	20.9	29.8	69.6
Shipment Weighted Average Price Per Unit (2019)	*2014$*	1,475	1,535	1,754	1,783	1,837

Note: Parentheses indicate negative values.

12.5.2 Impacts on Annual Cash Flow

While INPV is useful for evaluating the long-term effects of amended energy conservation standards, short-term changes in cash flow are also important indicators of the industry's financial situation. For example, a large investment over one or two years could strain the industry's access to capital. Consequently, a sharp drop in financial performance could cause investors to flee, even though recovery may be possible. Thus, a short-term disturbance can have long-term effects that the INPV cannot capture. To illustrate this possible short-term disturbance, Figure 12.5.1 and Figure 12.5.2 present annual net cash flows in the no-new-standards case and for each TSL in the standards case. In addition, Table 12.5.3 presents estimated free cash flow impacts in the year prior to the standard (2018).

Annual cash flows are discounted to the reference year, 2015. After the standards announcement date, industry cash flows begin to decline as companies use their financial resources to prepare for the new energy conservation standard. Cash flows between the announcement date and the compliance date are driven by the level of conversion costs and the proportion of these investments spent each year. The more stringent the energy conservation standard, and the higher the expected conversion costs, the greater the impact on industry cash flows in the years leading up to the compliance date. This is because product conversion costs increase operational expenses, thereby reducing net operating profit, while capital conversion costs increase capital expenses, resulting in higher cash outflows and further reducing free cash flow.

In the year amended standards take effect (2019), free cash flow is driven by two competing factors. In addition to capital and product conversion costs, amended energy conservation standards could create stranded assets, *i.e.*, tooling and equipment that could have been used longer if the energy conservation standards had not made them obsolete. In this year, manufacturers write down the remaining book value of existing tooling and equipment whose value is affected by the amended standards. This one-time write-down acts as a tax shield that alleviates decreases in cash flow from operations in the year of the write-down. In this year, there is also an increase in working capital that reduces cash flow from operations. A large increase in working capital is needed due to more costly production components and materials, carrying higher inventory to sell more expensive equipment, and higher accounts receivable for more expensive equipment. Depending on these two competing factors, cash flow can be affected either positively or negatively in the year the standard takes effect.

Table 12.5.3 presents free cash flow impacts in the year before the standard takes effect. Figure 12.5.1 and Figure 12.5.2 graph the net annual cash flows for the two markup scenarios. While free cash flows vary over the course of the analysis period depending on the markup scenario analyzed, they do not vary by markup scenario in the years prior to the standard, as a shift in product mix and markup structure triggered by a standard has not yet taken effect.

Table 12.5.3 Industry Free Cash Flow Impacts in the Year before Compliance (2018)

	Units	No-New-Standards Case	Trial Standard Level			
			1	2	3	4
Free Cash Flow (2018)	*million 2014$*	12.8	10.9	5.6	2.5	(10.2)
Change in Free Cash Flow	*million 2014$*	-	(2.0)	(7.3)	(10.3)	(23.1)
	%	-	(15.5)	(56.7)	(80.4)	(179.8)

Note: Parentheses indicate negative values.

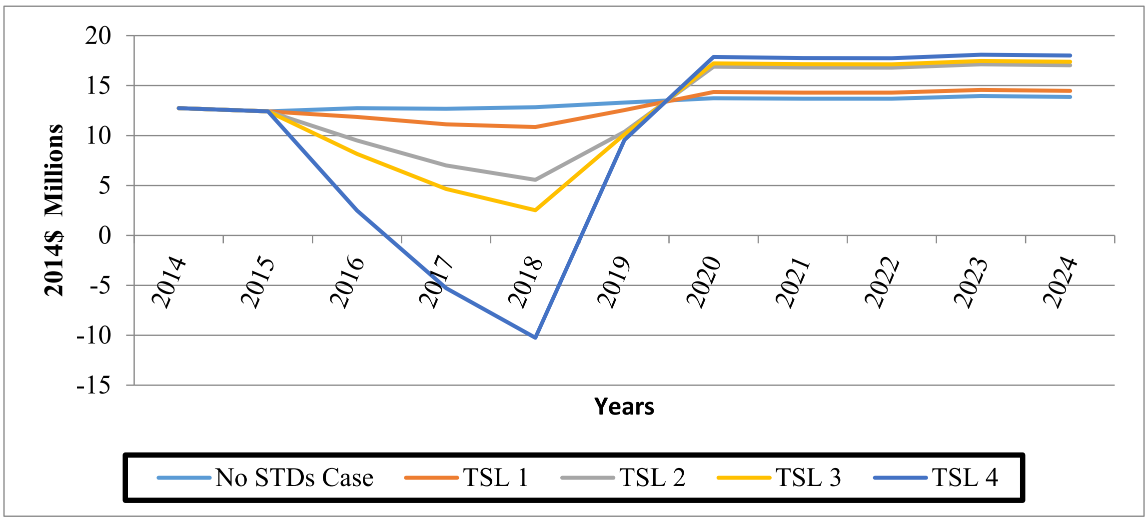

Figure 12.5.1 Annual Industry Net Cash Flows under the Preservation of Gross Margin Percentage Scenario

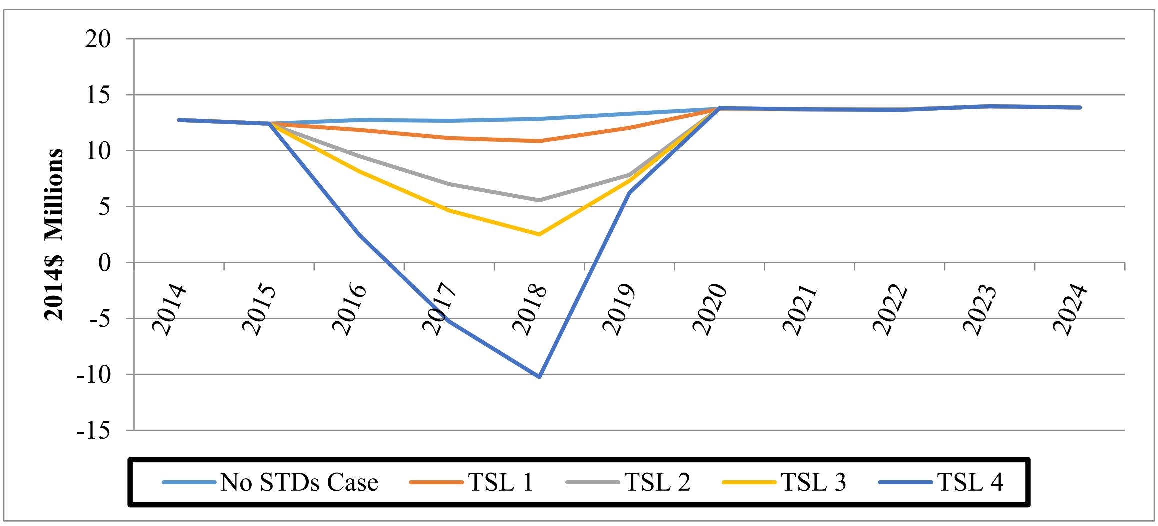

Figure 12.5.2 Annual Industry Net Cash Flows under the Preservation of Per-Unit Operating Profit Scenario

12.6 IMPACTS ON SMALL BUSINESS MANUFACTURERS

12.6.1 Description and Estimate of Small Entities Regulated

DOE conducted a focused inquiry of the companies that could be small business manufacturers of equipment covered by this rulemaking. For the category "Other Commercial and Service Industry Machinery Manufacturing," the SBA has set a size threshold of 1,000 employees or fewer for an entity to qualify as a small business. To identify the number of companies that could be small business manufacturers of equipment covered by this rulemaking, DOE conducted a market survey using available public information. DOE's research included industry trade association membership directories (*e.g.,* AHRI), public databases (*e.g.*, CEC Appliance Efficiency Database), individual company websites, market research tools (*e.g.*, Hoover's reports), and DOE's Certification Compliance Database to create a comprehensive list of companies that manufacture or sell equipment covered by this rulemaking. DOE also asked interested parties and industry representatives if they were aware of any small manufacturers during manufacturer interviews. DOE reviewed publicly available data and contacted select companies on its list, as necessary, to determine whether they met the SBA's definition of a small business manufacturer of covered equipment. DOE screened out companies that do not offer equipment covered by this rulemaking, do not meet the definition of a small business, or are foreign owned and operated.

DOE initially identified 25 manufacturers of CWH equipment sold in the United States. After reviewing publicly available information on these manufacturers, DOE determined that 12 are either large manufacturers or manufacturers that are foreign owned and operated. DOE was able to determine that 13 businesses meet the SBA's definition of a "small business" and manufacture or sell covered CWH equipment in the United States. Of these 13 businesses, 12 are original equipment manufacturers (OEMs) of covered CWH equipment, while the remaining company rebrands equipment manufactured by other OEMs.

DOE attempted to contact all small business manufacturers it identified to invite them to take part in a small business manufacturer impact analysis interview. Two of the small businesses agreed to participate in the MIA interview process. DOE also obtained information about small business impacts while interviewing large manufacturers.

DOE estimates that small businesses control approximately 7 percent of the CWH market. Based on DOE's research, six small businesses are primarily boiler manufacturers that produce hot water supply boilers covered under this rulemaking. Two of these manufacturers primarily produce high-efficiency condensing equipment, while the remaining four do not produce equipment that meet the efficiency level at the proposed TSL (TSL 3). DOE notes, however, that three of these four manufacturers offer condensing commercial packaged boilers. DOE believes the heat exchanger designs for commercial packaged boiler offerings could be adapted for the hot water supply boiler market. Of the six remaining small businesses, five primarily manufacture commercial gas-fired storage and electric storage water heaters. Three of these five companies produce primarily high-efficiency condensing gas-fired equipment, while two of the five primarily produce baseline equipment. However, both of the latter companies offer at least one condensing model. Of the remaining small businesses, one exclusively manufacturers condensing gas-fired tankless water heaters and one rebrands equipment that is produced by other CWH equipment manufacturers.

12.6.2 Comparison between Small and Large Entities

As previously mentioned, DOE used feedback from manufacturer interviews to help evaluate the potential impacts of standards on small businesses. DOE also used product listings data to better understand the percentage of models small manufacturers may have to convert in order to comply with standards.

In interviews, small manufacturers stated that they may be disproportionately affected by product conversion costs. Product redesign, testing, and certification costs tend to be fixed and do not scale with sales volume. When confronted with new or amended energy conservation standards, small businesses must make investments in research and development to redesign their equipment, but because they have lower sales volumes, they must spread these costs across fewer units. Small manufacturers also stated that they have limited lab space, personnel and equipment to test their CWH equipment. They argued that they would experience higher testing costs relative to larger manufacturers, as they would need to outsource some or all of their testing at a higher per-unit cost. Small manufacturers pointed out that in general, because they have fewer engineers and product development resources, they would likely have to divert engineering resources from customer and new product initiatives for a longer period of time than larger competitors.

These product conversion cost and engineering resource considerations are particularly applicable to the two small manufacturers that primarily offer baseline commercial gas-fired storage water heaters and the four manufacturers that only offer lower-efficiency hot water supply boilers. DOE estimates that 57 percent of commercial gas-fired storage models produced by small CWH equipment manufacturers do not meet the thermal efficiency level proposed in TSL 3. For the two manufacturers that primarily offer baseline commercial gas-fired storage water heaters, DOE estimates that 88 percent of their models do not meet the efficiency levels prescribed at TSL 3. For reference, DOE estimates that large commercial gas-fired storage water heaters manufacturers would have to covert approximately 76 percent of their commercial gas-fired storage water heater models at TSL 3. For hot water supply boilers, DOE estimates that small and large manufacturers would need to redesign similar proportions of their product offerings. Approximately 86 percent of the models currently produced by small CWH equipment manufacturers do not meet the level in TSL 3, while 79 percent of gas-fired hot water supply boilers produced by large manufacturers do not meet the level in TSL 3.

Smaller manufacturers also stated that they lack the purchasing power of larger manufacturers. The purchasing power issue may be of particular concern to the four manufacturers that produce lower-efficiency hot water supply boilers, because many manufacturers would purchase heat exchangers to comply with the thermal efficiency level proposed in TSL 3. Few hot water supply boiler manufacturers produce condensing boiler heat exchangers domestically, and most condensing boiler heat exchangers are sourced from European companies. A condensing standard, as proposed in TSL 3, could require small manufacturers to purchase a greater proportion of their components. This could exacerbate any pricing disadvantage small businesses experience today due to lower purchasing volumes.

12.7 OTHER IMPACTS

12.7.1 Direct Employment

12.7.1.1 Methodology

To quantitatively assess the impacts of amended energy conservation standards on employment, DOE used the GRIM to estimate the domestic labor expenditures and number of employees in the no-new-standards case and the standards case from 2014 through 2048. DOE used statistical data from the U.S. Census Bureau's 2013 Annual Survey of Manufacturers (ASM), the results of the engineering analysis, and interviews with manufacturers to determine the inputs necessary to calculate industry-wide labor expenditures and domestic employment levels. Labor expenditures related to manufacturing are a function of the labor intensity of the equipment, the sales volume, and an assumption that wages remain fixed in real terms over time. The total labor expenditures in each year are calculated by multiplying the MPCs by the labor percentage of MPCs.

The total labor expenditures in the GRIM were then converted to domestic production employment levels by dividing production labor expenditures by the annual payment per production worker (production worker hours times the labor rate found in the ASM). The production worker estimates in this section cover workers up to the line-supervisor level who are directly involved in fabricating and assembling a product within the original equipment manufacturer facility. Workers performing services that are closely associated with production operations, such as materials handling tasks using forklifts, are also included as production labor. DOE's estimates only account for production workers who manufacture the specific products covered by this rulemaking.

To estimate an upper bound to employment change, DOE assumes all domestic manufacturers would choose to continue producing their CWH equipment in the U.S. and would not move production to foreign countries. To estimate a lower bound to employment change, DOE considers the case where manufacturers choose to relocate some of their production to foreign countries and/or exit the market rather than make the necessary conversions at domestic production facilities.

12.7.1.2 Direct Employment Impacts

In the absence of energy conservation standards, DOE estimates that the CWH industry would employ 377 domestic production workers in 2019, the year the proposed standard takes effect. This estimate assumes U.S. production labor accounts for 90 percent of the industry total. Table 12.7.1 shows the potential range of impacts amended energy conservation standards could have on U.S. production workers of CWH equipment.

Table 12.7.1 Potential Changes in the Total Number of Domestic Production Workers in the CWH Industry in 2019

Worker Estimates	No-New-Standards Case	Trial Standard Level			
		1	2	3	4
Total Number of Domestic Production Workers (2019)	377	389 to 241	406 to 212	408 to 199	416 to 153
Potential Changes in Domestic Production Workers (2019)	-	12 to (136)	29 to (165)	31 to (178)	39 to (224)

Note: Parentheses indicate negative values.

To estimate an upper bound to direct employment impacts, DOE assumed all domestic manufacturers would choose to continue producing CWH equipment in the United States and would require some additional labor to produce more efficient equipment. In interviews, manufacturers generally indicated that higher efficiency standards would not cause production to migrate overseas due to shipping considerations. Some manufacturers also stated that producing more efficient equipment is generally more labor intensive and may require them to hire additional production employees. However, they also acknowledged that amended standards could potentially shift the production of some of the value content of CWH equipment overseas, causing U.S. manufacturers to become less vertically integrated. Especially in the hot water supply boiler market, companies could choose to source condensing heat exchangers rather than manufacture them in-house.

The establish a lower bound of potential direct employment impacts, DOE assumed some manufacturers would reduce their domestic production of CWH equipment in response to amended efficiency standards, either shifting production overseas, sourcing components they previously manufactured in-house, or leaving the industry. To derive the lower bound of direct employment impacts, DOE estimated the percentage of CWH models that fail to meet the thermal efficiency standards required at each TSL and assumed domestic direct employment in the industry would decline by an equal proportion. This is intended to serve as a conservative assumption and represents the lower bound of a range of potential impacts on direct employment in the CWH industry under amended standards.

DOE notes that the employment impacts discussed here are independent of the indirect employment impacts to the broader U.S. economy, which are documented in chapter 15 of the NOPR TSD.

12.7.2 Production Capacity

Based on manufacturer feedback, DOE estimates that the average CWH equipment manufacturer's current production is running at approximately 60-percent capacity. Most manufacturers stated in interviews that they generally did not anticipate production capacity constraints associated with this rulemaking. Some noted that condensing equipment is generally more labor-intensive and takes longer to build, however most agreed they could increase capacity by implementing a second shift with the current machinery they have, or by expanding production capacity. Some manufacturers did express concerns about engineering and laboratory resources if standards were set at a high level. However, given the compliance period, DOE believes that because most manufacturers already make equipment that meets the efficiency levels proposed in this NOPR, manufacturers would have time to redesign their product lines and production processes.

12.7.3 Cumulative Regulatory Burden

While any one regulation may not impose a significant burden on manufacturers, the combined effects of existing and impending regulations may have serious consequences for some manufacturers, subgroups of manufacturers, or an entire industry. Assessing the impact of a single regulation may overlook this cumulative regulatory burden. In addition to energy conservation standards, other regulations can significantly affect manufacturers' financial operations. Multiple regulations affecting the same manufacturer can strain profits and lead companies to abandon product lines or markets with lower expected future returns than competing products. For these reasons, DOE conducts an analysis of cumulative regulatory burden as part of its rulemakings pertaining to appliance efficiency.

12.7.3.1 DOE Regulations for Other Products Produced by Manufacturers in the CWH equipment Industry

For the cumulative regulatory burden analysis, DOE looks at other regulations that could affect CWH equipment manufacturers that will take effect approximately three years before or after the 2019 compliance date of amended energy conservation standards for this equipment. In interviews, manufacturers cited federal regulation of equipment other than CWH equipment that contributes to their cumulative regulatory burden. Table 12.7.2 presents the compliance years and expected industry conversion costs of relevant amended energy conservation standards. Table 12.7.3 identifies particular CWH equipment manufacturers impacted by other energy conservation standards.

Table 12.7.2 Compliance Dates and Expected Conversion Expenses of Federal Energy Conservation Standards Affecting the CWH Equipment Industry

Federal Energy Conservation Standards	Approximate Compliance Date	Estimated Total Industry Conversion Expense
Commercial Packaged Air-Conditioning and Heating Equipment 81 FR 2420 (January 15, 2016)	2018 and 2023*	$520.8M (*2014$*)
Residential Furnace Fans 79 FR 38129 (July 3, 2014)	2019	$40.6M (*2013$*)
Residential Boilers 81 FR 2320 (January 15, 2016)	2021	$2.5M (*2014$*)
Commercial Packaged Boilers**	2021	TBD
Residential Furnaces 80 FR 13120 (March 12, 2015) (NOPR)	2021	$55M (*2013$*)
Direct Heating Equipment/Pool Heaters**	2021	TBD
Residential Water Heaters**	2021	TBD

* This rule has multiple compliance dates.
** The NOPR and final rule for this energy conservation standard have not been published. The compliance date and analysis of conversion costs are estimates and have not been finalized at this time.

Table 12.7.3 Manufacturers of CWH Equipment Affected by Other Federal Energy Conservation Standards

Manufacturer	Comm. Packaged AC and Heat Pumps	Res. Furnace Fans	Res. Boilers	Comm. Pack. Boilers	Res. Furnaces	Direct Heating Equip./ Pool Heaters	Res. Water Heaters
Ace Heating Solutions				X			
ACV International NV			X	X			X
American International Water Heater Corp							X
A. O. Smith Corporation			X	X		X	X
Bradford White Corporation			X	X			X
Burnham Holdings Inc		X	X	X	X		X
Camus Hydronics Ltd			X	X			
Gasmaster Industries Inc				X			
Hamilton Engineering			X	X			
HTP, Inc.			X	X			X
Hubbell Electric Heater Company				X			X
Intellihot Green Technologies, Inc.							X
Interline Brands							X
Mestek Inc	X		X	X			
Miclau S.R.I.							X
National Combustion Co. Inc				X			X
Noritz Corporation			X				X
Paloma Co LTD	X	X	X	X	X	X	X
PVI Industries							
Rinnai Corporation			X			X	X
Robert Bosch GmbH			X			X	X
Sellers Manufacturing				X			
Sid E. Parker Boiler Mfg. Company				X			
Universal Technologies of Wisconsin Inc							X
Watts Water Technologies, Inc.				X			

During previous stages of this rulemaking, DOE identified other relevant requirements in addition to amended energy conservation standards CWH equipment. The following section briefly summarizes these regulatory requirements and addresses comments DOE received with respect to the cumulative regulatory burden, as well as other key related concerns manufacturers raised during interviews.

12.7.3.2 Environmental Protection Agency (EPA) Significant New Alternatives Policy (SNAP) Program

Several manufacturers raised concerns in interviews about EPA's SNAP program and, in particular, a proposed rule to modify the listings for certain hydrofluorocarbons in various end-uses in the aerosols, refrigeration and air conditioning, and foam blowing sectors. 79 FR 46126 (August 6, 2014). On July 20, 2015, the EPA published a final rule under the SNAP program that adopts modifications similar to those outlined in the August 6, 2014 proposed rule. 80 FR 42870, 42923-24. Specifically, the final rule changed the status of several hydrofluorocarbons to unacceptable for use as foam blowing agents beginning January 1, 2020. Several manufacturers of CWH equipment use these materials (*i.e.*, HFC-245fa) as blowing agents to insulate their CWH equipment. DOE acknowledges that the EPA ban on these substances will impact the materials used by some CWH equipment manufacturers, which could require them to alter the design of certain equipment.

12.8 CONCLUSION

This section summarizes the likely range of financial impacts CWH equipment manufacturers will experience as a result of amended energy conservation standards. DOE also notes that while these scenarios bound the range of most plausible impacts on manufacturers, circumstances could potentially cause manufacturers to experience impacts outside of this range. Table 12.8.1 summarizes INPV impacts and conversion costs projected to result from each of the trial standard levels analyzed.

Table 12.8.1 Manufacturer Impact Analysis Results

	Units	No-New-Standards Case	Trial Standard Level 1	2	3	4
INPV	*million 2014$*	176.2	171.5 To 177.4	158.8 to 187.8	152.8 to 185.0	128.6 to 166.6
Change in INPV	*million 2014$*	-	(4.7) to 1.2	(17.4) to 11.6	(23.4) to 8.8	(47.6) to (9.7)
	%	-	(2.7) to 0.7	(9.9) to 6.6	(13.3) to 5.0	(27.0) to (5.5)
Product Conversion Costs	*million 2014$*	-	3.6	12.5	18.1	48.2
Capital Conversion Costs	*million 2014$*	-	2.2	8.4	11.7	21.3
Total Investment Required	*million 2014$*	-	5.8	20.9	29.8	69.6
Free Cash Flow (2018)	*million 2014$*	12.8	10.9	5.6	2.5	(10.2)
Change in Free Cash Flow	*million 2014$*	-	(2.0)	(7.3)	(10.3)	(23.1)
	%	-	(15.5)	(56.7)	(80.4)	(179.8)

Note: Parentheses indicate negative numbers.

At TSL 1, DOE estimates impacts on INPV for CWH equipment manufacturers to range from -2.7 percent to 0.7 percent, or a change of -$4.7 million to $1.2 million. At this level, DOE estimates that industry free cash flow would decrease by approximately 15.5 percent to $10.9 million, compared to the no-new-standards-case value of $12.8 million in the year before compliance (2018).

DOE estimates that in the year of compliance (2019), 27% of CWH shipments in the no-new-standards case would already meet or exceed the thermal efficiency and standby loss standards at TSL 1. At this level, DOE expects CWH equipment manufacturers to incur $3.6 million in product conversion costs to redesign and test their equipment. DOE does not expect the modest increases in thermal efficiency standards at this TSL to require major equipment redesigns or capital investments. However, DOE expects manufacturers to incur approximately $2.2 million in capital conversion costs in order to comply with the proposed standby loss levels at this TSL. DOE expects manufacturers will incur these costs to purchase new tooling for the machinery used to make the jackets for storage water heaters, which would need to expand to enclose a thicker tank insulation layer.

At TSL 1, under the preservation of gross margin percentage scenario, the shipment-weighted average price per unit increases by 4.5 percent relative to the no-new-standards-case price per unit in the year of compliance (2019). In this scenario, manufacturers are able to fully pass on this cost increase to commercial consumers. This slight price increase would mitigate the $5.8 million in conversion costs estimated at TSL 1, resulting in slightly positive INPV impacts at TSL 1 under the this scenario. Under the preservation of per-unit operating profit markup scenario, manufacturers earn the same operating profit as would be earned in the no-new-standards case, but do not earn additional profit from their investments. A weighted average price increase of 4.1 percent in this scenario is outweighed by the expected conversion costs, resulting in slightly negative impacts at TSL 1.

At TSL 2, DOE estimates impacts on INPV for CWH manufacturers to range from -9.9 percent to 6.6 percent, or a change in INPV of -$17.4 million to $11.6 million. At this potential standard level, industry free cash flow would decrease by approximately 56.7 percent to $5.6 million, compared to the base-case value of $12.8 million in the year before compliance (2018).

DOE estimates that in the year of compliance (2019), 19% of CWH shipments in the no-new-standards case would already meet or exceed the thermal efficiency and standby loss standards at TSL 2. DOE estimates that conversion costs would increase significantly at this TSL because manufacturers would meet these thermal efficiency levels for gas-fired CWH equipment classes by using condensing technology, which significantly changes the equipment design. DOE estimates that most of these costs would be driven by commercial and residential-duty commercial gas-fired storage water heaters and gas-fired hot water supply boilers. DOE acknowledges that different manufacturers would likely make different investments in order to meet these thermal efficiency levels, because condensing heat exchanger designs vary from manufacturer to manufacturer. Manufacturers of gas-fired storage water heaters that use helical condensing heat exchanger designs may have to increase their tube-bending capacity to increase their production capacity of condensing heat exchangers, as would be required by a condensing standard. Other manufacturers may have to invest to increase their welding capacity. Additionally, manufacturers could incur capital costs for new press dies to form the holes for flue pipes in the top and bottom bells of storage water heaters. Overall, DOE estimates that manufacturers would incur $12.5 million in product conversion costs and $8.4 million in capital conversion costs to bring their CWH equipment portfolios into compliance with a standard set to TSL 2.

At TSL 2, under the preservation of gross margin percentage scenario, the shipment-weighted average price per unit increases by 20.9 percent relative to the no-new-standards-case price per unit in the year of compliance (2019). In this scenario, INPV impacts are positive because manufacturers' ability to pass higher production costs onto commercial consumers outweighs the $20.9 million in expected conversion costs. However, under the preservation of per-unit operating profit markup scenario, a lower markup means the weighted average price per unit increases by only 18.9 percent compared to the no-new-standards case price per unit in the year of compliance (2019). In this case, conversion costs outweigh the gain in weighted average price per unit, resulting in moderately negative impacts at TSL 2.

At TSL 3, DOE estimates impacts on INPV for CWH manufacturers to range from -13.3 percent to 5.0 percent, or a change in INPV of -$23.4 million to $8.8 million. At this potential standard level, DOE estimates industry free cash flow would decrease by approximately 80.4 percent to $2.5 million compared to the no-new-standards-case value of $12.8 million in the year before compliance (2018).

The impacts on INPV at TSL 3 are slightly more negative than at TSL 2. DOE estimates that in the year of compliance (2019), 16% of CWH shipments in the no-new-standards case would meet or exceed the thermal efficiency and standby loss standards at TSL 3. At this level, DOE estimates that product conversion costs would increase as manufacturers would have to redesign a larger percentage of their offerings to meet the higher thermal efficiency levels, which would require increased engineering resources. Additionally, capital conversion costs would increase as manufacturers may have to update their laboratories and test facilities to increase capacity for research, development, and testing for their gas-fired storage water heater offerings. Overall, DOE estimates that manufacturers would incur $18.1 million in product conversion costs and $11.7 million in capital conversion costs to bring their CWH equipment portfolios into compliance with a standard set to TSL 3.

At TSL 3, under the preservation of gross margin percentage markup scenario, the shipment-weighted average price per unit in the year of compliance (2019) increases by 23.1 percent relative to the no-new-standards case price per unit. In this scenario, INPV impacts are positive because manufacturers' ability to pass higher production costs onto commercial consumers outweighs the $29.8 million in total conversion costs. However, under the preservation of per-unit operating profit markup scenario, a lower markup means the weighted average price per unit increases by only 20.9 percent compared to the no-new-standards case price per unit in the year of compliance (2019). In this case, conversion costs outweigh the gain in weighted average price per unit, resulting in moderately negative impacts at TSL 3.

TSL 4 represents the max-tech thermal efficiency and standby loss levels for all equipment classes analyzed. At TSL 4, DOE estimates impacts on INPV for CWH equipment manufacturers to range from -27.0 percent to -5.5 percent, or a change in INPV of -$47.6 million to -$9.7 million. At this TSL, DOE estimates industry free cash flow in the year before compliance (2018) would decrease by approximately 179.8 percent to -$10.2 million compared to the no-new-standards case value of $12.8 million.

The impacts on INPV at TSL 4 are negative under both markup scenarios. DOE estimates that in 2019, only 4 percent of CWH equipment shipments would already meet or exceed the efficiency levels prescribed at TSL 4. DOE expects conversion costs to continue to increase at TSL 4, as almost all equipment on the market would have to be redesigned and many new products would have to be developed. DOE estimates that product conversion costs would increase to $48.2 million as manufacturers would have to redesign a larger percentage of their offerings to meet max-tech for all classes. In particular, manufacturers of commercial gas-fired storage water heaters would need to extensively redesign almost all of their product offerings. This extensive redesign would likely include many rounds of research and development and testing across most equipment platforms. DOE estimates that manufacturers would incur also $21.3 million in capital conversion costs. In addition to upgrading production lines, DOE believes manufacturers would likely be required to make extensive modifications and upgrades to their laboratories and possibly add laboratory space in order to develop and test products that meet max-tech efficiency levels, particularly for commercial gas-fired storage water heaters.

At TSL 4, under the preservation of gross margin percentage markup scenario, the shipment-weighted average price per unit in the year of compliance (2019) increases by 27.1 percent relative to the no-new-standards case price per unit. In this scenario, INPV impacts are negative because manufacturers' ability to pass higher production costs onto consumers is outweighed by the $69.6 million in total conversion costs. Under the preservation of per-unit operating profit markup scenario, a lower markup means the weighted average price per unit increases by only 24.5 percent compared to the no-new-standards case price per unit in the year of compliance (2019). In this case, conversion costs also outweigh the gain in weighted average price per unit, resulting in significantly negative impacts at TSL 4.

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APPENDIX 12A. MANUFACTURER IMPACT ANALYSIS INTERVIEW GUIDE

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APPENDIX 12A. MANUFACTURER IMPACT ANALYSIS INTERVIEW GUIDE

12A.1 MANUFACTURER IMPACT ANALYSIS INTERVIEW GUIDE FOR COMMERCIAL WATER HEATERS

Purpose:
To gather information on the U.S commercial water heater market to assist in the Department of Energy's energy conservation standards analysis.

Method:
Navigant Consulting, Inc. (Navigant) is circulating this interview guide to a limited number of manufacturers of commercial water heaters who operate in the U.S. market. Navigant will combine all the responses from individual manufacturers to protect proprietary information of any one manufacturer. Individual responses to this questionnaire and any other data provided will all be covered under a non-disclosure agreement, which Navigant will enter into with each participating manufacturer. Navigant will handle all individual company data in the strictest confidence.

The U.S. Department of Energy (DOE) is conducting a rulemaking to review the energy conservation standards for commercial water heaters. In this analysis, DOE uses publicly available information and information provided during interviews to assess possible impacts on manufacturers due to energy conservation standards. DOE began the rulemaking process with the publication of a request for information (RFI) which can be found at the following link: http://www.regulations.gov/#!documentDetail;D=EERE-2014-BT-STD-0042-0001. The RFI provides background on the history of federal commercial water heaters standards, statutory authority, rulemaking phases, and analysis conducted at each phase.

Under the current standard, covered equipment for this rulemaking includes:

Equipment type	Size	Minimum Thermal Efficiency	Maximum Standby Loss[1,2]
Electric storage water heaters	All	N/A	$0.30 + 27/V_m$ (%/hr)
Gas-fired storage water heaters	All	80%	$Q/800 + 110(V_r)^{1/2}$ (Btu/hr)
Oil-fired storage water heaters	All	78%	$Q/800 + 110(V_r)^{1/2}$ (Btu/hr)
Gas-fired instantaneous water heaters and hot water supply boilers[3]	< 10 gal	80%	N/A
	≥ 10 gal	80%	$Q/800 + 110(V_r)^{1/2}$ (Btu/hr)
Oil-fired instantaneous water heaters and hot water supply boilers[4]	< 10 gal	80%	N/A
	≥ 10 gal	78%	$Q/800 + 110(V_r)^{1/2}$ (Btu/hr)
Equipment type	**Size**	**Minimum Thermal Insulation**	
Unfired hot water storage tank	All	R-12.5	

1 KEY ISSUES

DOE is interested in understanding the impact of amended energy conservation standards on manufacturers. This section provides an opportunity for manufacturers to identify high priority issues that DOE should take into consideration.

1.1 In general, what are the key concerns for your company regarding the commercial water heaters rulemaking?

1.2 For the issues identified, how significant are they for different product classes and/or efficiency levels?

1.3 How would amended energy conservation standards affect your ability to compete in the marketplace?

2 ENGINEERING

2.1 For the NOPR analysis, DOE identified the design features in Table 2-1 as those

1 V_m is the measured storage volume, V_r is the rated volume, and Q is the nameplate input rate in Btu/hr.
2 Water heaters and hot water supply boilers having more than 140 gallons of storage capacity need not meet the standby loss requirement if (1) the tank surface area is thermally insulated to R-12.5 or more, (2) a standing pilot light is not used and (3) for gas- and oil-fired storage water heaters, they have a fire damper or a fan assisted combustion.
3 For hot water supply boilers with a capacity of less than 10 gallons: (1) the standards are mandatory for products manufactured on and after October 21, 2005, and (2) products manufactured prior to that date, and on or after October 23, 2003, must meet either the standards listed in this table or the applicable standards in subpart E of 10 CFR 431.110 for a "commercial packaged boiler."
4 Ibid.

that impact energy use and are generally incorporated into "baseline" (i.e., minimum efficiency) commercial water heaters in each equipment class with products available on the market. These features are reflected in DOE's estimates of the manufacturer production cost at the baseline efficiency levels in each product class. Please comment on the characteristics shown in Table 2-1. In addition, Table 2-2 shows the technologies currently used in products on the market that DOE identified that increase the thermal efficiency and/or reduce standby loss of commercial water heaters. Please also comment on these technologies, as well as any technologies not listed that should be included.

Table 2-1 Baseline Design Features by Product Class

Product Class	Characteristics	Manufacturer Feedback
Gas Storage	• Atmospheric vent/draft • Single-stage burner • Burner located below tank • Glass-lined steel tank • Flue tubes running length of tank • Flue baffles • Sacrificial anode rods • Polyurethane foam insulation	
Oil Storage	• Powered burner • Burner located below tank • Glass-lined steel tank • Flue tubes running length of tank • Flue baffles • Sacrificial anode rods • Polyurethane foam insulation	
Electric Storage	• Electric heating elements • Glass-lined steel tank • Sacrificial anode rods • Polyurethane foam insulation	
Gas Instantaneous	• Power vent with inducer fan (tankless only) • Copper heat exchanger	

Table 2-2 Design Features for Increasing Commercial Water Heater Efficiency (Thermal Efficiency and Standby Loss)

Technology	Design Features	Manufacturer Feedback
Gas Storage	Power Vent (to allow for increased heat exchanger/flue restriction)	
	Increased heat exchanger surface area (multiple pass or helical for condensing)	
	Thicker foam insulation	
	Concentric direct vent	
	Submerged burner	
	Premix burner	
Electric Storage	Thicker foam insulation	
	Plastic tank	
Gas Instantaneous	Concentric direct vent	
	Secondary condensing heat exchanger (stainless steel or aluminum)	
	Vent damper	

2.2 What percentages of units are sold with heat traps in each product class; are they standard in all equipment?

2.3 What percentage of gas and oil storage units are sold with flue dampers in each product class; are they standard in all equipment?

2.4 How much does a modulating burner affect the efficiency and performance of units in each relevant product class?

2.5 DOE has preliminarily chosen thermal efficiency levels to analyze for each equipment class, which are shown below. DOE chose these levels based on the most common units on the market, as found in publicly-available product databases (e.g., the AHRI certified directory of product performance). The equipment classes are divided into commercial and residential-duty commercial classes, as established by DOE in its July 2014 test procedure final rule. 79 FR 40542. No efficiency levels are shown for residential-duty gas instantaneous units because DOE has not found any such units currently on the market. The dividing criteria for commercial and residential-duty commercial units used are those specified in the July test procedure final rule and are as follows.

The uniform efficiency descriptor only applies to commercial water heaters that meet the definition of "residential-duty commercial water heater," which is defined as any gas-fired, electric, or oil storage or instantaneous commercial water heater that meets the following conditions:

(1) For models requiring electricity, uses single-phase external power supply;
(2) Is not designed to provide outlet hot water at temperatures greater than 180 °F; and

(3) Is not excluded by any of the specified limitations regarding rated input and storage volume established in Table 2-3(below). *Id.* at 40546

The input and volume limitations for the definition of a residential-duty commercial water heater are shown below by equipment class.

Table 2-3 Classification of Residential-Duty Commercial Water Heating Equipment

Water heater Type	Indicator of non-residential application
Gas-fired Storage	Rated input >105 kBtu/h; Rated storage volume >120 gallons
Oil-fired Storage	Rated input >140 kBtu/h; Rated storage volume >120 gallons
Electric Storage	Rated input >12 kW; Rated storage volume >120 gallons
Heat Pump with Storage	Rated input >12 kW; Rated current >24 A at a rated voltage of not greater than 250 V; Rated storage volume >120 gallons
Gas-fired Instantaneous	Rated input >200 kBtu/h; Rated storage volume >2 gallons
Electric Instantaneous	Rated input >58.6 kW; Rated storage volume >2 gallons
Oil-fired Instantaneous	Rated input >210 kBtu/h; Rated storage volume >2 gallons

Please provide comments on the following preliminary thermal efficiency levels for analysis, including any levels that aren't necessary or any levels missing that should be included to better represent distinctions in offerings on the market.

Table 2-4 Thermal Efficiency Levels for Commercial Gas Storage Water Heaters

Efficiency Level	Thermal Efficiency (%)	Manufacturer Feedback
EL 0 – Baseline	80	
EL 1	82	
EL 2	84	
EL 3	92	
EL 4	95	
EL 5 – Max-Tech	99	

Table 2-5 Thermal Efficiency Levels for Residential-Duty Gas Storage Water Heaters

Efficiency Level	Thermal Efficiency (%)	Manufacturer Feedback
EL 0 – Baseline	80	
EL 1	82	
EL 2	95	
EL 3 – Max-Tech	97	

Table 2-6 Thermal Efficiency Levels for Commercial and Residential-Duty Oil Storage Water Heaters

Efficiency Level	Thermal Efficiency (%)	Manufacturer Feedback
EL 0 – Baseline	80	
EL 1 – Max-Tech	82	

Table 2-7 Thermal Efficiency Levels for Commercial Gas Instantaneous Water Heaters

Efficiency Level	Thermal Efficiency (%)	Manufacturer Feedback
EL 0 – Baseline	80	
EL 1	82	
EL 2	84	
EL 3	89	
EL 4	94	
EL 5 – Max-Tech	97	

2.6 ASHRAE-90.1-2013 raised the minimum thermal efficiency standard for commercial oil storage water heaters from 78% to 80%. Will your company increase the efficiency of its units rated at 78% to meet the new standard or remove them from the market? What technology options contribute to increasing thermal efficiency of oil storage water heaters from 80% to 81% and 82%? Through a review of the published spec sheets, DOE has not been able to identify any obvious differences in equipment design at these efficiency levels.

2.7 What technology options contribute to differences among in thermal efficiency among condensing gas storage water heaters? Through review of available product databases, spec sheets, and physical examination during teardowns, DOE found that there are considerable differences in heat exchanger design; however some of the variation in thermal efficiency seemed to be related to the input rating and storage volume, as opposed to significant design differences.

2.8 What technology options contribute to differences in thermal efficiency among non-condensing and condensing gas instantaneous water heaters (within both "tankless" and "volume water heater/supply boiler" categories)? DOE found no clear trend in how heat exchanger design contributed to increasing thermal efficiency within each of these condensing or non-condensing regimes.

2.9 How does heat exchanger design vary by efficiency level for gas instantaneous units?

2.10 What are the significant design and application differences between "tankless" gas instantaneous units and "volume water heater/supply boiler" gas instantaneous water heaters? DOE notes that large "volume water heater" units are meant to be used with storage tanks and recirculation loops. Do "volume heater" style-units typically operate in applications with lower temperature rises than do tankless units? From spec sheets it appears that the larger "volume heater" units are capable of producing as high or higher temperature rises than tankless units. Are there significant differences in how each type of unit would respond to increased thermal efficiency standards? Is it reasonable that these two classes of units are grouped together for standards analysis, or are they sufficiently different that they should be analyzed in separate product classes?

2.11 Are there significant differences between "volume water heater" gas instantaneous water heaters and gas-fired hot water supply boilers, with regards to design or application? Are there significant differences in how each type of unit would respond to increased thermal efficiency standards?

2.12 Representative units were chosen for each product class by examining the most common unit ratings form the AHRI and CEC product databases. Please comment on the chosen units below, and note if there is a different unit that would be more representative of the market.

Table 2-8 Representative Unit Volume and Input Capacities for Commercial Water Heaters

Product Class	Representative Volume (gal)	Representative Input (kBTU/h)	Manufacturer Feedback
Commercial Gas Storage	100	200	
Residential-duty Gas Storage	75	76	
Commercial Oil Storage	70	200	
Commercial Electric Storage	120	TBD	
Residential-Duty Electric Storage	TBD	TBD	
Commercial Gas Instantaneous	-	200	

2.13 DOE plans to identify standby loss levels corresponding to the most common values on the market for analysis. Which values of standby loss correspond to your company's highest sale units? Are there any other design features for decreasing standby loss other than increasing tank insulation and modifying heat exchanger design? Has your company noted repeatability problems with the test procedure for standby loss? DOE notes several inconsistencies in standby loss data reported in the AHRI database for electric storage units, including values in BTU/h and %/h that don't match, and values in %/h that are far below the standard or 0.

3 COMPONENT PARTS, MATERIAL COSTS, AND FACTORY PARAMETER ASSUMPTIONS

3.1 In the following tables, we have compiled estimates for component pricing. These estimates are based on a number of different sources, most of which are not component suppliers. They are estimates and should NOT be construed as actual quotes for component and raw material prices. We are seeking feedback regarding the likely raw material and purchased part costs for parts that are utilized in your products.

Table 3-9 Gas Valves, Burners, and Ignition Elements Cost Estimates, as of 11/2014

Description	Cost ($/each)	Manufacturer Comments
Premix Gas Burner, SS tube, 75 kBTU	[redacted]	
Premix Gas Burner, SS tube, 199 kBTU		
Premix Gas Burner, SS tube, 300 kBTU		
Beckett Oil Burner Assembly		
24 V Gas Valve, up to 200 kBTU, Single Stage		
24 V Gas Valve, up to 300 kBTU, Single Stage		
24 V Gas Valve, up to 400 kBTU, Single Stage		
24 V Gas Valve, up to 400 kBTU, Modulating		
Hot Surface Igniter, Dual Rod, 115V		
Sparker rod		
Flame sensor		

Table 3-10 Fan Assemblies Cost Estimates, as of 11/2014

Description	Cost ($/each)	Manufacturer Comments
Inducer fan assembly, ECM, 250 W, 120 V	[redacted]	
Inducer fan assembly, PSC, 100 W, 120 V		

Table 3-11 Valves Cost Estimates, as of 11/2014

Description	Cost ($/each)	Manufacturer Comments
CashAcme T&P Relief Valve, ¾"Inlet	[redacted]	
Watts 140X T&P Relief Valve		
Watts 100XL T&P Relief Valve		
Sankyo Inlet water valve		
Drain valve		

Table 3-12 Probes and Sensors Cost Estimates, as of 11/2014

Description	Cost ($/each)	Manufacturer Comments
Large immersion temperature probe in well, 6"	[redacted]	
Small immersion temperature probe in well, 2"		
Bare RTD Probe		
Honeywell C6097A Gas Pressure Switch		
Cleveland Controls NS2 Gas Pressure Switch		
Condensate level switch		

Table 3-13 Misc. Parts Cost Estimates, as of 11/2014

Description	Cost ($/each)	Manufacturer Comments
Aluminum anode rod, 40"	[redacted]	
Magnesium anode rod, 48"		
Magnesium anode rod, 48"		
Powered anode rod, 50"		
Powered anode rod, 15"		
White-Rodgers dual-thermostat controller (for oil units)		
Electric flue damper assembly		
Barometric damper		
Taco 007-ST5-1 recirculation pump		
Taco IFSO1BR flow switch		
Armstrong Armflo E22.2B circulator pump		
Electric resistance heating element, 4.5 kW, 13"		

3.2 The following chart shows DOE's assumptions for raw material prices for common metals found in commercial water heaters. Please assume the delivered price at the shipping dock of your facility, inclusive of all processing costs, shipping costs, etc.

Table 3-14 Metal Raw Material Costs, as of 6/2014

Metal	Five Year Cost Avg. ($/lb 7/2009-6/2014)	Cost ($/lb) As of 6/2014	Manufacturer Feedback
Cold Rolled Steel (CRS)	[redacted]		
Hot Rolled Steel (HRS)			
Aluminized CRS			
Galvanized CRS			
Pre-Painted CRS			
Textured CRS			
Stainless Steel 304			
Stainless Steel 409			
Aluminum			
Copper			
HRS Tube			
CRS Tube			
CRS Wire			
SS304 Tube			
Plain Cu Tube, ≤0.75" OD			

3.3 For plastics, DOE notes that some parts are made in-house in a variety of injection-molding machines while many others are purchased. Please indicate what parts are typically made in-house versus those that are made by outside vendors.

In-House Parts:	Sourced Parts:

3.4 Below is an abridged table containing DOE's cost assumptions for plastic resin prices. These prices are in rail-car quantities, fully delivered to your shipping dock. Please indicate how the following prices compare to your raw material costs.

Table 3-15 Plastics Raw Material Costs, as of 6/2014

Resin	Five Year Cost Avg. ($/lb 7/2009-6/2014)	Cost ($/lb) As of 6/2014	Manufacturer Feedback
ABS	[redacted]	[redacted]	
ABS with Glass Fiber	[redacted]	[redacted]	
EPDM Rubber	[redacted]	[redacted]	
Nylon-6	[redacted]	[redacted]	
Nylon-6 with Glass Fiber	[redacted]	[redacted]	
Polypropylene (PP)	[redacted]	[redacted]	
PP with Glass Fiber	[redacted]	[redacted]	
Polystyrene (PS)	[redacted]	[redacted]	
HDPE	[redacted]	[redacted]	
LDPE	[redacted]	[redacted]	
Polybutylene	[redacted]	[redacted]	
Polycarbonate (PC)	[redacted]	[redacted]	
Polycarbonate (PC) with Glass Fiber	[redacted]	[redacted]	
Styrofoam	[redacted]	[redacted]	
Generic Ether Foam	[redacted]	[redacted]	
PVC (Hard)	[redacted]	[redacted]	
PVC (Flexible)	[redacted]	[redacted]	
High Temperature Silicone	[redacted]	[redacted]	
Silicone	[redacted]	[redacted]	
SBR Rubber (Buna)	[redacted]	[redacted]	

3.5 A single-material sourced part (such as an injection-molded name decal, for example) is assumed to cost approximately twice the raw material cost of a part made in house. For your sourced parts, how close is that assumption to actual parts costs (i.e., compare on a $/lb basis to the above raw material costs).

3.6 Below are some other raw materials on which DOE would like feedback. For cardboard and paper, please assume fully converted prices (i.e., printed, folded, etc.) delivered to your shipping dock. The fiberglass is either foil-faced or plain appliance grade.

Table 3-16 Other Raw Material Costs, as of 6/2014

Material Description	Five Year Cost Avg. ($/lb 7/2009-6/2014)	Cost ($/lb) As of 6/2014	Manufacturer Feedback
Plain Cardboard for Shipping	[redacted]	[redacted]	
2-Color Cardboard for Shipping	[redacted]	[redacted]	
Paper	[redacted]	[redacted]	
Wood for Shipping	[redacted]	[redacted]	
Fiberglass	[redacted]	[redacted]	
Foil Faced Fiberglass	[redacted]	[redacted]	
Fiberfrax	[redacted]	[redacted]	
Durafrax	[redacted]	[redacted]	
Polyurethane foam	[redacted]	[redacted]	
Enamel for lining of storage units	[redacted]	[redacted]	

3.7 DOE used information gathered from its analysis of common industry practices to formulate factory parameters for manufacturers. Please comment on the following factory parameter assumptions.

Table 3-17 Commercial Water Heater Factory Parameter Assumptions, as of 11/2014

Parameter	Estimate	Manufacturer Feedback
Actual Annual Production Volume (units/year)	[redacted]	
Work Days Per Year (days)		
Assembly Shifts Per Day (shifts)		
Fabrication Shifts Per Day (shifts)		
Fabrication Labor Wages ($/hr)		
Assembly Labor Wages ($/hr)		
Fringe Benefits Ratio		
Burdened Assembly Labor Wage ($/hr)		
Supervisor Span (workers/supervisor)		
Supervisor Wage Premium (over fabrication and assembly wage)		
Indirect to Direct Labor Ratio		
Length of Shift (hrs)		
Average Worker Downtime per shift		
Average Equipment Installation Cost (% of purchase price)		
Average Scrap Recovery Value (using base material value)		
Production Area Building Cost ($/ft^2)		
Storage Area Building Cost		
Building Life (in years)		

4 MANUFACTURER PRODUCTION COSTS

DOE will estimate the *manufacturer production costs* (MPC) of commercial water heaters for each efficiency level of each product class. DOE defines manufacturer production cost as all direct costs associated with manufacturing a product. It includes direct labor, direct materials, and overhead (including depreciation costs). The per unit production costs are necessary for DOE to estimate labor expenditures and other cash flow calculations. Shown below are tables of MPC estimates that will be developed for each thermal efficiency level of the different products classes. MPC estimates will also be made for standby loss levels once these levels are chosen.

Table 4-18 Estimated Manufacturer Production Costs (MPC's) for Commercial Gas Storage Water Heaters at 100 gal, 200 kBTU/h

Efficiency Level	Thermal Efficiency (%)	DOE's MPC Estimate (2014$)	Manufacturer Feedback
EL 0 – Baseline	80	[redacted]	
EL 1	82		
EL 2	84		
EL 3	92		
EL 4	95		
EL 5 – Max-Tech	99		

Table 4-19 Estimated Manufacturer Production Costs (MPC's) for Residential-Duty Gas Storage Water Heaters at 75 gal, 76 kBTU/h

Efficiency Level	Thermal Efficiency (%)	DOE's MPC Estimate (2014$)	Manufacturer Feedback
EL 0 – Baseline	80	[redacted]	
EL 1	82		
EL 2	95		
EL 3 – Max-Tech	97		

Table 4-20 Estimated Manufacturer Production Costs (MPC's) for Commercial Oil Storage Water Heaters at 70 gal, 200 kBTU/h

Efficiency Level	Thermal Efficiency (%)	DOE's MPC Estimate (2014$)	Manufacturer Feedback
EL 0 – Baseline	80	[redacted]	
EL 1 – Max-Tech	82		

Table 4-21 Estimated Manufacturer Production Costs (MPC's) for Commercial Gas Instantaneous Water Heaters at 250 kBTU/h

Efficiency Level	Thermal Efficiency (%)	DOE's MPC Estimate (2014$)	Manufacturer Feedback
EL 0 – Baseline	80	[redacted]	
EL 1	82		
EL 2	84		
EL 3	89		
EL 4	94		
EL 5 – Max-Tech	97		

5 COMPANY OVERVIEW AND ORGANIZATIONAL CHARACTERISTICS

5.1 Does your company have a parent company and/or any subsidiaries? If so, please provide their names.

5.2 What is your company's approximate market share in the commercial water heater market? Does this vary significantly for any particular equipment class that you manufacture?

5.3 Do you have any particular niches or relative strengths in the commercial water heater market?

5.4 What percentage of your overall revenue is from commercial water heater sales?

5.5 Who are your major competitors in the commercial water heater market and what are their approximate market shares?

5.6 What other products do you manufacture in addition to commercial water heaters? Do you produce them in the same facilities as commercial water heaters?

5.7 Where are your production facilities located, and what type of product is manufactured at each location? Please provide production figures for your company's manufacturing at each location by equipment class.

Table 5-22 Manufacturing Locations

Location	Equipment Class	Production Employees	Non-Production Employees	Units/Yr Produced

5.8 Are higher efficiency products built at different plants than lower efficiency products of the same equipment class?

6 MARKUPS AND PROFITABILITY

One of the primary objectives of the Manufacturer Impact Analysis (MIA) is to assess the impact of energy conservation standards on industry profitability. In this section, DOE would like to understand the markup structure of the industry and how setting an energy conservation standard would impact your company's markup structure and profitability.

As noted previously, DOE defines manufacturer production cost as all direct costs associated with manufacturing a product: direct labor, direct materials, and overhead (which includes depreciation).The manufacturer markup is a multiplier applied to the manufacturer production cost to cover non-production costs, such as R&D and SG&A expenses, as well as profit. It is not a profit margin. Some manufacturers also refer to this as gross margin. The manufacturer production cost multiplied by the manufacturer markup equals the manufacturer selling price. Manufacturer selling price is the price manufacturers charge their first customers, but does not include additional costs along the distribution channel.

6.1 Based on publicly-available data for commercial water heater manufacturers, DOE estimated an average markup of 1.43 for all equipment classes. Please comment on the accuracy of this figure and whether or not it varies significantly by equipment class.

Table 6-23 Commercial Water Heater Manufacturer Markup

Equipment Class	DOE Estimate Markup	Manufacturer Markup
Commercial Gas Storage	1.43	
Commercial Electric Storage	1.43	
Commercial Gas Instantaneous	1.43	
Commercial Oil Storage	1.43	
Commercial Unfired Storage Tanks	1.43	

6.2 Within each equipment class, do the per-unit markups vary by efficiency level? Is the markup on incremental costs for more efficient designs different than the markup for baseline models?

6.3 What factors besides efficiency affect markups for products that are in the same equipment class?

6.4 Would you expect energy conservation standards to affect your profitability? If so, please explain why.

7 FINANCIAL PARAMETERS

Navigant has developed a "straw man" model of financial performance called the Government Regulatory Impact Model (GRIM) using publicly available data. This section attempts to understand how your company's financial situation differs from our industry aggregate picture.

Please compare your company's financial parameters to the GRIM parameters tabulated below.

Table 7-24 Financial Parameters for Commercial Water Heater Manufacturers

GRIM Input	Definition	Industry Estimated Value	Your Actual
Income Tax Rate	Corporate effective income tax paid (percentage of earnings before taxes, EBT)	31.0%	
Discount Rate	Weighted average cost of capital (inflation-adjusted weighted average of corporate cost of debt and return on equity)	9.0%	
Working Capital	Current assets less current liabilities (percentage of revenues)	9.3%	
Net PPE	Net plant property and equipment (percentage of revenues)	20.3%	
SG&A	Selling, general, and administrative expenses (percentage of revenues)	21.6%	
R&D	Research and development expenses (percentage of revenues)	2.4%	
Depreciation	Amortization of fixed assets (percentage of revenues)	2.7%	
Capital Expenditures	Outlay of cash to acquire or improve capital assets (percentage of revenues, not including acquisition or sale of business units)	3.3%	
Cost of Goods Sold	Includes material, labor, overhead, and depreciation (percentage of revenues)	70.1%	

7.1 Are the figures in Table 7-1 representative of the commercial water heater industry as a whole? If not, why?

7.2 Do any of the financial parameters in Table 7-1 change for a particular subgroup of manufacturers? Please describe any differences.

8 SHIPMENTS PROJECTIONS AND MARKET SHARES

An amended energy conservation standard can change overall shipments by altering product attributes, marketing approaches, product availability, and price. The industry revenue calculations are based on the shipment projections developed by DOE's shipments model. The shipments model includes forecasts for the base case shipments (i.e., total industry shipments absent amended energy conservation standards) and standards case shipments (i.e., total industry shipments with amended energy conservation standards).

Below are DOE's estimates for 2013 shipments for the commercial water heater industry for each product class. These estimates are based upon information from AHRI shipment reports and the AHRI and CEC Certified Product Databases. Please comment on how well these shipment numbers represent the market. In particular, DOE notes that these may be underestimating shipments for gas and electric storage units because units marketed for residential application aren't included in AHRI commercial water heater shipment reports.

Table 8-25 Estimated 2013 Commercial Water Heater Shipments by Product Class

Product Class	2013 Unit Shipment Estimates	Manufacturer Feedback
Commercial Gas Storage	82,500	
Commercial Electric Storage	69,160	
Commercial Oil Storage	2,600	
Commercial Gas Instantaneous	35,000	
Commercial Storage Tanks	TBD	

8.1 DOE's estimate for the share of commercial gas storage water heaters that fall under the "residential-duty" classification is 17%. Please comment on how reasonable an estimate this is for the market.

8.2 Do you have sense of what fraction of purchases of residential duty commercial gas storage water heaters, as defined by DOE, currently go to residential applications (single family or multiple family residences)?

8.3 Below are DOE's estimates for share of the commercial gas storage market belonging to condensing and non-condensing units (with units greater than 86% thermal efficiency defined as condensing). Please comment on how well these estimates represent the market.

Table 8-26 Estimated Market Share for Condensing and Non-Condensing Gas Storage Water Heaters

Model Class	All Commercial	Commercial (not R-D)	Residential-Duty
Non-condensing	60%	57%	75%
Condensing	40%	43%	25%

8.4 Below are DOE's estimates of share of market shipments broken down by thermal efficiency levels. Please comment on how well these estimates represent the market.

Table 8-27 Estimated Market Share for Commercial Gas Storage Water Heaters by Thermal Efficiency Level

Thermal Efficiency Level	% of Units
80%	44
82%	10
84%	3
92%	12
95%	30
99%	1

Table 8-28 Estimated Market Share for Residential-Duty Gas Storage Water Heaters by Thermal Efficiency Level

Thermal Efficiency Level	% of Units
80%	72
82%	4
95%	20
97%	4

Table 8-29 Estimated Market Share for Commercial Gas Instantaneous Water Heaters by Thermal Efficiency Level

Thermal Efficiency Level	% of Units
80%	41
82%	20
84%	17
89%	4
94%	17
97%	1

8.5 Is a ratio of 2 commercial gas instantaneous heaters shipped for every 5 commercial gas storage units shipped a reasonable estimate for the market (this including both tankless water heaters and circulating/supply boiler type water heaters) – leading to estimate of 35,000 units shipped for 2013?

8.6 Gas instantaneous water heaters comprise a very large range of input ratings. Please comment on how well the estimates below represent the market.

Table 8-30 Estimated Market Share for Gas Instantaneous Water Heaters by Input Rating

Input Rating (kBTU/h)	% Market Share
< 200	9%
200-400	28%
400-1000	30%
1000-2000	21%
> 2000	12%

8.7 Do you have a sense of the long term (e.g. 5+ year) elasticity of commercial water heaters to increased prices (across all product classes)?

8.8 Is fuel switching in new commercial construction a significant issue that can be quantified (say for a 10% increase in installed cost of gas water heaters)? Are there particular market segments that are more susceptible than others?

8.9 Do you believe that Energy Star for commercial water heaters will drive a significant change in the commercial water heater efficiency distribution? Are there any other substantial programs, such as utility incentive programs, that significantly impact the sales of high efficiency commercial water heaters?

9 PRODUCT MIX

Product mix describes the distribution of current shipments by efficiency level. Changes in the product mix due to amended energy conservation standards can have a large impact on industry revenues. Having an accurate estimate of the current product mix allows DOE to better estimate how revenues might change due to amended energy conservation standards.

9.1 Can you provide a description of your company's product lines and their respective efficiency levels?

9.2 How would your company's equipment mix and marketing strategy change with changes in response to changes in the efficiency standards?

9.3 Would you expect your market share to change if DOE were to amend the efficiency standards?

9.4 Could amended efficiency standards disproportionately advance or harm the competitive position of some firms? If so, why

9.5 Beyond price and energy efficiency, could new standards result in equipment that will be more or less desirable to consumers or users due to changes in equipment functionality, utility, or other features?

9.6 An amended energy conservation standard affects the product mix by eliminating the sale of products below the minimum efficiency level. DOE assumes that all products that fall below the standard would roll-up to the new baseline efficiency level set by an amended energy conservation standard. DOE also assumes that the distribution of efficiencies above the efficiency level set by the energy conservation standards will not change. Please comment on these assumptions -- would amended energy conservation standards affect the sale of more efficient products above the new baseline efficiency level?

10 DISTRIBUTION CHANNELS

10.1 Please describe the distribution channel for commercial water heating equipment. Do distribution channels vary by equipment class? Do distribution channels vary between equipment sold in the replacement or new construction markets?

10.2 What is the share of equipment is sold through the replacement and new construction distribution channels respectively? Does this vary by equipment class?

11 CONVERSION COSTS

Amended energy conservation standards may cause the industry to incur conversion costs to meet the more stringent standards. The MIA considers three types of conversion costs:

- Capital conversion costs: One-time investments in plant, property, and equipment (PPE) necessitated by an energy conservation standard. These may be incremental changes to existing PPE or the replacement of existing PPE. Included are expenditures on buildings, equipment, and tooling.

- Product conversion costs: One-time investments in research, product development, testing, and marketing, as well as other costs for redesigning products necessitated by an energy conservation standard.

- Stranded assets: Assets replaced before the end of their useful lives as a direct result of amended energy conservation standards.

With a detailed understanding of the conversion costs necessitated by different standard levels, DOE can better model the impact of amended standards on the commercial water heater industry.

11.1 At your manufacturing facilities, would potential energy conservation standards be difficult to implement? If so, would your company modify existing facilities or develop new facilities?

11.2 Please provide an estimate of the capital and product conversion costs, as well as any stranded assets that might result at the various efficiency levels for each product class in the tables below. Any qualitative information you can provide about these costs will be useful in DOE's analysis as well.

Table 11-31 Conversion Costs for Commercial Gas Storage Water Heaters

Efficiency Level	Thermal Efficiency (%)	Capital Conversion Costs	Product Conversion Costs	Stranded Assets	Overview of Changes
Baseline	80				
EL 1	82				
EL 2	84				
EL 3	92				
EL 4	95				
EL 5 – Max-Tech	99				

Table 11-32 Conversion Costs for Residential-Duty Gas Storage Water Heaters

Efficiency Level	Thermal Efficiency (%)	Capital Conversion Costs	Product Conversion Costs	Stranded Assets	Overview of Changes
Baseline	80				
EL 1	82				
EL 2	95				
EL 3 – Max-Tech	97				

Table 11-33 Conversion Costs for Commercial Gas Instantaneous Water Heaters

Efficiency Level	Thermal Efficiency (%)	Capital Conversion Costs	Product Conversion Costs	Stranded Assets	Overview of Changes
Baseline	80				
EL 1	82				
EL 2	84				
EL 3	89				
EL 4	94				
EL 5 – Max-Tech	97				

Table 11-34 Conversion Costs for Commercial Oil Storage Water Heaters

Efficiency Level	Thermal Efficiency (%)	Capital Conversion Costs	Product Conversion Costs	Stranded Assets	Overview of Changes
Baseline	80				
EL 1 – Max-Tech	82				

11.3 For efficiency levels that would require new production equipment, please describe how much downtime, if any, would be required. What impact would downtime have on your business?

11.4 Please provide any additional qualitative information that might help DOE understand the type and nature of your conversion investments, including plant and tooling changes and product development efforts required for different design options.

12 CUMULATIVE REGULATORY BURDEN

Cumulative regulatory burden refers to the burden that industry faces from overlapping effects of new or revised DOE standards, and/or other regulatory actions affecting the same product or industry.

12.1 Are there other product regulations that commercial water heater manufacturers face from other federal agencies? If so, please identify the regulation and the corresponding possible effective dates for those regulations.

12.2 Are there any additional regulatory burdens that DOE should take into consideration? If so, please identify the regulation, the effective dates, and expected costs.

12.3 Under what circumstances would you be able to coordinate expenditures related to these other regulations with an energy conservation standard, thereby lessening the cumulative burden?

13 DIRECT EMPLOYMENT IMPACT ASSESSMENT

The impact of amended energy conservation standards on employment is an important consideration in the rulemaking process. This section of the interview guide seeks to explore current trends in commercial water heater production employment and solicit manufacturer views on how domestic employment patterns might be affected by energy conservation standards.

13.1 Would your domestic employment levels be expected to change significantly under amended energy conservation standards? If so, please identify particular standard levels which may trigger changes in employment.

14 CAPACITY/ OUTSOURCING/ FOREIGN COMPETITION

Disparity between domestic and foreign energy conservation standards could impact exports or imports. Labor content and material changes, resulting from energy conservation standards, may impact sourcing decisions.

14.1 Are your production lines currently running at full capacity? If not, how much excess capacity do you have available?

14.2 How would amended energy conservation standards impact your company's manufacturing capacity, in both the short term and the long term?

14.3 What percentage of your company's commercial water heater production is domestic?

14.4 Absent amended energy conservation standards, are production facilities being relocated to foreign countries?

14.5 Would amended energy conservation standards impact your domestic vs. foreign manufacturing decision?

14.6 What percentage of the U.S. market for commercial water heaters is imported?

14.7 What portion of your sales is exported?

14.8 What are the alternatives to commercial water heating equipment? Are these substitute products being imported or manufactured domestically?

15 CONSOLIDATION

Energy conservation standards can alter the competitive dynamics of the market. This can include prompting companies to enter or exit the market, or to merge. DOE and the Department of Justice are both interested in any potential reduction in competition that would result from an energy conservation standard.

15.1 Please comment on industry consolidation trends over the last 10 years.

15.2 In the absence of amended energy conservation standards, do you expect any industry consolidation?

15.3 How would industry competition change as a result of amended energy conservation standards?

15.4 To your knowledge, are there any niche manufacturers for which the adoption of amended energy conservation standards would have a particularly severe impact?

16 SMALL BUSINESS ISSUES

The Small Business Association (SBA) denotes a small business in the commercial water heater industry as having less than 1,000 employees. By this definition, is your company considered a small business?

16.1 Below is an initial list of small manufacturers of commercial water heaters. Please comment on the accuracy of the list and whether we have omitted any small businesses.

- AERCO International, Inc.
- ECR International
- Vanguard Technology, Inc
- American Standard
- Eemax
- Gasmaster Industries, Inc.
- Stiebel Eltron, Inc.
- Triangle Tube Phase III Inc.
- Ace Boiler, Inc.
- Bock Water Heaters, Inc.
- Garrison Heating and Cooling Products
- Giant Factories, Inc.
- Hamilton Engineering
- HTP, Inc.
- Intellihot Green Technologies, Inc.
- National Combustion Co. Inc.
- Burnham Holdings, Inc.
- Kemco Systems, Inc.
- Sioux Corporation
- Reco Industries, Inc.
- Luddell Manufacturing Co.
- Parker Boiler
- Precision Boilers LLC
- PVI Industries
- Quikwater, Inc.
- Thermal Engineering of Arizona
- Green Boiler Technologies
- Camus Hydronics

16.2 Are there specific manufacturers on this list that may be more severely impacted by an amended energy conservation standard than others?

16.3 Are there any reasons a small business might be at a disadvantage relative to a larger business if energy conservation standards were to be amended? Please consider factors such as technical expertise, access to capital, bulk purchasing power for materials/components, engineering resources, and any other relevant issues.

16.4 Would small business manufacturers have different incremental impacts from energy conservation standards than the rest of the industry?

APPENDIX 12B. GOVERNMENT REGULATORY IMPACT MODEL OVERVIEW

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12B.1 INTRODUCTION AND PURPOSE

The purpose of the Government Regulatory Impact Model (GRIM) is to help quantify the impacts of energy conservation standards and other regulations on manufacturers. The basic mode of analysis is to estimate the change in the value of the industry or manufacturers(s) following a regulation or a series of regulations. The model structure also allows an analysis of multiple equipment types with regulations taking effect over a period of time, and of multiple regulations on the same equipment.

Industry net present value (INPV) is defined, for the purpose of this analysis, as the discounted sum of industry free cash flows plus a discounted terminal value. The model calculates the actual cash flows by year and then determines the present value of those cash flows both without an energy conservation standard (*i.e.*, the no-new-standards case) and under different trial standard levels (*i.e.*, the standards case).

Outputs from the model consist of summary financial metrics, graphs of major variables, and, when appropriate, access to the complete cash flow calculation.

12B.2 MODEL DESCRIPTION

The basic structure of the GRIM is a standard annual cash flow analysis that uses manufacturer selling prices, manufacturing costs, a shipments forecast, and financial parameters as inputs and accepts a set of regulatory conditions as changes in costs and investments. The cash flow analysis is separated into two major blocks: income and cash flow. The income calculation determines net operating profit after taxes. The cash flow calculation converts net operating profit after taxes into an annual cash flow by including investment and non-cash items. Below are definitions of listed items on the printout of the output sheet of the GRIM.

(1) ***Revenues:*** Annual revenues, computed by multiplying equipment unit prices at each efficiency level by the appropriate manufacturer markup.

(2) ***Shipping Cost:*** Total annual shipping costs, computed by multiplying the unit shipping price for each equipment class at each efficiency level by the number of annual shipments of each equipment class at that efficiency level

(3) ***Shipments:*** Total annual shipments for the industry were obtained from the National Impact Analysis Spreadsheet.

(4) ***Revenue – Shipping:*** Annual revenues minus annual shipping costs.

(5) ***Materials:*** The portion of COGS that includes materials.

(6) ***Labor:*** The portion of cost of goods sold (COGS) that includes direct labor, commissions, dismissal pay, bonuses, vacation, sick leave, social security contributions, fringe, and assembly labor up-time.

(7) ***Depreciation:*** The portion of overhead that includes an allowance for the total amount of fixed assets used to produce that one unit. Annual depreciation is computed as a percentage of ***COGS.*** While included in overhead, the depreciation is shown as a separate line item.

(8) ***Overhead:*** The portion of COGS that includes indirect labor, indirect material, energy use, maintenance, depreciation, property taxes, and insurance related to assets. While included in overhead, the depreciation is shown as a separate line item.

(9) ***Standard SG&A:*** Selling, general, and administrative costs are computed as a percentage of ***Revenues (1)***.

(10) ***R&D:*** The GRIM separately accounts for ordinary research and development (R&D) as a percentage of ***Revenues (1)***.

(11) ***Product Conversion Costs:*** Product conversion costs are one-time investments in research, development, testing, marketing, and other costs focused on making equipment designs comply with the new energy conservation standard. The GRIM allocates these costs over the period between the standard's announcement and compliance dates.

(12) ***Stranded Assets:*** In the year the standard becomes effective, a one-time write-off of stranded assets is accounted for.

(13) ***Earnings Before Interest and Taxes (EBIT):*** Includes profits before deductions for interest paid and taxes.

(14) ***Per Unit EBIT:*** Average ***EBIT (13)*** per unit sold. Per-unit EBIT in the year after compliance is used to calibrate the standards-case markup in the preservation of per-unit operating profit markup scenario.

(15) ***EBIT/Revenues (%):*** GRIM calculates ***EBIT (13)*** as a percentage of sales to compare with the industry's average reported in financial statements.

(16) ***Taxes:*** Taxes on ***EBIT (13)*** are calculated by multiplying the tax rate listed on the Financials tab by ***EBIT (13)***.

(17) ***Net Operating Profits After Taxes (NOPAT):*** Computed by subtracting ***Cost of Goods Sold ((5) to (8))***, ***SG&A (9)***, ***R&D (10)***, ***Product Conversion Costs (11)***, and ***Taxes (16)*** from ***Revenues (1)***.

(18) ***NOPAT repeated***: NOPAT is repeated in the Statement of Cash Flows.

(19) ***Depreciation repeated***: Depreciation is added back in the Statement of Cash Flows because they are non-cash expenses.

(20) Loss on Disposal of Stranded Assets: Stranded assets are added back in the Statement of Cash Flows because they are non-cash expenses.

(21) Change in Working Capital: Change in cash tied up in accounts receivable, inventory, and other cash investments necessary to support operations is calculated by multiplying working capital (as a percentage of revenues) by the change in annual revenues.

(22) Cash Flow from Operations: Calculated by taking ***NOPAT (18)***, adding back non-cash items such as a ***Depreciation (19)***, and subtracting the ***Change in Working Capital (21)***.

(23) Ordinary Capital Expenditures: Ordinary investments in property, plant, and equipment to maintain and replace existing production assets, computed as a percentage of ***Revenues (1)***.

(24) Capital Conversion Costs: Capital conversion costs are one-time investments in property, plant, and equipment to adapt or change existing production facilities so that new equipment designs can be fabricated and assembled under the new regulation. The GRIM allocates these costs over the period between the standard's announcement and compliance dates.

(25) Free Cash Flow: Annual cash flow from operations and investments; computed by subtracting ***Ordinary Capital Expenditures (23)*** and ***Capital Conversion Costs (24)*** from ***Cash Flow from Operations (22)***.

(26) Terminal Value: Estimate of the continuing value of the industry after the analysis period. Computed by growing the Free Cash Flow at a constant rate in perpetuity.

(27) Present Value Factor: Factor used to calculate an estimate of the present value of an amount to be received in the future.

(28) Discounted Cash Flow: Free Cash Flows (25) multiplied by the ***Present Value Factor (27)***. For the final year of the analysis period, the discounted cash flow includes the discounted ***Terminal Value (26)***.

(29) INPV at TSL X: The sum of ***Discounted Cash Flows (28)***.

Table 12B.1 Detailed Cash Flow Example

Industry Income Statement (in 2014$ millions)	2014	Reference Yr 2015	Ancmt Yr 2016	2017	2018	Std Yr 2019	2020	2021	2022	2023	2024	2025	2026
Revenues	$ 310.6	$ 316.9	$ 320.5	$ 327.7	$ 336.7	$ 342.7	$ 343.1	$ 344.6	$ 348.1	$ 349.2	$ 353.7	$ 364.6	$ 372.5
Shipping Cost	10.610	10.854	11.012	11.298	11.642	11.865	11.875	11.879	11.935	11.969	12.170	12.583	12.879
Shipments	0.208	0.213	0.216	0.221	0.228	0.232	0.234	0.236	0.239	0.239	0.241	0.248	0.254
Revenue - Shipping	299.983	306.021	309.474	316.416	325.097	330.863	331.241	332.734	336.118	337.227	341.574	352.050	359.668
- Materials	$ 160.6	$ 163.9	$ 165.8	$ 169.6	$ 174.2	$ 177.3	$ 177.7	$ 178.8	$ 180.7	$ 181.2	$ 183.3	$ 188.6	$ 192.6
- Labor	$ 15.5	$ 15.8	$ 16.0	$ 16.4	$ 16.9	$ 17.2	$ 17.3	$ 17.4	$ 17.6	$ 17.6	$ 17.8	$ 18.4	$ 18.9
- Depreciation	$ 8.5	$ 8.6	$ 8.7	$ 8.9	$ 9.2	$ 9.3	$ 9.3	$ 9.4	$ 9.5	$ 9.5	$ 9.6	$ 9.9	$ 10.1
- Overhead	$ 24.4	$ 24.9	$ 25.2	$ 25.7	$ 26.5	$ 26.9	$ 26.8	$ 26.6	$ 26.8	$ 26.9	$ 27.5	$ 28.6	$ 29.3
- Standard SG&A	$ 61.9	$ 63.1	$ 63.9	$ 65.3	$ 67.1	$ 68.3	$ 68.3	$ 68.7	$ 69.4	$ 69.6	$ 70.5	$ 72.6	$ 74.2
- R&D	$ 7.4	$ 7.5	$ 7.6	$ 7.8	$ 8.0	$ 8.1	$ 8.1	$ 8.2	$ 8.3	$ 8.3	$ 8.4	$ 8.7	$ 8.8
- Product Conversion Costs	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
- Stranded Assets	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Earnings Before Interest and Taxes (EBIT)	$ 21.8	$ 22.2	$ 22.3	$ 22.8	$ 23.3	$ 23.7	$ 23.6	$ 23.7	$ 24.0	$ 24.1	$ 24.4	$ 25.2	$ 25.7
Per Unit EBIT *($/unit)*	$ 104.61	$ 104.16	$ 103.58	$ 102.91	$ 102.43	$ 101.82	$ 100.87	$ 100.19	$ 100.31	$ 100.89	$ 101.33	$ 101.45	$ 101.23
EBIT/Revenues (%)	*7.0%*	*7.0%*	*7.0%*	*6.9%*	*6.9%*	*6.9%*	*6.9%*	*6.9%*	*6.9%*	*6.9%*	*6.9%*	*6.9%*	*6.9%*
- Taxes	$ 8.0	$ 8.1	$ 8.2	$ 8.3	$ 8.5	$ 8.7	$ 8.6	$ 8.7	$ 8.8	$ 8.8	$ 8.9	$ 9.2	$ 9.4
Net Operating Profit after Taxes (NOPAT)	**$ 13.8**	**$ 14.1**	**$ 14.2**	**$ 14.4**	**$ 14.8**	**$ 15.0**	**$ 15.0**	**$ 15.0**	**$ 15.2**	**$ 15.3**	**$ 15.5**	**$ 16.0**	**$ 16.3**
Cash Flow Statement													
NOPAT	$ 13.8	$ 14.1	$ 14.2	$ 14.4	$ 14.8	$ 15.0	$ 15.0	$ 15.0	$ 15.2	$ 15.3	$ 15.5	$ 16.0	$ 16.3
+ Depreciation	$ 8.5	$ 8.6	$ 8.7	$ 8.9	$ 9.2	$ 9.3	$ 9.3	$ 9.4	$ 9.5	$ 9.5	$ 9.6	$ 9.9	$ 10.1
+ Loss on Disposal of Stranded Assets	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
- Change in Working Capital	$ -	$ 0.5	$ 0.3	$ 0.6	$ 0.8	$ 0.5	$ 0.0	$ 0.1	$ 0.3	$ 0.1	$ 0.4	$ 0.9	$ 0.7
Cash Flows from Operations	$ 22.3	$ 22.1	$ 22.6	$ 22.7	$ 23.2	$ 23.8	$ 24.3	$ 24.3	$ 24.4	$ 24.7	$ 24.7	$ 25.0	$ 25.8
- Ordinary Capital Expenditures	$ 9.5	$ 9.7	$ 9.8	$ 10.1	$ 10.3	$ 10.5	$ 10.5	$ 10.6	$ 10.7	$ 10.7	$ 10.9	$ 11.2	$ 11.4
- Capital Conversion Costs	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Free Cash Flow	**$ 12.7**	**$ 12.4**	**$ 12.7**	**$ 12.7**	**$ 12.8**	**$ 13.3**	**$ 13.7**	**$ 13.7**	**$ 13.7**	**$ 14.0**	**$ 13.9**	**$ 13.8**	**$ 14.3**
Discounted Cash Flow													
Free Cash Flow	$ 12.7	$ 12.4	$ 12.7	$ 12.7	$ 12.8	$ 13.3	$ 13.7	$ 13.7	$ 13.7	$ 14.0	$ 13.9	$ 13.8	$ 14.3
Terminal Value	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Present Value Factor	*0.000*	*1.000*	*0.917*	*0.841*	*0.771*	*0.708*	*0.648*	*0.594*	*0.544*	*0.499*	*0.458*	*0.420*	*0.385*
Discounted Cash Flow	**$ -**	**$ 12.4**	**$ 11.7**	**$ 10.6**	**$ 9.9**	**$ 9.4**	**$ 8.9**	**$ 8.1**	**$ 7.5**	**$ 7.0**	**$ 6.3**	**$ 5.8**	**$ 5.5**
INPV at Baseline	**$ 176.2**												
Net PPE	$ 54.2	$ 55.3	$ 56.4	$ 57.6	$ 58.7	$ 59.9	$ 61.1	$ 62.3	$ 63.5	$ 64.7	$ 66.0	$ 67.2	$ 68.5
Net PPE as % of Sales	17.5%	17.5%	17.6%	17.6%	17.4%	17.5%	17.8%	18.1%	18.3%	18.5%	18.6%	18.4%	18.4%
Net Working Capital	$ 26.5	$ 27.1	$ 27.4	$ 28.0	$ 28.8	$ 29.3	$ 29.3	$ 29.4	$ 29.7	$ 29.8	$ 30.2	$ 31.1	$ 31.8
Return on Invested Capital (ROIC)	17.11%	17.06%	16.90%	16.86%	16.89%	16.81%	16.55%	16.36%	16.28%	16.14%	16.10%	16.23%	16.26%
Weighted Average Cost of Capital (WACC)	9.08%	9.08%	9.08%	9.08%	9.08%	9.08%	9.08%	9.08%	9.08%	9.08%	9.08%	9.08%	9.08%
Return on Sales (EBIT/Sales)	7.02%	7.00%	6.97%	6.94%	6.92%	6.90%	6.88%	6.87%	6.88%	6.90%	6.90%	6.91%	6.91%

This tab computes key parameters from an income statement based on unit sales, revenues and COGS, and initial financial inputs (parameters as a % of revenue). It also computes an INPV based on a discounted cash flow model.

CHAPTER 13. EMISSIONS IMPACT ANALYSIS

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CHAPTER 13. EMISSIONS IMPACT ANALYSIS

13.1 INTRODUCTION

The emissions analysis consists of two components. The first component estimates the effect of potential energy conservation standards on power sector emissions of carbon dioxide (CO_2), nitrogen oxides (NO_X), sulfur dioxide (SO_2), and mercury (Hg). The second component estimates the impacts of a potential standard on emissions of two additional greenhouse gases, methane (CH_4) and nitrous oxide (N_2O), as well as the reductions to emissions of all species due to "upstream" activities in the fuel production chain. These upstream activities comprise extraction, processing, and transporting fuels to the site of combustion. The associated emissions are referred to as upstream emissions. Together, these emissions account for the full-fuel-cycle (FFC), in accordance with the U.S. Department of Energy's (DOE's) FFC Statement of Policy. 76 FR 51282 (Aug. 18, 2011).

The analysis of power sector emissions uses marginal emissions intensity factors calculated by DOE. As of 2014, DOE is using a new methodology based on results published for the *Annual Energy Outlook 2015* (*AEO2015*) Reference case and a set of side cases that implement a variety of efficiency-related policies.[1] The new methodology is described in chapter 15 of this TSD and in the report "Utility Sector Impacts of Reduced Electricity Demand" (Coughlin 2014).[2] For site combustion of natural gas or petroleum fuels, the combustion emissions of CH_4 and N_2O are estimated using emissions intensity factors from a publication of the Environmental Protection Agency (EPA).[3]

The emissions intensity factors are expressed in terms of physical units per megawatt hour (MWh) or million British thermal units (MMBtu) of site energy savings. Total emissions reductions are estimated by multiplying the emissions intensity factor by the energy savings calculated in the national impact analysis (chapter 10 of this TSD). This chapter presents the results of the emissions analysis. The emissions factors used in the calculations are provided in appendix 13A of this TSD. For power sector emissions, the factors depend on the sector and end use. The results presented here use factors from residential and commercial water heating.

13.2 AIR QUALITY REGULATIONS AND EMISSIONS IMPACTS

Each annual version of the Annual Energy Outlook (AEO) incorporates the projected impacts of existing air quality regulations on emissions. *AEO2015* generally represents current Federal and State legislation and final implementation regulations in place as of the end of October 2014.

SO_2 emissions from affected electric generating units (EGUs) are subject to nationwide and regional emissions cap and trading programs. Title IV of the Clean Air Act sets an annual emissions cap on SO_2 for affected EGUs in the 48 contiguous states and the District of Columbia (D.C.). SO_2 emissions from 28 eastern states and D.C. were also limited under the Clean Air Interstate Rule (CAIR), which created an allowance-based trading program that that operates along with the Title IV program in those States and D.C. 70 FR 25162 (May 12, 2005). CAIR was remanded to EPA by the U.S. Court of Appeals for the District of Columbia Circuit (D.C.

Circuit) but parts of it remained in effect. On July 6, 2011 EPA issued a replacement for CAIR, the Cross-State Air Pollution Rule (CSAPR). 76 FR 48208 (August 8, 2011). On August 21, 2012, the D.C. Circuit issued a decision to vacate CSAPR. See EME Homer City Generation, LP v. EPA, 696 F.3d 7, 38 (D.C. Cir. 2012). The court ordered EPA to continue administering CAIR. The *AEO2015* emissions factors used for the present analysis assume that CAIR remains a binding regulation through 2040.[a]

The attainment of emissions caps is typically flexible among affected EGUs and is enforced through the use of emissions allowances and tradable permits. Under existing EPA regulations, any excess SO_2 emissions allowances resulting from the lower electricity demand caused by the imposition of an efficiency standard could be used to permit offsetting increases in SO_2 emissions by any regulated EGU. In past rulemakings, DOE recognized that there was uncertainty about the effects of efficiency standards on SO_2 emissions covered by the existing cap-and-trade system, but it concluded that no reductions in power sector emissions would occur for SO_2 as a result of standards.

Beginning in 2016, however, SO_2 emissions will fall as a result of the Mercury and Air Toxics Standards (MATS) for power plants. 77 FR 9304 (Feb. 16, 2012).[b] In the final MATS rule, EPA established a standard for hydrogen chloride as a surrogate for acid gas hazardous air pollutants (HAP), and also established a standard for SO_2 (a non-HAP acid gas) as an alternative equivalent surrogate standard for acid gas HAP. The same controls are used to reduce HAP and non-HAP acid gas; thus, SO_2 emissions will be reduced as a result of the control technologies installed on coal-fired power plants to comply with the MATS requirements for acid gas. *AEO2015* assumes that, in order to continue operating, coal plants must have either flue gas desulfurization or dry sorbent injection systems installed by 2016. Both technologies, which are used to reduce acid gas emissions, also reduce SO_2 emissions. Under the MATS, NEMS shows a reduction in SO_2 emissions when electricity demand decreases (*e.g.,* as a result of energy efficiency standards). Emissions will be far below the cap established by CAIR, so it is unlikely that excess SO_2 emissions allowances resulting from the lower electricity demand would be

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[a] On April 29, 2014, the U.S. Supreme Court reversed the judgment of the D.C. Circuit and remanded the case for further proceedings consistent with the Supreme Court's opinion. The Supreme Court held in part that EPA's methodology for quantifying emissions that must be eliminated in certain states due to their impacts in other downwind states was based on a permissible, workable, and equitable interpretation of the Clean Air Act provision that provides statutory authority for CSAPR. See *EPA v. EME Homer City Generation*, No 12-1182, slip op. at 32 (U.S. April 29, 2014). On October 23, 2014, the D.C. Circuit lifted the stay of CSAPR and CSAPR went into effect (and the CAIR sunset) in January 1, 2015. On July 28, 2015, the D.C. Circuit issued its opinion regarding CSAPR on remand from the Supreme Court. The court largely upheld CSAPR, but remanded to EPA without vacateur certain states' emissions budgets for reconsideration. The difference between CAIR and CSAPR is not relevant for the purpose of DOE's analysis of SO_2 emissions.
[b] On July 20, 2012, EPA announced a partial stay, for a limited duration, of the effectiveness of national new source emission standards for hazardous air pollutants from coal- and oil-fired electric utility steam generating units. www.reginfo.gov/public/do/eAgendaViewRule?pubId=201110&RIN=2060-AP52

needed or used to permit offsetting increases in SO_2 emissions by any regulated EGU. Therefore, DOE believes that efficiency standards will reduce SO_2 emissions in 2016 and beyond.[c]

CAIR established a cap on NO_X emissions in 28 eastern states and D.C. Energy conservation standards are expected to have little effect on NO_X emissions in those states covered by CSAPR because excess NO_X emissions allowances resulting from the lower electricity demand could be used to permit offsetting increases in NO_X emissions. However, standards would be expected to reduce NO_X emissions in the states not affected by CAIR, so DOE estimated NO_X emissions reductions from potential standards for those states.

The MATS limit Hg emissions from power plants, but they do not include emissions caps and, as such, DOE's energy conservation standards would likely reduce Hg emissions. DOE estimated marginal Hg emissions reductions using the Reference case and side cases published with *AEO2015*, which incorporate the MATS.

13.3 EMISSIONS IMPACT RESULTS

Table 13.3.1 presents the estimated cumulative emissions reductions for the lifetime of equipment sold in 2019 - 2048 for each trial standard level (TSL).

[c] DOE notes that the Supreme Court recently remanded EPA's 2012 rule regarding national emission standards for hazardous air pollutants from certain electric utility steam generating units. See Michigan v. EPA (Case No. 14-46, 2015). DOE has tentatively determined that the remand of the MATS rule does not change the assumptions regarding the impact of energy efficiency standards on SO_2 emissions. Further, while the remand of the MATS rule may have an impact on the overall amount of mercury emitted by power plants, it does not change the impact of the energy efficiency standards on mercury emissions. DOE will continue to monitor developments related to this case and respond to them as appropriate.

Table 13.3.1 Cumulative Emissions Reduction for Potential Standards for Commercial Water Heating Equipment

Emissions	TSL			
	1	**2**	**3**	**4**
Power Sector and Site Emissions				
CO_2 (*million metric tons*)	22.1	68.3	85.4	104
NO_X (*thousand tons*)	30.3	96.6	121	148
Hg (*tons*)	0.01	0.004	0.004	0.005
N_2O (*thousand tons*)	0.08	0.16	0.20	0.24
CH_4 (*thousand tons*)	0.66	1.52	1.89	2.30
SO_2 (*thousand tons*)	2.02	1.36	1.57	1.82
Upstream Emissions				
CO_2 (*million metric tons*)	2.93	9.74	12.2	14.9
NO_X (*thousand tons*)	46.6	156	195	239
Hg (*tons*)	0.0001	0.00004	0.00004	0.00005
N_2O (*thousand tons*)	0.01	0.02	0.02	0.03
CH_4 (*thousand tons*)	279	934	1,170	1,432
SO_2 (*thousand tons*)	0.05	0.06	0.08	0.09
Total Emissions				
CO_2 (*million metric tons*)	25.1	78.1	97.6	119
NO_X (*thousand tons*)	76.9	252	316	386
Hg (*tons*)	0.01	0.004	0.004	0.005
N_2O (*thousand tons*)	0.08	0.18	0.22	0.26
CH_4 (*thousand tons*)	279	936	1,172	1,434
SO_2 (*thousand tons*)	2.07	1.42	1.65	1.91

Figure 13.3.1 through Figure 13.3.6 show the annual reductions for total emissions for each type of emission from each TSL. The reductions reflect the lifetime impacts of equipment sold in 2019-2048.

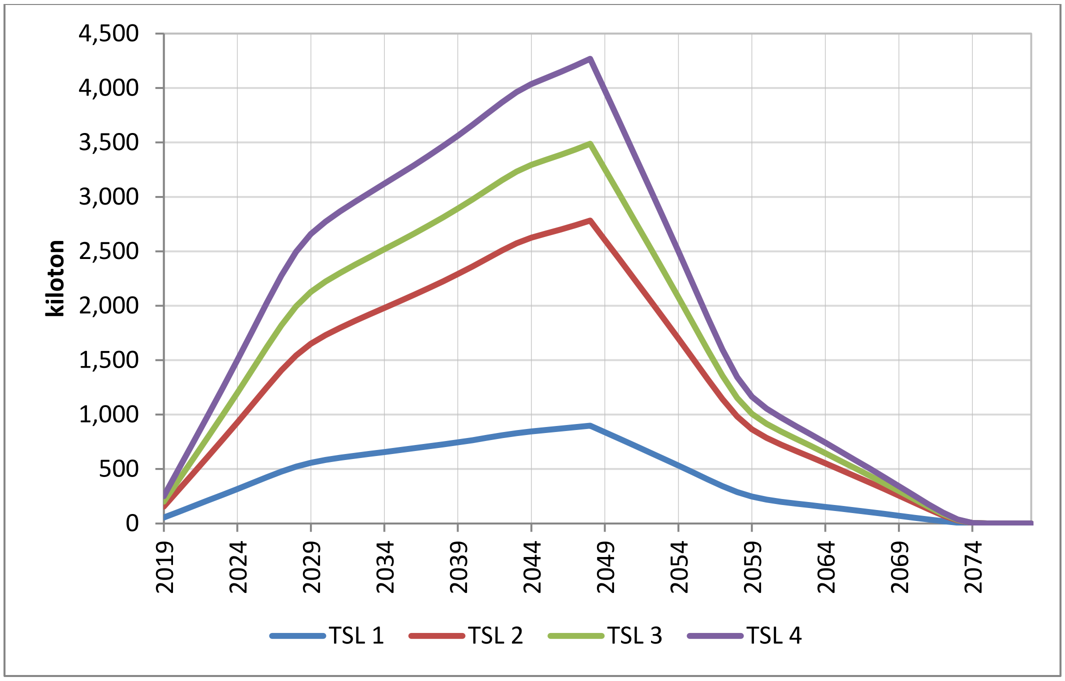

Figure 13.3.1 Commercial Water Heating Equipment: CO_2 Total Emissions Reduction

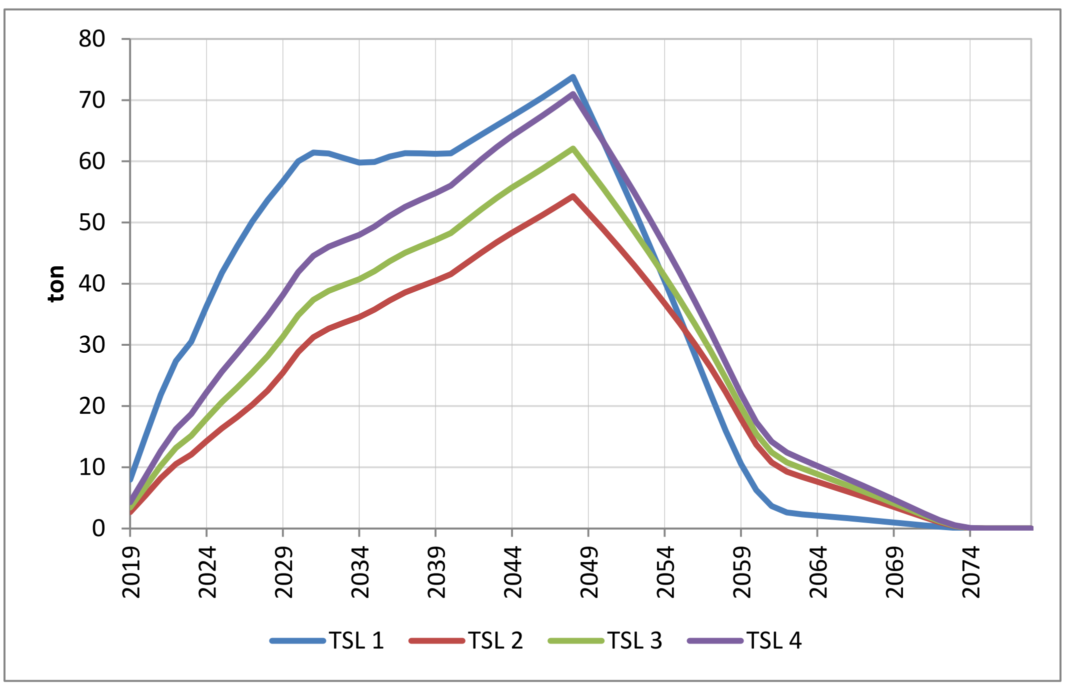

Figure 13.3.2 Commercial Water Heating Equipment: SO_2 Total Emissions Reduction

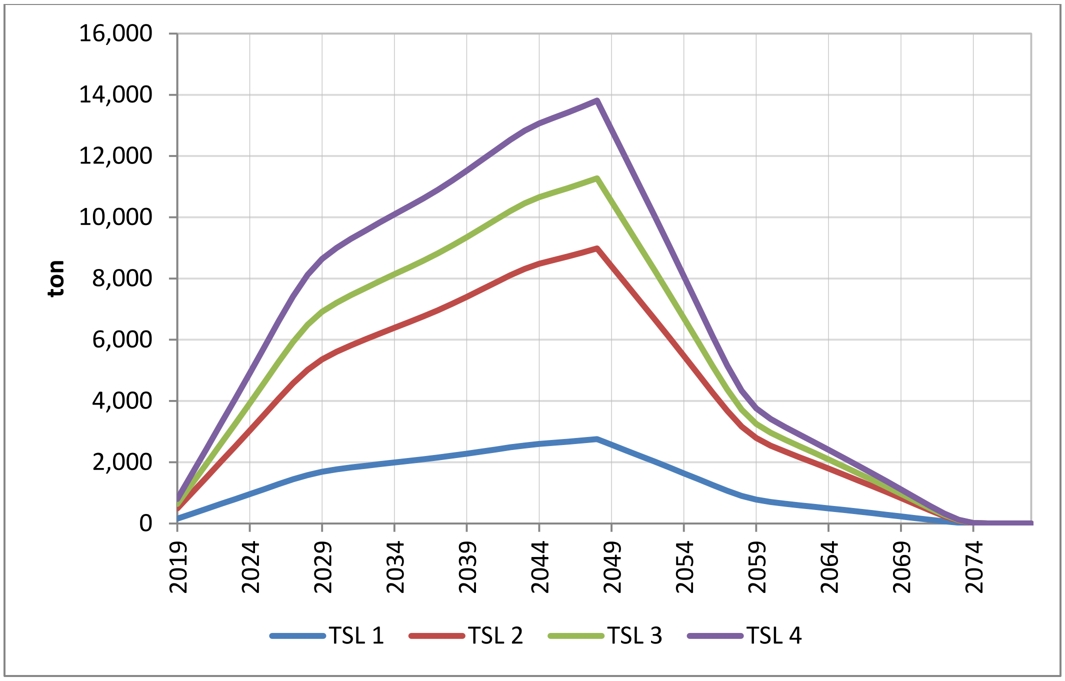

Figure 13.3.3 Commercial Water Heating Equipment: NO_X Total Emissions Reduction

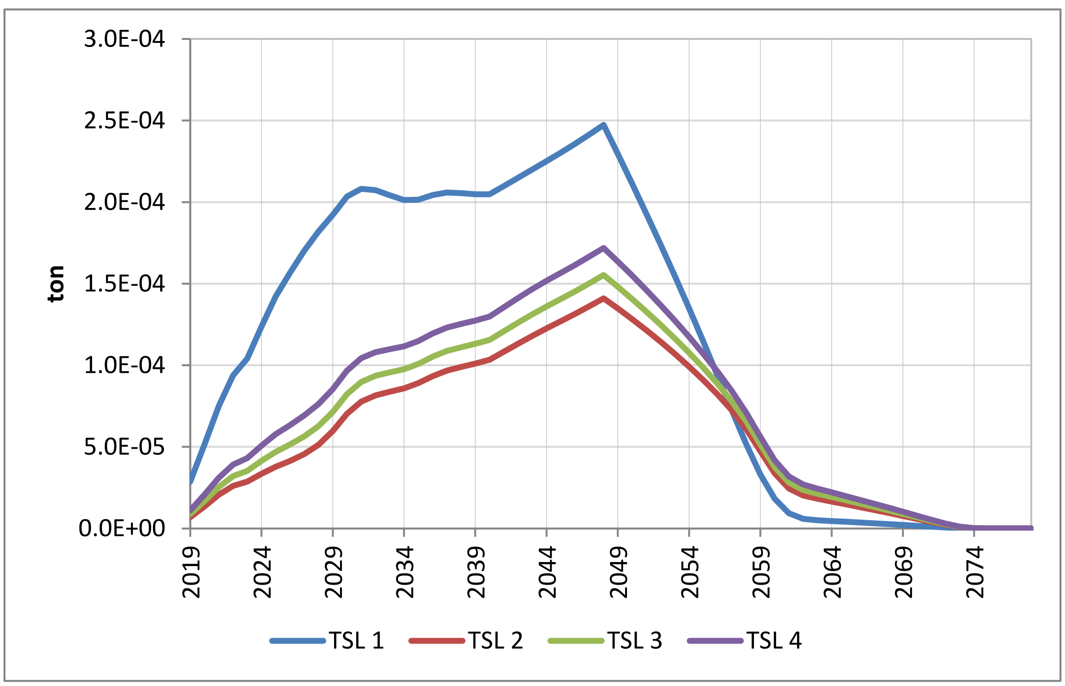

Figure 13.3.4 Commercial Water Heating Equipment: Hg Total Emissions Reduction

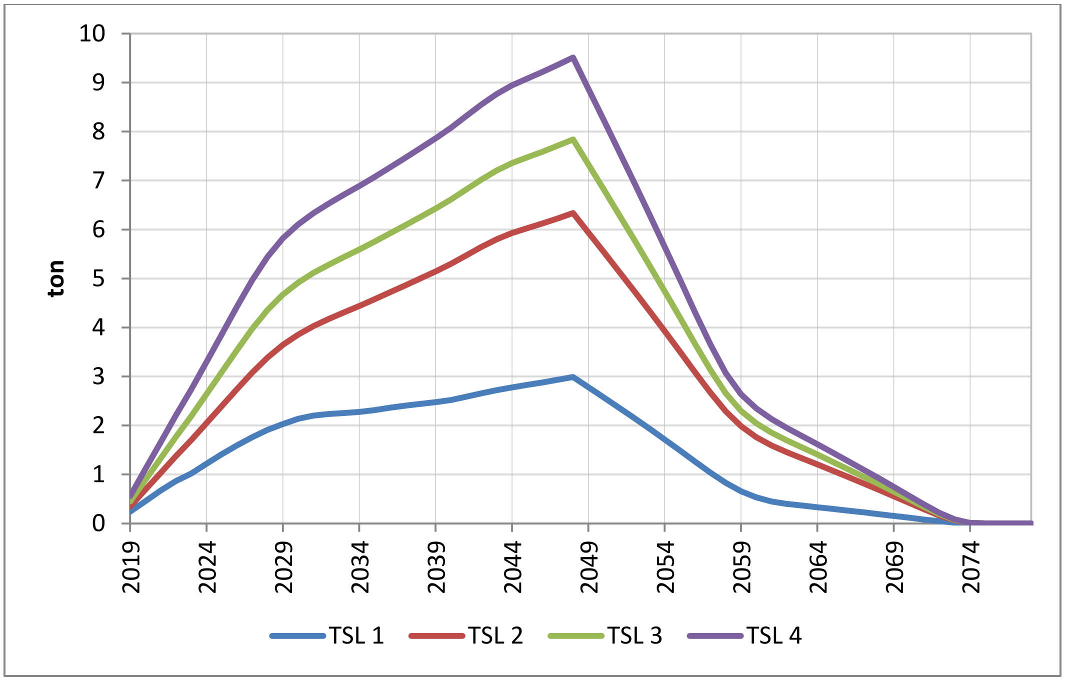

Figure 13.3.5 Commercial Water Heating Equipment: N_2O Total Emissions Reduction

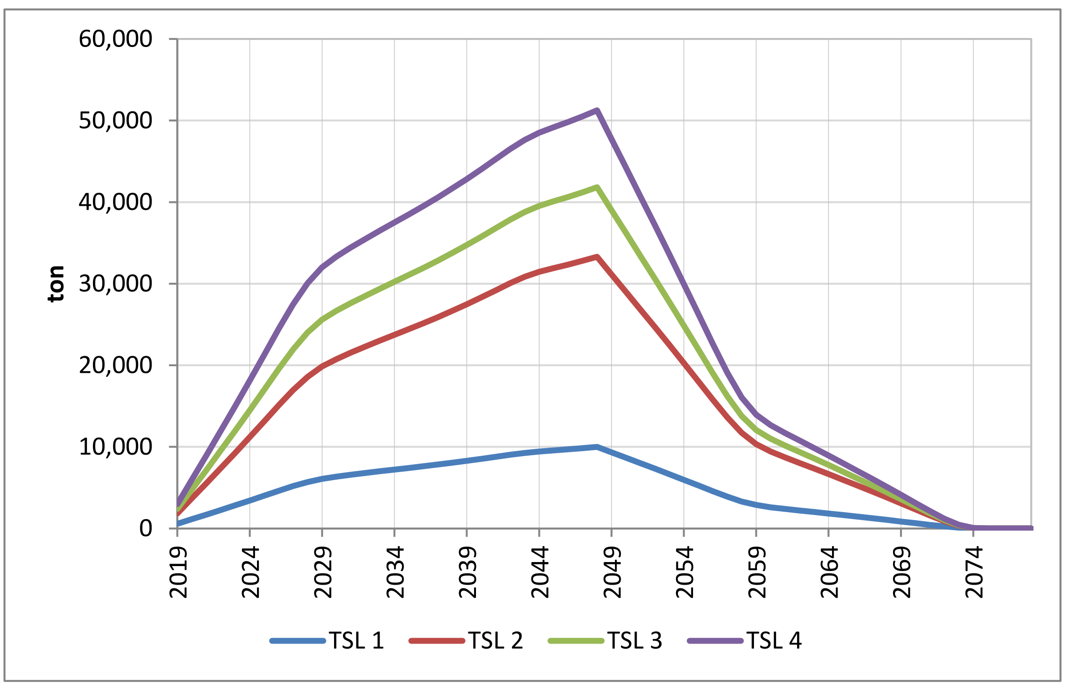

Figure 13.3.6 Commercial Water Heating Equipment: CH_4 Total Emissions Reduction

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2. Coughlin, K. *Utility Sector Impacts of Reduced Electricity Demand*. 2014. Lawrence Berkeley National Laboratory: Berkeley, CA. LBNL-6864E. Available at www.osti.gov/scitech/servlets/purl/1165372.

3. U.S. Environmental Protection Agency, *Compilation of Air Pollutant Emission Factors, AP-42, Fifth Edition, Volume I: Stationary Point and Area Sources*. 1998. Available at www.epa.gov/ttn/chief/ap42/index.html.

APPENDIX 13A. EMISSIONS ANALYSIS METHODOLOGY

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APPENDIX 13A. EMISSIONS ANALYSIS METHODOLOGY

13A.1 INTRODUCTION

The emissions analysis consists of two components. The first component estimates the effect of potential energy conservation standards on power sector and site combustion emissions of carbon dioxide (CO_2), nitrogen oxides (NO_X), sulfur dioxide (SO_2) and mercury (Hg). The second component estimates the impacts of a potential standard on emissions of two additional greenhouse gases, methane (CH_4) and nitrous oxide (N_2O), as well as the reductions to emissions of all species due to "upstream" activities in the fuel production chain. These upstream activities comprise extraction, processing, and transporting fuels to the site of combustion. The associated emissions are referred to as upstream emissions. Together, these emissions account for the full-fuel-cycle (FFC), in accordance with DOE's FFC Statement of Policy. 76 FR 51282 (Aug. 18, 2011).

The analysis of power sector emissions uses marginal emissions intensity factors calculated by DOE. As of 2014, DOE uses a methodology based on results published with the most recent edition of the *Annual Energy Outlook* (*AEO*), which is published by the Energy Information Agency (EIA). For this analysis DOE used the version published in May 2015 (*AEO2015*).[1] The *AEO* includes a Reference case and a set of side cases that implement a variety of economic and policy scenarios. In 2015 the EIA announced the adoption of a 2-year release cycle for the *AEO*, alternating between a full set of scenarios and a shorter edition containing only five alternate scenarios. As the *AEO2015* is a shorter edition, DOE has adapted its calculation methodology accordingly.

DOE developed end-use specific emissions intensity coefficients, in units of mass of pollutant per kilowatt hour (kWh) of site electricity, for each pollutant. The methodology is based on the more general approach used for all the utility sector impacts calculations, which is described in appendix 15A of this TSD and in the report *Utility Sector Impacts of Reduced Electricity Demand* (Coughlin 2014).[2] This appendix describes the methodology used to estimate the upstream emissions factors and presents the values used for all emissions factors.

13A.2 POWER SECTOR AND SITE EMISSIONS FACTORS

Power sector marginal emissions factors are calculated by looking at the difference, over the full analysis period, between the *AEO* Reference case and the policy side cases. The analysis produces a set of emissions intensity factors that quantify the reduction in emissions of a given pollutant per unit reduction of site consumption of electricity. Distinct factors are calculated for the residential and commercial sectors, and for each of the end uses that are modeled explicitly in the National Energy Modeling System (NEMS) as listed in the tables in this appendix. Total emissions reductions are estimated by multiplying the intensity factors times the energy savings calculated in the national impact analysis (chapter 10). Power sector emissions factors are presented in Table 13A.4.2 through Table 13A.4.7.

Site combustion of fossil fuels in buildings (for example in water-heating, space-heating or cooking applications) also produces emissions of CO_2 and other pollutants. To quantify the reduction in these emissions from a considered standard level, DOE used emissions factors published by the U.S. Environmental Protection Agency (EPA),[3] which are constant in time. These factors are presented in Table 13A.4.1.

13A.3 UPSTREAM FACTORS

The FFC upstream emissions are estimated based on the methodology developed by Coughlin (2013).[4] The upstream emissions include both emissions from fuel combustion during extraction, processing, and transportation of fuel, and "fugitive" emissions (direct leakage to the atmosphere) of CH_4 and CO_2.

The FFC accounting approach is described briefly in appendix 10D and in Coughlin (2013).[4] When demand for a particular fuel is reduced, there is a corresponding reduction in the upstream activities associated with production of that fuel (mining, refining etc.) These upstream activities also consume energy and therefore produce combustion emissions. The FFC accounting estimates the total consumption of electricity, natural gas, and petroleum-based fuels in these upstream activities. The relevant combustion emissions factors are then applied to this fuel use to determine the total upstream emissions intensities from combustion, per unit of fuel delivered to the consumer.

In addition to combustion emissions, extraction and processing of fossil fuels also produce fugitive emissions of CO_2 and CH_4. Fugitive emissions of CO_2 are small relative to combustion emissions, comprising about 2–3 percent of total CO_2 emissions for natural gas and 1–2 percent for petroleum fuels. In contrast, the fugitive emissions of methane from fossil fuel production are relatively large compared to combustion emissions of CH_4. Hence, fugitive emissions make up over 99 percent of total methane emissions for natural gas, about 95 percent for coal, and 93 percent for petroleum fuels.

Fugitive emissions factors for CO_2 and methane from coal mining and natural gas production were estimated based on a review of recent studies compiled by Burnham (2011).[5] This review includes estimates of the difference between fugitive emissions factors for conventional production of natural vs. unconventional (shale or tight gas). These estimates rely in turn on data gathered by EPA under new greenhouse gas (GHG) reporting requirements for the petroleum and natural gas industries.[6,7] As more data are made available, DOE will continue to update these estimated emissions factors.

Upstream emissions factors account for both fugitive emissions and combustion emissions in extraction, processing, and transport of primary fuels. For ease of application in its analysis, DOE developed all of the emissions factors using site (point of use) energy savings in the denominator. Table 13A.4.8 presents the electricity upstream emissions factors for selected years. The caps that apply to power sector NO_X emissions do not apply to upstream combustion sources, so some components of the upstream fuel cycle (particularly off-road mobile engines) can contribute significantly to the upstream NO_X emissions factors.

13A.4 DATA TABLES

Summary tables of all the emissions factor data used by DOE for rules using *AEO2015* are presented in the tables in this appendix. Table 13A.4.1 provides combustion emissions factors for fuels commonly used in buildings. Table 13A.4.2 through Table 13A.4.7 present the marginal power sector emissions factors as a function of sector and end use for a selected set of years. Table 13A.4.8 through Table 13A.4.10 provide the upstream emissions factors for all pollutants, for site electricity, natural gas, and petroleum fuels. In all cases, the emissions factors are defined relative to site use of the fuel.

Table 13A.4.1 Site Combustion Emissions Factors

Species	Natural Gas *lb/Mmcf*	Distillate Oil *lb/1000 gal*	Propane *lb/1000 gal*	Kerosene *lb/1000 gal*
CO_2	1.20E+05	2.25E+04	1.25E+04	2. 24E+04
SO_2	6.00E-01	142×(S)	0.1×(S)	142×(S)
NO_X	9.60E+01	1.90E+01	1.40E+01	1.80E+01
N_2O	2.20E+00	1.76E-01	1.10E-01	1.76E-01
CH_4	2.30E+00	9.04E-01	5.95E-01	9.04E-01

Table 13A.4.2 Power Sector Emissions Factors for CO_2 (Tons of CO_2 per kWh of Site Electricity Use)

End Use	2020	2025	2030	2035	2040
Commercial Sector					
Cooking	8.06E-04	7.24E-04	6.57E-04	6.05E-04	5.54E-04
Lighting	8.10E-04	7.27E-04	6.59E-04	6.07E-04	5.55E-04
Office Equipment (Non-PC)	7.94E-04	7.15E-04	6.49E-04	5.98E-04	5.49E-04
Office Equipment (PC)	7.94E-04	7.15E-04	6.49E-04	5.98E-04	5.49E-04
Other Uses	7.99E-04	7.19E-04	6.52E-04	6.01E-04	5.51E-04
Refrigeration	8.24E-04	7.37E-04	6.68E-04	6.14E-04	5.61E-04
Space Cooling	7.85E-04	7.07E-04	6.42E-04	5.93E-04	5.46E-04
Space Heating	8.34E-04	7.45E-04	6.76E-04	6.20E-04	5.65E-04
Ventilation	8.24E-04	7.38E-04	6.69E-04	6.14E-04	5.61E-04
Water Heating	8.12E-04	7.29E-04	6.61E-04	6.08E-04	5.56E-04
Industrial Sector					
All Uses	7.99E-04	7.19E-04	6.52E-04	6.01E-04	5.51E-04
Residential Sector					
Clothes Dryers	8.12E-04	7.29E-04	6.61E-04	6.08E-04	5.56E-04
Cooking	8.05E-04	7.23E-04	6.57E-04	6.04E-04	5.52E-04
Freezers	8.23E-04	7.37E-04	6.68E-04	6.14E-04	5.61E-04
Lighting	8.23E-04	7.37E-04	6.69E-04	6.14E-04	5.60E-04
Other Uses	8.11E-04	7.28E-04	6.61E-04	6.08E-04	5.55E-04
Refrigeration	8.22E-04	7.36E-04	6.68E-04	6.13E-04	5.61E-04
Space Cooling	7.86E-04	7.09E-04	6.43E-04	5.94E-04	5.46E-04
Space Heating	8.31E-04	7.43E-04	6.74E-04	6.18E-04	5.63E-04
Water Heating	8.13E-04	7.30E-04	6.62E-04	6.09E-04	5.56E-04

Table 13A.4.3 Power Sector Emissions Factors for Hg (tons/TWh)

End Use	2020	2025	2030	2035	2040
Commercial Sector					
Cooking	2.14E-03	1.67E-03	1.40E-03	1.18E-03	1.05E-03
Lighting	2.15E-03	1.68E-03	1.41E-03	1.19E-03	1.06E-03
Office Equipment (Non-PC)	2.06E-03	1.61E-03	1.36E-03	1.14E-03	1.01E-03
Office Equipment (PC)	2.06E-03	1.61E-03	1.36E-03	1.14E-03	1.01E-03
Other Uses	2.09E-03	1.63E-03	1.37E-03	1.15E-03	1.03E-03
Refrigeration	2.23E-03	1.74E-03	1.47E-03	1.23E-03	1.10E-03
Space Cooling	1.97E-03	1.54E-03	1.30E-03	1.08E-03	9.69E-04
Space Heating	2.31E-03	1.80E-03	1.52E-03	1.27E-03	1.14E-03
Ventilation	2.24E-03	1.75E-03	1.47E-03	1.23E-03	1.10E-03
Water Heating	2.16E-03	1.69E-03	1.42E-03	1.19E-03	1.07E-03
Industrial Sector					
All Uses	2.09E-03	1.63E-03	1.37E-03	1.15E-03	1.03E-03
Residential Sector					
Clothes Dryers	2.18E-03	1.70E-03	1.43E-03	1.20E-03	1.07E-03
Cooking	2.15E-03	1.68E-03	1.41E-03	1.18E-03	1.06E-03
Freezers	2.23E-03	1.74E-03	1.46E-03	1.23E-03	1.10E-03
Lighting	2.25E-03	1.76E-03	1.48E-03	1.24E-03	1.11E-03
Other Uses	2.18E-03	1.70E-03	1.43E-03	1.20E-03	1.07E-03
Refrigeration	2.22E-03	1.74E-03	1.46E-03	1.23E-03	1.10E-03
Space Cooling	1.99E-03	1.55E-03	1.31E-03	1.09E-03	9.77E-04
Space Heating	2.30E-03	1.79E-03	1.51E-03	1.27E-03	1.13E-03
Water Heating	2.20E-03	1.72E-03	1.44E-03	1.21E-03	1.08E-03

Table 13A.4.4 Power Sector Emissions Factors for NO_X (tons/MWh)

End Use	2020	2025	2030	2035	2040
Commercial Sector					
Cooking	7.24E-04	6.91E-04	6.44E-04	6.11E-04	5.64E-04
Lighting	7.26E-04	6.92E-04	6.46E-04	6.12E-04	5.65E-04
Office Equipment (Non-PC)	7.20E-04	6.88E-04	6.42E-04	6.10E-04	5.63E-04
Office Equipment (PC)	7.20E-04	6.88E-04	6.42E-04	6.10E-04	5.63E-04
Other Uses	7.22E-04	6.89E-04	6.43E-04	6.10E-04	5.64E-04
Refrigeration	7.32E-04	6.96E-04	6.49E-04	6.15E-04	5.66E-04
Space Cooling	7.22E-04	6.88E-04	6.41E-04	6.10E-04	5.67E-04
Space Heating	7.33E-04	6.97E-04	6.51E-04	6.16E-04	5.64E-04
Ventilation	7.32E-04	6.96E-04	6.49E-04	6.15E-04	5.66E-04
Water Heating	7.28E-04	6.93E-04	6.46E-04	6.13E-04	5.65E-04
Industrial Sector					
All Uses	7.22E-04	6.89E-04	6.43E-04	6.10E-04	5.64E-04
Residential Sector					
Clothes Dryers	7.24E-04	6.91E-04	6.45E-04	6.12E-04	5.63E-04
Cooking	7.20E-04	6.88E-04	6.43E-04	6.10E-04	5.61E-04
Freezers	7.32E-04	6.96E-04	6.49E-04	6.15E-04	5.66E-04
Lighting	7.28E-04	6.94E-04	6.48E-04	6.14E-04	5.63E-04
Other Uses	7.23E-04	6.90E-04	6.45E-04	6.11E-04	5.62E-04
Refrigeration	7.31E-04	6.96E-04	6.49E-04	6.15E-04	5.66E-04
Space Cooling	7.22E-04	6.88E-04	6.41E-04	6.10E-04	5.66E-04
Space Heating	7.31E-04	6.96E-04	6.50E-04	6.15E-04	5.64E-04
Water Heating	7.23E-04	6.90E-04	6.44E-04	6.11E-04	5.61E-04

Table 13A.4.5 Power Sector Emissions Factors for SO_2 (tons/MWh)

End Use	2020	2025	2030	2035	2040
Commercial Sector					
Cooking	5.75E-04	4.49E-04	3.77E-04	3.16E-04	2.83E-04
Lighting	5.79E-04	4.52E-04	3.80E-04	3.19E-04	2.85E-04
Office Equipment (Non-PC)	5.55E-04	4.33E-04	3.64E-04	3.05E-04	2.73E-04
Office Equipment (PC)	5.55E-04	4.33E-04	3.64E-04	3.05E-04	2.73E-04
Other Uses	5.62E-04	4.39E-04	3.69E-04	3.09E-04	2.76E-04
Refrigeration	6.00E-04	4.69E-04	3.94E-04	3.31E-04	2.96E-04
Space Cooling	5.30E-04	4.14E-04	3.48E-04	2.92E-04	2.60E-04
Space Heating	6.21E-04	4.85E-04	4.08E-04	3.42E-04	3.06E-04
Ventilation	6.01E-04	4.69E-04	3.95E-04	3.31E-04	2.96E-04
Water Heating	5.82E-04	4.54E-04	3.82E-04	3.20E-04	2.86E-04
Industrial Sector					
All Uses	5.62E-04	4.39E-04	3.69E-04	3.09E-04	2.76E-04
Residential Sector					
Clothes Dryers	5.87E-04	4.58E-04	3.85E-04	3.23E-04	2.89E-04
Cooking	5.77E-04	4.51E-04	3.79E-04	3.18E-04	2.84E-04
Freezers	5.99E-04	4.68E-04	3.93E-04	3.30E-04	2.95E-04
Lighting	6.06E-04	4.73E-04	3.98E-04	3.34E-04	2.98E-04
Other Uses	5.87E-04	4.58E-04	3.85E-04	3.23E-04	2.89E-04
Refrigeration	5.98E-04	4.67E-04	3.93E-04	3.30E-04	2.95E-04
Space Cooling	5.35E-04	4.18E-04	3.51E-04	2.94E-04	2.63E-04
Space Heating	6.17E-04	4.82E-04	4.05E-04	3.40E-04	3.04E-04
Water Heating	5.91E-04	4.62E-04	3.88E-04	3.26E-04	2.91E-04

Table 13A.4.6 Power Sector Emissions Factors for CH_4 (tons/MWh)

End Use	2020	2025	2030	2035	2040
Commercial Sector					
Cooking	7.79E-05	6.25E-05	5.34E-05	4.57E-05	4.11E-05
Lighting	7.85E-05	6.29E-05	5.38E-05	4.60E-05	4.14E-05
Office Equipment (Non-PC)	7.54E-05	6.05E-05	5.17E-05	4.42E-05	3.98E-05
Office Equipment (PC)	7.54E-05	6.05E-05	5.17E-05	4.42E-05	3.98E-05
Other Uses	7.63E-05	6.12E-05	5.23E-05	4.48E-05	4.02E-05
Refrigeration	8.12E-05	6.51E-05	5.56E-05	4.76E-05	4.28E-05
Space Cooling	7.20E-05	5.78E-05	4.94E-05	4.23E-05	3.81E-05
Space Heating	8.40E-05	6.72E-05	5.74E-05	4.92E-05	4.42E-05
Ventilation	8.14E-05	6.52E-05	5.57E-05	4.77E-05	4.28E-05
Water Heating	7.88E-05	6.32E-05	5.40E-05	4.62E-05	4.15E-05
Industrial Sector					
All Uses	7.63E-05	6.12E-05	5.23E-05	4.48E-05	4.02E-05
Residential Sector					
Clothes Dryers	7.96E-05	6.38E-05	5.45E-05	4.67E-05	4.19E-05
Cooking	7.83E-05	6.28E-05	5.37E-05	4.60E-05	4.13E-05
Freezers	8.11E-05	6.49E-05	5.55E-05	4.75E-05	4.27E-05
Lighting	8.20E-05	6.57E-05	5.61E-05	4.80E-05	4.32E-05
Other Uses	7.95E-05	6.37E-05	5.45E-05	4.66E-05	4.19E-05
Refrigeration	8.10E-05	6.49E-05	5.54E-05	4.74E-05	4.26E-05
Space Cooling	7.26E-05	5.83E-05	4.98E-05	4.27E-05	3.84E-05
Space Heating	8.35E-05	6.69E-05	5.71E-05	4.89E-05	4.39E-05
Water Heating	8.02E-05	6.43E-05	5.49E-05	4.70E-05	4.22E-05

Table 13A.4.7 Power Sector Emissions Factors for N_2O (tons/MWh)

End Use	2020	2025	2030	2035	2040
Commercial Sector					
Cooking	1.12E-05	8.92E-06	7.59E-06	6.45E-06	5.79E-06
Lighting	1.13E-05	8.99E-06	7.64E-06	6.50E-06	5.83E-06
Office Equipment (Non-PC)	1.08E-05	8.62E-06	7.33E-06	6.24E-06	5.60E-06
Office Equipment (PC)	1.08E-05	8.62E-06	7.33E-06	6.24E-06	5.60E-06
Other Uses	1.10E-05	8.73E-06	7.43E-06	6.32E-06	5.67E-06
Refrigeration	1.17E-05	9.30E-06	7.91E-06	6.73E-06	6.04E-06
Space Cooling	1.03E-05	8.24E-06	7.00E-06	5.96E-06	5.35E-06
Space Heating	1.21E-05	9.62E-06	8.18E-06	6.96E-06	6.25E-06
Ventilation	1.17E-05	9.32E-06	7.92E-06	6.74E-06	6.05E-06
Water Heating	1.13E-05	9.02E-06	7.67E-06	6.53E-06	5.86E-06
Industrial Sector					
All Uses	1.10E-05	8.73E-06	7.43E-06	6.32E-06	5.67E-06
Residential Sector					
Clothes Dryers	1.15E-05	9.11E-06	7.75E-06	6.59E-06	5.91E-06
Cooking	1.13E-05	8.97E-06	7.63E-06	6.49E-06	5.82E-06
Freezers	1.17E-05	9.28E-06	7.89E-06	6.72E-06	6.03E-06
Lighting	1.18E-05	9.39E-06	7.99E-06	6.80E-06	6.10E-06
Other Uses	1.15E-05	9.11E-06	7.74E-06	6.59E-06	5.91E-06
Refrigeration	1.17E-05	9.27E-06	7.88E-06	6.71E-06	6.02E-06
Space Cooling	1.04E-05	8.31E-06	7.06E-06	6.01E-06	5.39E-06
Space Heating	1.20E-05	9.57E-06	8.14E-06	6.92E-06	6.21E-06
Water Heating	1.16E-05	9.18E-06	7.81E-06	6.64E-06	5.96E-06

Table 13A.4.8 Electricity Upstream Emissions Factors

Species	Unit	2020	2025	2030	2035	2040
CO_2	*kg/MWh*	30.3	30.7	30.8	30.4	30.0
SO_2	*g/MWh*	5.53	5.62	5.45	5.20	5.06
NO_X	*g/MWh*	388	395	399	396	391
Hg	*g/MWh*	1.34E-05	1.26E-05	1.17E-05	1.11E-05	1.08E-05
N_2O	*g/MWh*	0.275	0.270	0.261	0.253	0.246
CH_4	*g/MWh*	2127	2163	2200	2196	2160

Table 13A.4.9 Natural Gas Upstream Emissions Factors

Species	Unit	2020	2025	2030	2035	2040
CO_2	*kg/MWh*	7.89	7.96	7.90	7.85	7.88
SO_2	*g/MWh*	0.0344	0.0348	0.0344	0.0341	0.0343
NO_X	*g/MWh*	115	116	115	114	114
N_2O	*g/MWh*	0.0126	0.0128	0.0127	0.0126	0.0126
CH_4	*g/MWh*	686	689	686	686	687

Table 13A.4.10 Fuel Oil Upstream Emissions Factors

Species	Unit*	2020	2025	2030	2035	2040
CO_2	*kg/bbl*	70.0	69.1	67.8	67.7	67.5
SO_2	*g/bbl*	15.4	15.3	15.0	14.9	14.8
NO_X	*g/bbl*	814	810	791	787	781
Hg	*g/bbl*	6.93E-06	6.47E-06	6.22E-06	6.21E-06	6.09E-06
N_2O	*g/bbl*	0.630	0.625	0.611	0.608	0.603
CH_4	*g/bbl*	882	872	857	855	854

* bbl is the abbreviation for "oil barrel," which in the United States is defined at 42 U.S. gallons.

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CHAPTER 14. MONETIZATION OF EMISSIONS REDUCTION BENEFITS

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CHAPTER 14. MONETIZATION OF EMISSIONS REDUCTION BENEFITS

14.1 INTRODUCTION

As part of its assessment of energy conservation standards for commercial water heating (CWH) equipment, the U.S. Department of Energy (DOE) estimated the monetary benefits likely to result from the reduced emissions of carbon dioxide (CO_2) and nitrogen oxides (NO_X) that are expected to result from each trial standard level (TSL) considered. This chapter summarizes the basis for the monetary values used for each of these emissions and presents the modeled benefits from the estimated reductions.

14.2 MONETIZING CARBON DIOXIDE EMISSIONS

14.2.1 Social Cost of Carbon

The social cost of carbon (SCC) is an estimate of the monetized damages associated with an incremental increase in carbon emissions in a given year. It is intended to include (but is not limited to) changes in net agricultural productivity, human health, property damages from increased flood risk, and the value of ecosystem services. Estimates of the SCC are provided in dollars per metric ton of CO_2. A domestic SCC value is meant to reflect the value of damages in the United States resulting from a unit change in CO_2 emissions, while a global SCC value is meant to reflect the value of damages worldwide.

Under section 1(b) of Executive Order 12866, agencies must, to the extent permitted by law, “assess both the costs and the benefits of the intended regulation and, recognizing that some costs and benefits are difficult to quantify, propose or adopt a regulation only upon a reasoned determination that the benefits of the intended regulation justify its costs.” The purpose of the SCC estimates presented here is to allow agencies to incorporate the monetized social benefits of reducing CO_2 emissions into cost-benefit analyses of regulatory actions that have small, or “marginal,” impacts on cumulative global emissions. The estimates are presented with an acknowledgement of the many uncertainties involved and with a clear understanding that they should be updated over time to reflect increasing knowledge of the science and economics of climate impacts.

As part of the interagency process that developed these SCC estimates, technical experts from numerous agencies met on a regular basis to explore the technical literature in relevant fields, discuss key model inputs and assumptions, and consider public comments. The main objective of this process was to develop a range of SCC values using a defensible set of input assumptions grounded in the existing scientific and economic literatures. In this way, key uncertainties and model differences transparently and consistently inform the range of SCC estimates used in the rulemaking process.

14.2.2 Monetizing Carbon Dioxide Emissions

When attempting to assess the incremental economic impacts of CO_2 emissions, the analyst faces a number of serious challenges. A report from the National Research Council[1] points out that any assessment will suffer from uncertainty, speculation, and lack of information about (1) future emissions of greenhouse gases, (2) the effects of past and future emissions on the climate system, (3) the impact of changes in climate on the physical and biological environment, and (4) the translation of these environmental impacts into economic damages. As a result, any effort to quantify and monetize the harms associated with climate change will raise serious questions of science, economics, and ethics and should be viewed as provisional.

Despite the serious limits of both quantification and monetization, SCC estimates can be useful in estimating the social benefits of reducing CO_2 emissions. Most Federal regulatory actions can be expected to have marginal impacts on global emissions. For such policies, the agency can estimate the benefits from reduced (or costs from increased) emissions in any future year by multiplying the change in emissions in that year by the SCC value appropriate for that year. The net present value of the benefits can then be calculated by multiplying each of these future benefits by an appropriate discount factor and summing across all affected years. This approach assumes that the marginal damages from increased emissions are constant for small departures from the baseline emissions path, an approximation that is reasonable for policies that have effects on emissions that are small relative to cumulative global CO_2 emissions.

In 2009, an interagency process was initiated to offer a preliminary assessment of how best to quantify the benefits from reducing CO_2 emissions. To ensure consistency in how benefits are evaluated across agencies, the U.S. government sought to develop a transparent and defensible method, specifically designed for the rulemaking process, to quantify avoided climate change damages from reduced CO_2 emissions. The interagency group did not undertake any original analysis. Instead, it combined SCC estimates from the existing literature to use as interim values until a more comprehensive analysis could be conducted. The outcome of the preliminary assessment by the interagency group was a set of five interim values: global SCC estimates for 2007 (in 2006 dollars) of $55, $33, $19, $10, and $5 per ton of CO_2.[2] These interim values represented the first sustained interagency effort within the U.S. government to develop an SCC for use in regulatory analysis. The results of this preliminary effort were presented in several proposed and final rules.

14.2.3 Current Approach and Key Assumptions

After the release of the interim values, the interagency group reconvened on a regular basis to generate improved SCC estimates, which were considered for this notice. Specifically, the group considered public comments and further explored the technical literature in relevant fields. The interagency group relied on three integrated assessment models (IAMs) commonly used to estimate the SCC: the FUND, DICE, and PAGE models.[a] These models are frequently cited in the peer-reviewed literature and were used in the last assessment of the Intergovernmental Panel on Climate Change. Each model was given equal weight in the SCC values that were developed.

Each model takes a slightly different approach to model how changes in emissions result in changes in economic damages. A key objective of the interagency process was to enable a consistent exploration of the three models while respecting the different approaches to quantifying damages taken by the key modelers in the field. An extensive review of the literature

[a] The models are described in appendix 14A of this technical support document (TSD).

was conducted to select three sets of input parameters for these models: (1) climate sensitivity, (2) socio-economic and emissions trajectories, and (3) discount rates. A probability distribution for climate sensitivity was specified as an input into all three models. In addition, the interagency group used a range of scenarios for the socio-economic parameters and a range of values for the discount rate. All other model features were left unchanged, relying on the model developers' best estimates and judgments.

The interagency group selected four SCC values for use in regulatory analyses (the 2010 report is reproduced in appendix 14A of this TSD).[2] Three values are based on the average SCC from three integrated assessment models, at discount rates of 2.5, 3, and 5 percent. The fourth value, which represents the 95th percentile SCC estimate across all three models at a 3-percent discount rate, is included to represent higher-than-expected impacts from temperature change further out in the tails of the SCC distribution. The values grow in real terms over time, as depicted in Table 14.2.1. Additionally, the interagency group determined that a range of values from 7 percent to 23 percent should be used to adjust the global SCC to calculate domestic effects,[b] although preference is given to consideration of the global benefits of reducing CO_2 emissions.

The SCC values used for this analysis were generated using the most recent versions of the three integrated assessment models that have been published in the peer-reviewed literature, as described in the 2013 update from the interagency working group (revised July 2015).[3] Table 14.2.2 shows the updated sets of SCC estimates in 5-year increments from 2010 to 2050. Appendix 14B of this TSD provides the full set of SCC estimates, as well as the 2013 report from the interagency group. The central value that emerges is the average SCC across models at the 3-percent discount rate. However, for purposes of capturing the uncertainties involved in regulatory impact analysis, the interagency group emphasizes the importance of including all four sets of SCC values.

Table 14.2.1 Annual SCC Values from 2010 Interagency Report, 2010–2050 (in 2007 dollars per metric ton)

Year	Discount Rate %			
	5	3	2.5	3
	Average	Average	Average	95th Percentile
2010	4.7	21.4	35.1	64.9
2015	5.7	23.8	38.4	72.8
2020	6.8	26.3	41.7	80.7
2025	8.2	29.6	45.9	90.4
2030	9.7	32.8	50.0	100.0
2035	11.2	36.0	54.2	109.7
2040	12.7	39.2	58.4	119.3
2045	14.2	42.1	61.7	127.8
2050	15.7	44.9	65.0	136.2

[b] It is recognized that this calculation for domestic values is approximate, provisional, and highly speculative. There is no *a priori* reason why domestic benefits should be a constant fraction of net global damages over time.

Table 14.2.2 Annual SCC Values from 2013 Interagency Update (Revised July 2015), 2010–2050 (in 2007 dollars per metric ton CO_2)

Year	Discount Rate %			
	5	3	2.5	3
	Average	Average	Average	95th Percentile
2010	10	31	50	86
2015	11	36	56	105
2020	12	42	62	123
2025	14	46	68	138
2030	16	50	73	152
2035	18	55	78	168
2040	21	60	84	183
2045	23	64	89	197
2050	26	69	95	212

It is important to recognize that a number of key uncertainties remain, and that current SCC estimates should be treated as provisional and revisable since they will evolve with improved scientific and economic understanding. The interagency group also recognizes that the existing models are imperfect and incomplete. The National Research Council report mentioned previously points out that there is tension between the goal of producing quantified estimates of the economic damages from an incremental ton of carbon and the limits of existing efforts to model these effects. There are a number of concerns and problems that should be addressed by the research community, including research programs housed in many of the agencies participating in the interagency process to estimate the SCC. The interagency group intends to periodically review and reconsider estimates of the SCC used for cost-benefit analyses to reflect increasing knowledge of the science and economics of climate impacts, as well as improvements in modeling.

In summary, in considering the potential global benefits resulting from reduced CO_2 emissions, DOE used the values from the 2013 interagency report (revised in July 2015), which is reprinted in appendix 14B of this TSD, escalated to 2014$ using the implicit price deflator for gross domestic product (GDP) price deflator from the Bureau of Economic Analysis . For each of the four cases specified, the values used for emissions in 2015 were $12.2, $40.0, $62.3, and $117 per metric ton avoided. DOE derived values after 2050 using the relevant growth rates for the 2040–2050 period in the interagency update.

DOE multiplied the CO_2 emissions reduction estimated for each year by the SCC value for that year in each of the four cases. To calculate a present value of the stream of monetary values, DOE discounted the values in each of the four cases using the specific discount rate that had been used to obtain the SCC values in each case.

14.3 VALUATION OF OTHER EMISSIONS REDUCTIONS

As noted in chapter 13 of this TSD, new or amended energy conservation standards would reduce NO_X emissions in those 22 states that are not affected by caps. DOE considered the potential monetary benefit of reduced NO_X emissions from the TSLs it considered. DOE estimated the monetized value of NO_X emissions reductions using benefit per ton estimates from the *Regulatory Impact Analysis for the Proposed Carbon Pollution Guidelines for Existing Power Plants and Emission Standards for Modified and Reconstructed Power Plants,* published in June 2014 by the U.S. Environmental Protection Agency's (EPA's) Office of Air Quality Planning and Standards.[c] The report includes low and high values for 2020, 2025, and 2030 that use discount rates of 3 percent and 7 percent (see Tables 4-7, 4–8, and 4–9 in the report). As shown in Table 14.3.1, DOE assigned values for 2021–2024 and 2026–2029 using, respectively, the values for 2020 and 2025. DOE assigned values after 2030 using the value for 2030. DOE assigned values before 2020 using the value for 2020. To be conservative, DOE's primary estimates presented in this chapter utilize the low benefit per ton estimates.

Table 14.3.1 National Benefit per Ton for Emissions from Electricity Generating Units (2011$)

Year of Emission	NO_X (as $PM_{2.5}$)	
	3% discount rate	*7% discount rate*
2020	5,600 to 13,000	5,000 to 11,000
2025	6,000 to 14,000	5,400 to 12,000
2030	6,400 to 14,000	5,800 to 13,000

To calculate present value of the total monetary sum from reduced NO_X emissions, DOE applied discount rates of 3 percent and 7 percent to the appropriate $/ton series.

DOE is evaluating appropriate values to use to monetize avoided SO_2 and Hg emissions. The interagency group is investigating appropriate values to use to monetize avoided CH_4 emissions. DOE did not monetize these emissions for the current analysis.

14.4 RESULTS

Table 14.4.1 presents the global values of CO_2 emissions reductions for each considered TSL. DOE calculated domestic values as a range from 7 percent to 23 percent of the global values, and these results are presented in Table 14.4.2.

[c] www3.epa.gov/ttnecas1/regdata/RIAs/111dproposalRIAfinal0602.pdf. Note that DOE is primarily using a national benefit-per-ton estimate for particulate matter emitted from the Electric Generating Unit sector based on an estimate of premature mortality derived from the ACS study (Krewski et al. 2009).[4] If the benefit-per-ton estimates were based on the Six Cities study (Lepuele et al. 2012),[5] the values would be nearly two-and-a-half times larger. Because of the sensitivity of the benefit-per-ton estimate to the geographical considerations of sources and receptors of emissions, DOE intends to investigate refinements to the agency's current approach of one national estimate by assessing the regional approach taken by EPA's Regulatory Impact Analysis for the Clean Power Plan Final Rule.

Table 14.4.1 Estimates of Global Present Value of CO_2 Emissions Reduction for Potential Standards for CWH Equipment

TSL	SCC Case*			
	5% discount rate, average	3% discount rate, average	2.5% discount rate, average	3% discount rate, 95th percentile
	million 2014$			
Power Sector and Site Emissions				
1	145	680	1,085	2,073
2	441	2,081	3,327	6,348
3	555	2,612	4,173	7,967
4	682	3,202	5,113	9,765
Upstream Emissions				
1	19	90	143	273
2	63	297	474	905
3	79	373	596	1,138
4	98	458	731	1,396
Total Emissions				
1	164	769	1,228	2,346
2	504	2,378	3,801	7,253
3	635	2,985	4,769	9,105
4	780	3,660	5,844	11,161

* For each of the four cases, the corresponding SCC value for emissions in 2015 are $12.2, $40.0, $62.3, and $117 per metric ton (2014$).

Table 14.4.2 Estimates of Domestic Present Value of CO_2 Emissions Reduction for Potential Standards for CWH Equipment

TSL	SCC Case*			
	5% Discount Rate, Average	3% Discount Rate, Average	2.5% Discount Rate, Average	3% Discount Rate, 95th Percentile
	million 2014$			
Power Sector and Site Emissions				
1	10.1 to 33.3	47.6 to 156.3	76.0 to 249.6	145.1 to 476.7
2	30.9 to 101.5	145.7 to 478.7	232.9 to 765.2	444.3 to 1,460.0
3	38.9 to 127.7	182.9 to 600.8	292.1 to 959.9	557.7 to 1,832.4
4	47.7 to 156.9	224.2 to 736.5	357.9 to 1,176.1	683.6 to 2,246.0
Upstream Emissions				
1	1.3 to 4.4	6.3 to 20.6	10.0 to 32.9	19.1 to 62.9
2	4.4 to 14.5	20.8 to 68.3	33.2 to 109.1	63.4 to 208.2
3	5.6 to 18.2	26.1 to 85.8	41.7 to 137.1	79.7 to 261.7
4	6.8 to 22.4	32.0 to 105.3	51.2 to 168.1	97.7 to 321.1
Total Emissions				
1	11.5 to 37.7	53.9 to 176.9	86.0 to 282.5	164.2 to 539.6
2	35.3 to 116.0	166.5 to 547.0	266.1 to 874.3	507.7 to 1,668.2
3	44.4 to 146.0	209.0 to 686.7	333.9 to 1,097.0	637.3 to 2,094.1
4	54.6 to 179.3	256.2 to 841.8	409.1 to 1,344.2	781.3 to 2,567.1

* For each of the four cases, the corresponding SCC value for emissions in 2015 are $12.2, $40.0, $62.3, and $117 per metric ton (2014$).

Table 14.4.3 presents the present value of cumulative NO_X emissions reductions for each TSL, calculated using 7-percent and 3-percent discount rates.

Table 14.4.3 Estimates of Present Value of NO_X Emissions Reduction for Potential Standards for CWH Equipment

TSL	3% Discount Rate	7% Discount Rate
	million 2014$	
Power Sector Emissions		
1	93	36
2	294	112
3	371	142
4	456	176
Upstream Emissions		
1	143	55
2	475	181
3	599	231
4	737	285
Total Emissions		
1	236	91
2	769	294
3	970	373
4	1,193	461

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APPENDIX 14A. SOCIAL COST OF CARBON FOR REGULATORY IMPACT ANALYSIS UNDER EXECUTIVE ORDER 12866

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Prepared by
Interagency Working Group on Social Cost of Carbon, United States Government

With participation by

Council of Economic Advisers
Council on Environmental Quality
Department of Agriculture
Department of Commerce
Department of Energy
Department of Transportation
Environmental Protection Agency
National Economic Council
Office of Energy and Climate Change
Office of Management and Budget
Office of Science and Technology Policy
Department of the Treasury

14A.1 EXECUTIVE SUMMARY

Under Executive Order (E.O.) 12866, agencies are required, to the extent permitted by law, "to assess both the costs and the benefits of the intended regulation and, recognizing that some costs and benefits are difficult to quantify, propose or adopt a regulation only upon a reasoned determination that the benefits of the intended regulation justify its costs." The purpose of the "social cost of carbon" (SCC) estimates presented here is to allow agencies to incorporate the social benefits of reducing carbon dioxide (CO_2) emissions into cost-benefit analyses of regulatory actions that have small, or "marginal," impacts on cumulative global emissions. The estimates are presented with an acknowledgement of the many uncertainties involved and with a clear understanding that they should be updated over time to reflect increasing knowledge of the science and economics of climate impacts.

The SCC is an estimate of the monetized damages associated with an incremental increase in carbon emissions in a given year. It is intended to include but is not limited to changes in net agricultural productivity, human health, property damages from increased flood risk, and the value of ecosystem services due to climate change.

This document presents a summary of the interagency process that developed these SCC estimates. Technical experts from numerous agencies met on a regular basis to consider public comments, explore the technical literature in relevant fields, and discuss key model inputs and assumptions. The main objective of this process was to develop a range of SCC values using a defensible set of input assumptions grounded in the existing scientific and economic literatures. In this way, key uncertainties and model differences transparently and consistently inform the range of SCC estimates used in the rulemaking process.

The interagency group selected four SCC values for use in regulatory analyses (Table 14A.1.1. Three values are based on the average SCC from three integrated assessment models, at discount rates of 2.5, 3, and 5 percent. The fourth value, which represents the 95th percentile SCC estimate across all three models at a 3-percent discount rate, is included to represent higher-than-expected impacts from temperature change further out in the tails of the SCC distribution.

Table 14A.1.1 Social Cost of CO_2, 2010–2050 (2007$)

Year	Discount Rate %			
	5	3	2.5	3
	Avg	Avg	Avg	95th
2010	4.7	21.4	35.1	64.9
2015	5.7	23.8	38.4	72.8
2020	6.8	26.3	41.7	80.7
2025	8.2	29.6	45.9	90.4
2030	9.7	32.8	50.0	100.0
2035	11.2	36.0	54.2	109.7
2040	12.7	39.2	58.4	119.3
2045	14.2	42.1	61.7	127.8
2050	15.7	44.9	65.0	136.2

14A.2 MONETIZING CARBON DIOXIDE EMISSIONS

The SCC is an estimate of the monetized damages associated with an incremental increase in carbon emissions in a given year. It is intended to include but is not limited to changes in net agricultural productivity, human health, property damages from increased flood risk, and the value of ecosystem services. We report estimates of the social cost of carbon in dollars per metric ton of CO_2 throughout this document.[a]

When attempting to assess the incremental economic impacts of CO_2 emissions, the analyst faces a number of serious challenges. A recent report from the National Academies of Science (NRC 2009) points out that any assessment will suffer from uncertainty, speculation, and lack of information about (1) future emissions of greenhouse gases; (2) the effects of past and future emissions on the climate system; (3) the impact of changes in climate on the physical and biological environment; and (4) the translation of these environmental impacts into economic damages. As a result, any effort to quantify and monetize the harms associated with climate change will raise serious questions of science, economics, and ethics and should be viewed as provisional.

Despite the serious limits of both quantification and monetization, SCC estimates can be useful in estimating the social benefits of reducing CO_2 emissions. Under E.O. 12866, agencies are required, to the extent permitted by law, "to assess both the costs and the benefits of the intended regulation and, recognizing that some costs and benefits are difficult to quantify,

[a] In this document, we present all values of the SCC as the cost per metric ton of CO_2 emissions. Alternatively, one could report the SCC as the cost per metric ton of carbon emissions. The multiplier for translating between mass of CO_2 and the mass of carbon is 3.67 (the molecular weight of CO_2 divided by the molecular weight of carbon = 44/12 = 3.67).

propose or adopt a regulation only upon a reasoned determination that the benefits of the intended regulation justify its costs." The purpose of the SCC estimates presented here is to make it possible for agencies to incorporate the social benefits from reducing CO_2 emissions into cost-benefit analyses of regulatory actions that have small or "marginal" impacts on cumulative global emissions. Most Federal regulatory actions can be expected to have marginal impacts on global emissions.

For such policies, the benefits from reduced (or costs from increased) emissions in any future year can be estimated by multiplying the change in emissions in that year by the SCC value appropriate for that year. The net present value of the benefits can then be calculated by multiplying each of these future benefits by an appropriate discount factor and summing across all affected years. This approach assumes that the marginal damages from increased emissions are constant for small departures from the baseline emissions path, an approximation that is reasonable for policies that have effects on emissions that are small relative to cumulative global CO_2 emissions. For policies that have a large (non-marginal) impact on global cumulative emissions, there is a separate question of whether the SCC is an appropriate tool for calculating the benefits of reduced emissions; we do not attempt to answer that question here.

An interagency group convened on a regular basis to consider public comments, explore the technical literature in relevant fields, and discuss key inputs and assumptions in order to generate SCC estimates. Agencies that actively participated in the interagency process include the Environmental Protection Agency, and the Departments of Agriculture, Commerce, Energy, Transportation, and Treasury. This process was convened by the Council of Economic Advisers and the Office of Management and Budget, with active participation and regular input from the Council on Environmental Quality, National Economic Council, Office of Energy and Climate Change, and Office of Science and Technology Policy. The main objective of this process was to develop a range of SCC values using a defensible set of input assumptions that are grounded in the existing literature. In this way, key uncertainties and model differences can more transparently and consistently inform the range of SCC estimates used in the rulemaking process.

The interagency group selected four SCC estimates for use in regulatory analyses. For 2010, these estimates are \$4.7, \$21.4, \$35.1, and \$64.9 (2007\$). The first three estimates are based on the average SCC across models and socio-economic and emissions scenarios at the 5-, 3-, and 2.5-percent discount rates, respectively. The fourth value is included to represent the higher-than-expected impacts from temperature change further out in the tails of the SCC distribution. For this purpose, we use the SCC value for the 95^{th} percentile at a 3-percent discount rate. The central value is the average SCC across models at the 3-percent discount rate. For purposes of capturing the uncertainties involved in regulatory impact analysis, we emphasize the importance and value of considering the full range. These SCC estimates also grow over time. For instance, the central value increases to \$24 per ton of CO_2 in 2015 and \$26 per ton of CO_2 in 2020. See Appendix A for the full range of annual SCC estimates from 2010 to 2050.

It is important to emphasize that the interagency process is committed to updating these estimates as the science and economic understanding of climate change and its impacts on society improves over time. Specifically, we have set a preliminary goal of revisiting the SCC values within 2 years or at such time as substantially updated models become available, and to continue to support research in this area. In the meantime, we will continue to explore the issues raised in this document and consider public comments as part of the ongoing interagency process.

14A.3 SOCIAL COST OF CARBON VALUES USED IN PAST REGULATORY ANALYSES

To date, economic analyses for Federal regulations have used a wide range of values to estimate the benefits associated with reducing CO_2 emissions. In the final model year 2011 CAFE rule, the Department of Transportation (DOT) used both a "domestic" SCC value of $2 per ton of CO_2 and a "global" SCC value of $33 per ton of CO_2 for 2007 emission reductions (2007$), increasing both values at 2.4 percent per year. It also included a sensitivity analysis at $80 per ton of CO_2. A domestic SCC value is meant to reflect the value of damages in the United States resulting from a unit change in CO_2 emissions, while a global SCC value is meant to reflect the value of damages worldwide.

A 2008 regulation proposed by DOT assumed a domestic SCC value of $7 per ton CO_2 (in 2006 dollars) for 2011 emission reductions (with a range of $0–$14 for sensitivity analysis), also increasing at 2.4 percent per year. A regulation finalized by DOE in October of 2008 used a domestic SCC range of $0 to $20 per ton CO_2 for 2007 emission reductions (2007$). In addition, the 2008 Advance Notice of Proposed Rulemaking for Greenhouse Gases identified what it described as "very preliminary" SCC estimates subject to revision. EPA's global mean values were $68 and $40 per ton CO_2 for discount rates of approximately 2 percent and 3 percent, respectively (2006$ for 2007 emissions).

In 2009, an interagency process was initiated to offer a preliminary assessment of how best to quantify the benefits from reducing CO_2 emissions. To ensure consistency in how benefits are evaluated across agencies, the Administration sought to develop a transparent and defensible method, specifically designed for the rulemaking process, to quantify avoided climate change damages from reduced CO_2 emissions. The interagency group did not undertake any original analysis. Instead, it combined SCC estimates from the existing literature to use as interim values until a more comprehensive analysis could be conducted.

The outcome of the preliminary assessment by the interagency group was a set of five interim values: global SCC estimates for 2007 (in 2006 dollars) of $55, $33, $19, $10, and $5 per ton of CO_2. The $33 and $5 values represented model-weighted means of the published estimates produced from the most recently available versions of three integrated assessment models—DICE, PAGE, and FUND—at approximately 3- and 5-percent discount rates. The $55 and $10 values were derived by adjusting the published estimates for uncertainty in the discount rate (using factors developed by Newell and Pizer (2003)) at 3- and 5-percent discount rates, respectively. The $19 value was chosen as a central value between the $5 and $33 per ton estimates. All of these values were assumed to increase at 3 percent annually to represent growth in incremental damages over time as the magnitude of climate change increases.

These interim values represent the first sustained interagency effort within the U.S. government to develop an SCC for use in regulatory analysis. The results of this preliminary effort were presented in several proposed and final rules and were offered for public comment in connection with proposed rules, including the joint EPA-DOT fuel economy and CO_2 tailpipe emission proposed rules.

14A.4 APPROACH AND KEY ASSUMPTIONS

Since the release of the interim values, interagency group has reconvened on a regular basis to generate improved SCC estimates. Specifically, the group has considered public comments and further explored the technical literature in relevant fields. This section details the several choices and assumptions that underlie the resulting estimates of the SCC.

It is important to recognize that a number of key uncertainties remain, and that current SCC estimates should be treated as provisional and revisable since they will evolve with improved scientific and economic understanding. The interagency group also recognizes that the existing models are imperfect and incomplete. The National Academy of Science (2009) points out that there is tension between the goal of producing quantified estimates of the economic damages from an incremental ton of carbon and the limits of existing efforts to model these effects. Throughout this document, we highlight a number of concerns and problems that should be addressed by the research community, including research programs housed in many of the agencies participating in the interagency process to estimate the SCC.

The U.S. Government will periodically review and reconsider estimates of the SCC used for cost-benefit analyses to reflect increasing knowledge of the science and economics of climate impacts, as well as improvements in modeling. In this context, statements recognizing the limitations of the analysis and calling for further research take on exceptional significance. The interagency group offers the new SCC values with all due humility about the uncertainties embedded in them and with a sincere promise to continue work to improve them.

14A.4.1 Integrated Assessment Models

We rely on three integrated assessment models (IAMs) commonly used to estimate the SCC: the FUND, DICE, and PAGE models.[b] These models are frequently cited in the peer-reviewed literature and used in the IPCC assessment. Each model is given equal weight in the SCC values developed through this process, bearing in mind their different limitations (discussed below).

These models are useful because they combine climate processes, economic growth, and feedbacks between the climate and the global economy into a single modeling framework. At the same time, they gain this advantage at the expense of a more detailed representation of the underlying climatic and economic systems. DICE, PAGE, and FUND all take stylized, reduced-form approaches (see NRC 2009 for a more detailed discussion; see Nordhaus 2008 on the

[b] The DICE (Dynamic Integrated Climate and Economy) model by William Nordhaus evolved from a series of energy models and was first presented in 1990 (Nordhaus and Boyer 2000, Nordhaus 2008). The PAGE (Policy Analysis of the Greenhouse Effect) model was developed by Chris Hope in 1991 for use by European decision-makers in assessing the marginal impact of carbon emissions (Hope 2006, Hope 2008). The FUND (Climate Framework for Uncertainty, Negotiation, and Distribution) model, developed by Richard Tol in the early 1990s, originally to study international capital transfers in climate policy. is now widely used to study climate impacts (*e.g.*, Tol 2002a, Tol 2002b, Anthoff *et al.* 2009, Tol 2009).

possible advantages of this approach). Other IAMs may better reflect the complexity of the science in their modeling frameworks but do not link physical impacts to economic damages. There is currently a limited amount of research linking climate impacts to economic damages, which makes this exercise even more difficult. Underlying the three IAMs selected for this exercise are a number of simplifying assumptions and judgments reflecting the various modelers' best attempts to synthesize the available scientific and economic research characterizing these relationships.

The three IAMs translate emissions into changes in atmospheric greenhouse concentrations, atmospheric concentrations into changes in temperature, and changes in temperature into economic damages. The emissions projections used in the models are based on specified socio-economic (gross domestic product (GDP) and population) pathways. These emissions are translated into concentrations using the carbon cycle built into each model, and concentrations are translated into warming based on each model's simplified representation of the climate and a key parameter, climate sensitivity. Each model uses a different approach to translate warming into damages. Finally, transforming the stream of economic damages over time into a single value requires judgments about how to discount them.

Each model takes a slightly different approach to model how changes in emissions result in changes in economic damages. In PAGE, for example, the consumption-equivalent damages in each period are calculated as a fraction of GDP, depending on the temperature in that period relative to the pre-industrial average temperature in each region. In FUND, damages in each period also depend on the rate of temperature change from the prior period. In DICE, temperature affects both consumption and investment. We describe each model in greater detail here. In a later section, we discuss key gaps in how the models account for various scientific and economic processes (*e.g.*, the probability of catastrophe, and the ability to adapt to climate change and the physical changes it causes).

The parameters and assumptions embedded in the three models vary widely. A key objective of the interagency process was to enable a consistent exploration of the three models while respecting the different approaches to quantifying damages taken by the key modelers in the field. An extensive review of the literature was conducted to select three sets of input parameters for these models: climate sensitivity, socio-economic and emissions trajectories, and discount rates. A probability distribution for climate sensitivity was specified as an input into all three models. In addition, the interagency group used a range of scenarios for the socio-economic parameters and a range of values for the discount rate. All other model features were left unchanged, relying on the model developers' best estimates and judgments. In DICE, these parameters are handled deterministically and represented by fixed constants; in PAGE, most parameters are represented by probability distributions. FUND was also run in a mode in which parameters were treated probabilistically.

The sensitivity of the results to other aspects of the models (*e.g.*, the carbon cycle or damage function) is also important to explore in the context of future revisions to the SCC but has not been incorporated into these estimates. Areas for future research are highlighted at the end of this document.

14A.4.1.1 The DICE Model

The DICE model is an optimal growth model based on a global production function with an extra stock variable (atmospheric CO_2 concentrations). Emission reductions are treated as analogous to investment in "natural capital." By investing in natural capital today through reductions in emissions—implying reduced consumption—harmful effects of climate change can be avoided and future consumption thereby increased.

For purposes of estimating the SCC, CO_2 emissions are a function of global GDP and the carbon intensity of economic output, with the latter declining over time due to technological progress. The DICE damage function links global average temperature to the overall impact on the world economy. It varies quadratically with temperature change to capture the more rapid increase in damages expected to occur under more extreme climate change, and is calibrated to include the effects of warming on the production of market and nonmarket goods and services. It incorporates impacts on agriculture, coastal areas (due to sea level rise), "other vulnerable market sectors" (based primarily on changes in energy use), human health (based on climate-related diseases, such as malaria and dengue fever, and pollution), non-market amenities (based on outdoor recreation), and human settlements and ecosystems. The DICE damage function also includes the expected value of damages associated with low probability, high impact "catastrophic" climate change. This last component is calibrated based on a survey of experts (Nordhaus 1994). The expected value of these impacts is then added to the other market and non-market impacts mentioned above.

No structural components of the DICE model represent adaptation explicitly, though it is included implicitly through the choice of studies used to calibrate the aggregate damage function. For example, its agricultural impact estimates assume that farmers can adjust land use decisions in response to changing climate conditions, and its health impact estimates assume improvements in healthcare over time. In addition, the small impacts on forestry, water systems, construction, fisheries, and outdoor recreation imply optimistic and costless adaptation in these sectors (Nordhaus and Boyer, 2000; Warren *et al*. 2006). Costs of resettlement due to sea level rise are incorporated into damage estimates, but their magnitude is not clearly reported. Mastrandrea's (2009) review concludes that "in general, DICE assumes very effective adaptation, and largely ignores adaptation costs."

Note that the damage function in DICE has a somewhat different meaning from the damage functions in FUND and PAGE. Because GDP is endogenous in DICE and because damages in a given year reduce investment in that year, damages propagate forward in time and reduce GDP in future years. In contrast, GDP is exogenous in FUND and PAGE, so damages in any given year do not propagate forward.[c]

14A.4.1.2 The PAGE Model

PAGE2002 (version 1.4epm) treats GDP growth as exogenous. It divides impacts into economic, non-economic, and catastrophic categories and calculates these impacts separately for eight geographic regions. Damages in each region are expressed as a fraction of output, where the fraction lost depends on the temperature change in each region. Damages are expressed as power functions of temperature change. The exponents of the damage function are the same in all regions but are treated as uncertain, with values ranging from 1 to 3 (instead of being fixed at 2 as in DICE).

PAGE2002 includes the consequences of catastrophic events in a separate damage sub-function. Unlike DICE, PAGE2002 models these events probabilistically. The probability of a "discontinuity" (*i.e.*, a catastrophic event) is assumed to increase with temperature above a specified threshold. The threshold temperature, the rate at which the probability of experiencing a discontinuity increases above the threshold, and the magnitude of the resulting catastrophe are all modeled probabilistically.

Adaptation is explicitly included in PAGE. Impacts are assumed to occur for temperature increases above some tolerable level (2 °C for developed countries and 0 °C for developing countries for economic impacts, and 0 °C for all regions for non-economic impacts), but adaptation is assumed to reduce these impacts. Default values in PAGE2002 assume that the developed countries can ultimately eliminate up to 90 percent of all economic impacts beyond the tolerable 2 °C increase and that developing countries can eventually eliminate 50 percent of their economic impacts. All regions are assumed to be able to mitigate 25 percent of the non-economic impacts through adaptation (Hope 2006).

14A.4.1.3 The FUND Model

Like PAGE, the FUND model treats GDP growth as exogenous. It includes separately calibrated damage functions for eight market and nonmarket sectors: agriculture, forestry, water, energy (based on heating and cooling demand), sea level rise (based on the value of land lost and the cost of protection), ecosystems, human health (diarrhea, vector-borne diseases, and cardiovascular and respiratory mortality), and extreme weather. Each impact sector has a

[c] Using the default assumptions in DICE 2007, this effect generates an approximately 25 percent increase in the SCC relative to damages calculated by fixing GDP. In DICE2007, the time path of GDP is endogenous. Specifically, the path of GDP depends on the rate of saving and level of abatement in each period chosen by the optimizing representative agent in the model. We made two modifications to DICE to make it consistent with EMF GDP trajectories (see next section): we assumed a fixed rate of savings of 20%, and we re- calibrated the exogenous path of total factor productivity so that DICE would produce GDP projections in the absence of warming that exactly matched the EMF scenarios.

different functional form, and is calculated separately for sixteen geographic regions. In some impact sectors, the fraction of output lost or gained due to climate change depends not only on the absolute temperature change but also on the rate of temperature change and level of regional income.[d] In the forestry and agricultural sectors, economic damages also depend on CO_2 concentrations.

Tol (2009) discusses impacts not included in FUND, noting that many are likely to have a relatively small effect on damage estimates (both positive and negative). However, he characterizes several omitted impacts as "big unknowns:" for instance, extreme climate scenarios, biodiversity loss, and effects on economic development and political violence. With regard to potentially catastrophic events, he notes, "Exactly what would cause these sorts of changes or what effects they would have are not well-understood, although the chance of any one of them happening seems low. But they do have the potential to happen relatively quickly, and if they did, the costs could be substantial. Only a few studies of climate change have examined these issues."

Adaptation is included both implicitly and explicitly in FUND. Explicit adaptation is seen in the agriculture and sea level rise sectors. Implicit adaptation is included in sectors such as energy and human health, where wealthier populations are assumed to be less vulnerable to climate impacts. For example, the damages to agriculture are the sum of three effects: (1) those due to the rate of temperature change (damages are always positive); (2) those due to the level of temperature change (damages can be positive or negative depending on region and temperature); and (3) those from CO_2 fertilization (damages are generally negative but diminishing to zero).

Adaptation is incorporated into FUND by allowing damages to be smaller if climate change happens more slowly. The combined effect of CO_2 fertilization in the agricultural sector, positive impacts to some regions from higher temperatures, and sufficiently slow increases in temperature across these sectors can result in negative economic damages from climate change.

14A.4.1.4 Damage Functions

To generate revised SCC values, we rely on the IAM modelers' current best judgments of how to represent the effects of climate change (represented by the increase in global-average surface temperature) on the consumption-equivalent value of both market and non-market goods (represented as a fraction of global GDP). We recognize that these representations are incomplete and highly uncertain. Given the paucity of data linking the physical impacts to economic damages, we were not able to identify a better way to translate changes in climate into net economic damages, short of launching our own research program.

The damage functions for the three IAMs are presented in Figure 14A.4.1 and Figure 14A.4.2, using the modeler's default scenarios and mean input assumptions. There are significant differences between the three models both at lower (Figure 14A.4.1) and higher (Figure 14A.4.2) increases in global-average temperature.

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[d] In the deterministic version of FUND, the majority of damages are attributable to increased air conditioning demand, while reduced cold stress in Europe, North America, and Central and East Asia results in health benefits in those regions at low to moderate levels of warming (Warren *et al*. 2006).

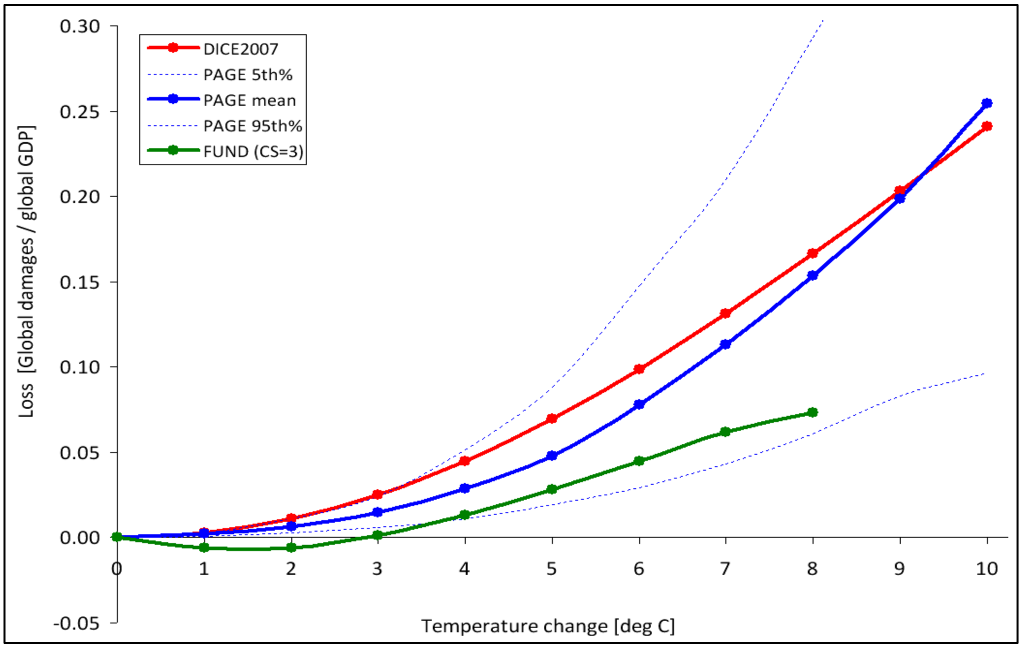

Figure 14A.4.1 Annual Consumption Loss as a Fraction of Global GDP in 2100 Due to an Increase in Annual Global Temperature in the DICE, FUND, and PAGE Models[e]

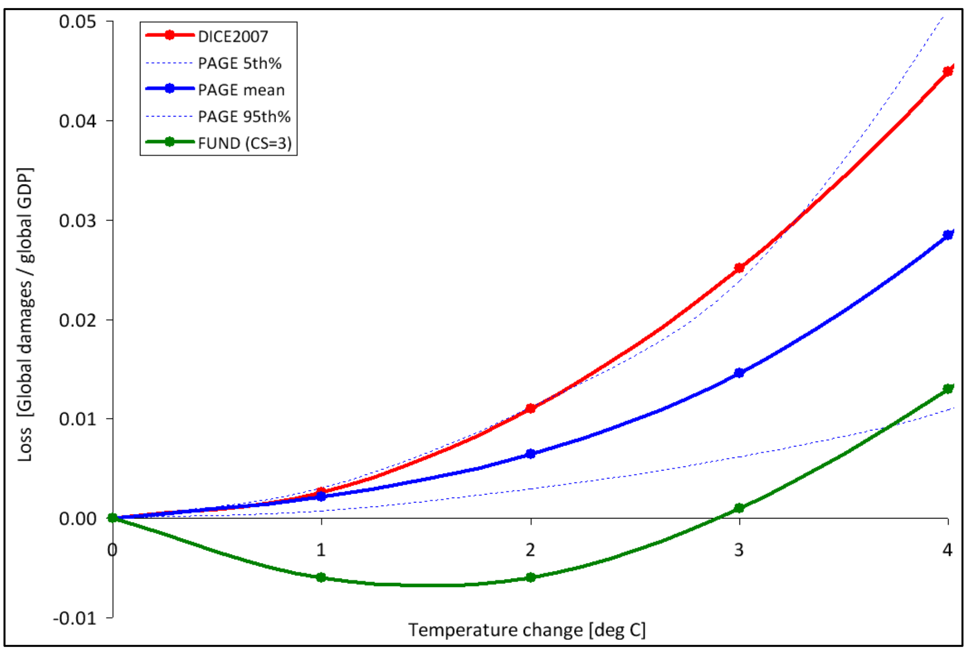

Figure 14A.4.2 Annual Consumption Loss for Lower Temperature Changes in DICE, FUND, and PAGE

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[e] The x-axis represents increases in annual, rather than equilibrium, temperature, while the y-axis represents the annual stream of benefits as a share of global GDP. Each specific combination of climate sensitivity, socio-economic, and emissions parameters will produce a different realization of damages for each IAM. The damage functions represented in Figure 14A.4.1 and Figure 14A.4.2 are the outcome of default assumptions. For instance, under alternate assumptions, the damages from FUND may cross from negative to positive at less than or greater than 3 °C.

The lack of agreement among the models at lower temperature increases is underscored by the fact that the damages from FUND are well below the 5th percentile estimated by PAGE, while the damages estimated by DICE are roughly equal to the 95th percentile estimated by PAGE. This is significant because at higher discount rates we expect that a greater proportion of the SCC value is due to damages in years with lower temperature increases. For example, when the discount rate is 2.5 percent, about 45 percent of the 2010 SCC value in DICE is due to damages that occur in years when the temperature is less than or equal to 3 °C. This increases to approximately 55 percent and 80 percent at discount rates of 3 and 5 percent, respectively.

These differences underscore the need for a thorough review of damage functions—in particular, how the models incorporate adaptation, technological change, and catastrophic damages. Gaps in the literature make modifying these aspects of the models challenging, which highlights the need for additional research. As knowledge improves, the Federal government is committed to exploring how these (and other) models can be modified to incorporate more accurate estimates of damages.

14A.4.2 Global versus Domestic Measures of SCC

Because of the distinctive nature of the climate change problem, we center our current attention on a global measure of SCC. This approach is the same as that taken for the interim values, but it otherwise represents a departure from past practices, which tended to put greater emphasis on a domestic measure of SCC (limited to impacts of climate change experienced within U.S. borders). As a matter of law, consideration of both global and domestic values is generally permissible; the relevant statutory provisions are usually ambiguous and allow selection of either measure.[f]

14A.4.2.1 Global SCC

Under current OMB guidance contained in Circular A-4, analysis of economically significant proposed and final regulations from the domestic perspective is required, while analysis from the international perspective is optional. However, the climate change problem is highly unusual in at least two respects. First, it involves a global externality: emissions of most greenhouse gases contribute to damages around the world even when they are emitted in the United States. Consequently, to address the global nature of the problem, the SCC must incorporate the full (global) damages caused by GHG emissions. Second, climate change presents a problem that the United States alone cannot solve. Even if the United States were to reduce its greenhouse gas emissions to zero, that step would be far from enough to avoid substantial climate change. Other countries would also need to take action to reduce emissions if significant changes in the global climate are to be avoided. Emphasizing the need for a global solution to a global problem, the United States has been actively involved in seeking international agreements to reduce emissions and in encouraging other nations, including emerging major economies, to take significant steps to reduce emissions. When these

[f] It is true that Federal statutes are presumed not to have extraterritorial effect, in part to ensure that the laws of the United States respect the interests of foreign sovereigns. But use of a global measure for the SCC does not give extraterritorial effect to federal law and hence does not intrude on such interests.

considerations are taken as a whole, the interagency group concluded that a global measure of the benefits from reducing U.S. emissions is preferable.

When quantifying the damages associated with a change in emissions, a number of analysts (*e.g.*, Anthoff *et al*. 2009a) employ "equity weighting" to aggregate changes in consumption across regions. This weighting takes into account the relative reductions in wealth in different regions of the world. A per-capita loss of $500 in GDP, for instance, is weighted more heavily in a country with a per-capita GDP of $2,000 than in one with a per-capita GDP of $40,000. The main argument for this approach is that a loss of $500 in a poor country causes a greater reduction in utility or welfare than does the same loss in a wealthy nation. Notwithstanding the theoretical claims on behalf of equity weighting, the interagency group concluded that this approach would not be appropriate for estimating a SCC value used in domestic regulatory analysis.[g] For this reason, the group concluded that using the global (rather than domestic) value, without equity weighting, is the appropriate approach.

14A.4.2.2 Domestic SCC

As an empirical matter, the development of a domestic SCC is greatly complicated by the relatively few region- or country-specific estimates of the SCC in the literature. One potential source of estimates comes from the FUND model. The resulting estimates suggest that the ratio of domestic to global benefits of emission reductions varies with key parameter assumptions. For example, with a 2.5- or 3-percent discount rate, the U.S. benefit is about 7–10 percent of the global benefit, on average, across the scenarios analyzed. Alternatively, if the fraction of GDP lost due to climate change is assumed to be similar across countries, the domestic benefit would be proportional to the U.S. share of global GDP, which is currently about 23 percent.[h]

On the basis of this evidence, the interagency workgroup determined that a range of values from 7 to 23 percent should be used to adjust the global SCC to calculate domestic effects. Reported domestic values should use this range. It is recognized that these values are approximate, provisional, and highly speculative. There is no *a priori* reason why domestic benefits should be a constant fraction of net global damages over time. Further, FUND does not account for how damages in other regions could affect the United States (*e.g.*, global migration, economic and political destabilization). If more accurate methods for calculating the domestic SCC become available, the Federal government will examine these to determine whether to update its approach.

[g] It is plausible that a loss of $X inflicts more serious harm on a poor nation than on a wealthy one, but development of the appropriate "equity weight" is challenging. Emissions reductions also impose costs, and hence a full account would have to consider that a given cost of emissions reductions imposes a greater utility or welfare loss on a poor nation than on a wealthy one. Even if equity weighting—for both the costs and benefits of emissions reductions—is appropriate when considering the utility or welfare effects of international action, the interagency group concluded that it should not be used in developing an SCC for use in regulatory policy at this time.
[h] Based on 2008 GDP (in current US dollars) from the *World Bank Development Indicators Report*.

14A.4.3 Valuing Non-CO_2 Emissions

While CO_2 is the most prevalent greenhouse gas emitted into the atmosphere, the U.S. included five other greenhouse gases in its recent endangerment finding: methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride. The climate impact of these gases is commonly discussed in terms of their 100-year global warming potential (GWP). GWP measures the ability of different gases to trap heat in the atmosphere (*i.e.*, radiative forcing per unit of mass) over a particular timeframe relative to CO_2. However, because these gases differ in both radiative forcing and atmospheric lifetimes, their relative damages are not constant over time. For example, because methane has a short lifetime, its impacts occur primarily in the near term and thus are not discounted as heavily as those caused by longer-lived gases. Impacts other than temperature change also vary across gases in ways that are not captured by GWP. For instance, CO_2 emissions, unlike methane and other greenhouse gases, contribute to ocean acidification. Likewise, damages from methane emissions are not offset by the positive effect of CO_2 fertilization. Thus, transforming gases into CO_2-equivalents using GWP, and then multiplying the carbon-equivalents by the SCC, would not result in accurate estimates of the social costs of non-CO_2 gases.

In light of these limitations, and the significant contributions of non-CO_2 emissions to climate change, further research is required to link non-CO_2 emissions to economic impacts. Such work would feed into efforts to develop a monetized value of reductions in non-CO_2 greenhouse gas emissions. As part of ongoing work to further improve the SCC estimates, the interagency group hopes to develop methods to value these other greenhouse gases. The goal is to develop these estimates by the time we issue revised SCC estimates for CO_2 emissions.

14A.4.4 Equilibrium Climate Sensitivity

Equilibrium climate sensitivity (ECS) is a key input parameter for the DICE, PAGE, and FUND models.[i] It is defined as the long-term increase in the annual global-average surface temperature from a doubling of atmospheric CO_2 concentration relative to pre-industrial levels (or stabilization at a concentration of approximately 550 parts per million (ppm)). Uncertainties in this important parameter have received substantial attention in the peer-reviewed literature.

The most authoritative statement about equilibrium climate sensitivity appears in the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC):

> Basing our assessment on a combination of several independent lines of evidence…including observed climate change and the strength of known feedbacks simulated in [global climate models], we conclude that the global mean equilibrium warming for doubling CO_2, or

[i] The equilibrium climate sensitivity includes the response of the climate system to increased greenhouse gas concentrations over the short to medium term (up to 100–200 years), but it does not include long-term feedback effects due to possible large-scale changes in ice sheets or the biosphere, which occur on a time scale of many hundreds to thousands of years (*e.g.*, Hansen *et al*. 2007).

'equilibrium climate sensitivity,' is likely to lie in the range 2 °C to 4.5 °C, with a most likely value of about 3 °C. Equilibrium climate sensitivity is very likely larger than 1.5 °C.[j]

For fundamental physical reasons as well as data limitations, values substantially higher than 4.5 °C still cannot be excluded, but agreement with observations and proxy data is generally worse for those high values than for values in the 2 °C to 4.5 °C range. (Meehl *et al*. 2007, p. 799)

After consulting with several lead authors of this chapter of the IPCC report, the interagency workgroup selected four candidate probability distributions and calibrated them to be consistent with the above statement: Roe and Baker (2007), log-normal, gamma, and Weibull. Table 14A.4.1 gives summary statistics for the four calibrated distributions.

Table 14A.4.1 Summary Statistics for Four Calibrated Climate Sensitivity Distributions

Rank	Roe & Baker	Log-Normal	Gamma	Weibull
Pr(ECS < 1.5 °C)	0.013	0.050	0.070	0.102
Pr(2 °C < ECS < 4.5 °C)	0.667	0.667	0.667	0.667
5th Percentile	1.72	1.49	1.37	1.13
10th Percentile	1.91	1.74	1.65	1.48
Mode	2.34	2.52	2.65	2.90
Median (50th percentile)	3.00	3.00	3.00	3.00
Mean	3.50	3.28	3.19	3.07
90th Percentile	5.86	5.14	4.93	4.69
95th Percentile	7.14	5.97	5.59	5.17

Each distribution was calibrated by applying three constraints from the IPCC:

1. a median equal to 3 °C, to reflect the judgment of "a most likely value of about 3 °C;"[k]
2. two-thirds probability that the equilibrium climate sensitivity lies between 2 and 4.5 °C; and
3. zero probability that it is less than 0 °C or greater than 10 °C (Hegerl *et al.* 2006, p. 721).

We selected the calibrated Roe and Baker distribution from the four candidates for two reasons. First, the Roe and Baker distribution is the only one of the four that is based on a

[j] This is in accord with the judgment that it "is likely to lie in the range 2 °C to 4.5 °C" and the IPCC definition of "likely" as greater than 66 percent probability (Le Treut *et al*. 2007). "Very likely" indicates a greater than 90 percent probability.

[k] Strictly speaking, "most likely" refers to the mode of a distribution rather than the median, but common usage would allow the mode, median, or mean to serve as candidates for the central or "most likely" value and the IPCC report is not specific on this point. For the distributions we considered, the median was between the mode and the mean. For the Roe and Baker distribution, setting the median equal to 3 °C, rather than the mode or mean, gave a 95th percentile that is more consistent with IPCC judgments and the literature. For example, setting the mean and mode equal to 3 °C produced 95th percentiles of 5.6 and 8.6 °C, respectively, which are in the lower and upper end of the range in the literature. Finally, the median is closer to 3 °C than is the mode for the truncated distributions selected by the IPCC (Hegerl *et al*. 2006); the average median is 3.1 °C and the average mode is 2.3 °C, which is most consistent with a Roe and Baker distribution with the median set equal to 3 °C.

theoretical understanding of the response of the climate system to increased greenhouse gas concentrations (Roe and Baker 2007; Roe 2008). In contrast, the other three distributions are mathematical functions that are arbitrarily chosen based on simplicity, convenience, and general shape. The Roe and Baker distribution results from three assumptions about climate response: (1) absent feedback effects, the equilibrium climate sensitivity is equal to 1.2 °C; (2) feedback factors are proportional to the change in surface temperature; and (3) uncertainties in feedback factors are normally distributed. There is widespread agreement on the first point and the second and third points are common assumptions.

Second, the calibrated Roe and Baker distribution better reflects the IPCC judgment that "values substantially higher than 4.5°C still cannot be excluded." Although the IPCC made no quantitative judgment, the 95th percentile of the calibrated Roe & Baker distribution (7.1 °C) is much closer to the mean and the median (7.2 °C) of the 95th percentiles of 21 previous studies summarized by Newbold and Daigneault (2009). It is also closer to the mean (7.5 °C) and median (7.9 °C) of the nine truncated distributions examined by the IPCC (Hegerl *et al*. 2006) than are the 95th percentiles of the three other calibrated distributions (5.2–6.0 °C).

Finally, we note the IPCC judgment that the equilibrium climate sensitivity "is very likely larger than 1.5°C." Although the calibrated Roe & Baker distribution, for which the probability of equilibrium climate sensitivity being greater than 1.5 °C is almost 99 percent, is not inconsistent with the IPCC definition of "very likely" as "greater than 90 percent probability," it reflects a greater degree of certainty about very low values of ECS than was expressed by the IPCC.

To show how the calibrated Roe and Baker distribution compares to different estimates of the probability distribution function of equilibrium climate sensitivity in the empirical literature, Figure 14A.4.3 overlays it on Figure 14A.9.2 from the IPCC Fourth Assessment Report. These functions are scaled to integrate to unity between 0 °C and 10 °C. The horizontal bars show the respective 5 percent to 95 percent ranges; dots indicate the median estimate.[1]

[1] The estimates based on instrumental data are from Andronova and Schlesinger (2001), Forest *et al*. (2002; dashed line, anthropogenic forcings only), Forest *et al*. (2006; solid line, anthropogenic and natural forcings), Gregory *et al*. (2002), Knutti *et al*. (2002), Frame *et al*. (2005), and Forster and Gregory (2006). Hegerl *et al*. (2006) are based on multiple palaeoclimatic reconstructions of north hemisphere mean temperatures over the last 700 years. Also shown are the 5–95 percent approximate ranges for two estimates from the last glacial maximum (dashed, Annan *et al*. 2005; solid, Schneider von Deimling *et al*. 2006), which are based on models with different structural properties.

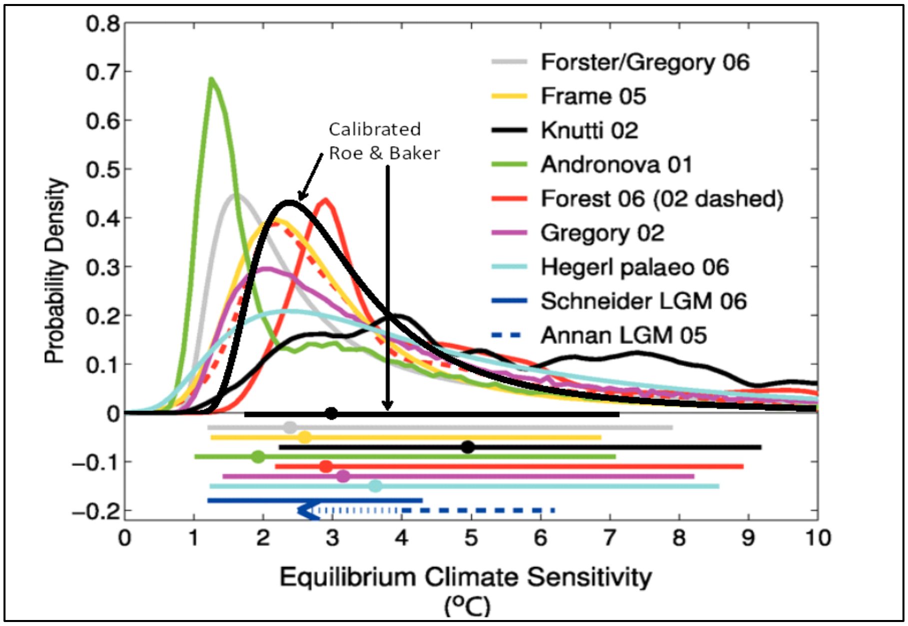

Figure 14A.4.3 Estimates of the Probability Density Function for Equilibrium Climate Sensitivity

14A.4.5 Socio-Economic and Emissions Trajectories

Another key issue considered by the interagency group is how to select the set of socio-economic and emissions parameters for use in PAGE, DICE, and FUND. Socio-economic pathways are closely tied to climate damages because, all else equal, more and wealthier people tend to emit more greenhouse gases and also have a higher (absolute) willingness to pay to avoid climate disruptions. For this reason, we consider how to model several input parameters in tandem: GDP, population, CO_2 emissions, and non-CO_2 radiative forcing. A wide variety of scenarios have been developed and used for climate change policy simulations (*e.g.*, SRES 2000, CCSP 2007, EMF 2009). In determining which scenarios are appropriate for inclusion, we aimed to select scenarios that span most of the plausible ranges of outcomes for these variables.

To accomplish this task in a transparent way, we decided to rely on the recent Stanford Energy Modeling Forum exercise, EMF-22, which uses ten well-recognized models to evaluate substantial, coordinated global action to meet specific stabilization targets. A key advantage of relying on these data is that GDP, population, and emission trajectories are internally consistent for each model and scenario evaluated. The EMF-22 modeling effort also is preferable to the IPCC SRES due to their age (SRES were developed in 1997) and the fact that 3 of 4 of the SRES scenarios are now extreme outliers in one or more variables. Although the EMF-22 scenarios have not undergone the same level of scrutiny as the SRES scenarios, they are recent, peer-reviewed, published, and publicly available.

To estimate the SCC for use in evaluating domestic policies that will have a small effect on global cumulative emissions, we use socio-economic and emission trajectories that span a range of plausible scenarios. Five trajectories were selected from EMF-22 (Table 14A.4.2). Four of these represent potential business-as-usual (BAU) growth in population, wealth, and emissions and are associated with CO_2 (only) concentrations ranging from 612 to 889 ppm in

2100. One represents an emissions pathway that achieves stabilization at 550 ppm CO_2e (*i.e.*, CO_2-only concentrations of 425–484 ppm or a radiative forcing of 3.7 W/m^2) in 2100, a lower-than-BAU trajectory.[m] Out of the 10 models included in the EMF-22 exercise, we selected the trajectories used by MiniCAM, MESSAGE, IMAGE, and the optimistic scenario from MERGE. For the BAU pathways, we used the GDP, population, and emission trajectories from each of these four models. For the 550 ppm CO_2e scenario, we averaged the GDP, population, and emission trajectories implied by these same four models.

Table 14A.4.2 Socioeconomic and Emissions Projections from Select EMF-22 Reference Scenarios

Reference Fossil and Industrial CO_2 Emissions ***$GtCO_2/yr$***						
EMF – 22 Based Scenarios	**2000**	**2010**	**2020**	**2030**	**2050**	**2100**
IMAGE	26.6	31.9	36.9	40.0	45.3	60.1
MERGE Optimistic	24.6	31.5	37.6	45.1	66.5	117.9
MESSAGE	26.8	29.2	37.6	42.1	43.5	42.7
MiniCAM	26.5	31.8	38.0	45.1	57.8	80.5
550 ppm average	26.2	31.1	33.2	32.4	20.0	12.8
Reference GDP ***market exchange rates in trillion 2005$***[n]						
EMF – 22 Based Scenarios	**2000**	**2010**	**2020**	**2030**	**2050**	**2100**
IMAGE	38.6	53.0	73.5	97.2	156.3	396.6
MERGE Optimistic	36.3	45.9	59.7	76.8	122.7	268.0
MESSAGE	38.1	52.3	69.4	91.4	153.7	334.9
MiniCAM	36.1	47.4	60.8	78.9	125.7	369.5
550 ppm average	37.1	49.6	65.6	85.5	137.4	337.9
Global Population ***billions***						
EMF – 22 Based Scenarios	**2000**	**2010**	**2020**	**2030**	**2050**	**2100**
IMAGE	6.1	6.9	7.6	8.2	9.0	9.1
MERGE Optimistic	6.0	6.8	7.5	8.2	9.0	9.7
MESSAGE	6.1	6.9	7.7	8.4	9.4	10.4
MiniCAM	6.0	6.8	7.5	8.1	8.8	8.7

[m] Such an emissions path would be consistent with widespread action by countries to mitigate GHG emissions, though it could also result from technological advances. It was chosen because it represents the most stringent case analyzed by the EMF-22 where all the models converge: a 550 ppm, not to exceed, full participation scenario.

[n] While the EMF-22 models used market exchange rates (MER) to calculate global GDP, it is also possible to use purchasing power parity (PPP), which takes into account the different price levels across countries, so it more accurately describes relative standards of living across countries. MERs tend to make low-income countries appear poorer than they actually are. Because many models assume convergence in per capita income over time, use of MER-adjusted GDP gives rise to projections of higher economic growth in low income countries. There is an ongoing debate about how much this will affect estimated climate impacts. Critics of the use of MER argue that it leads to overstated economic growth and hence a significant upward bias in projections of greenhouse gas emissions, and unrealistically high future temperatures (*e.g.*, Castles and Henderson 2003). Others argue that convergence of the emissions-intensity gap across countries at least partially offset the overstated income gap so that differences in exchange rates have less of an effect on emissions (Holtsmark and Alfsen, 2005; Tol, 2006). Nordhaus (2007b) argues that the ideal approach is to use superlative PPP accounts (*i.e.*, using cross-sectional PPP measures for relative incomes and outputs and national accounts price and quantity indexes for time-series extrapolations). However, he notes that it important to keep this debate in perspective; it is by no means clear that exchange-rate-conversion issues are as important as uncertainties about population, technological change, or the many geophysical uncertainties.

Reference Fossil and Industrial CO_2 Emissions *$GtCO_2/yr$*						
550 ppm average	6.1	6.8	7.6	8.2	8.7	9.1

We explore how sensitive the SCC is to various assumptions about how the future will evolve without prejudging what is likely to occur. The interagency group considered formally assigning probability weights to different states of the world, but this proved challenging to do in an analytically rigorous way given the dearth of information on the likelihood of a full range of future socio-economic pathways.

There are a number of caveats. First, EMF BAU scenarios represent the modelers' judgment of the most likely pathway absent mitigation policies to reduce greenhouse gas emissions, rather than the wider range of possible outcomes. Nevertheless, these views of the most likely outcome span a wide range, from the more optimistic (*e.g.*, abundant low-cost, low-carbon energy) to more pessimistic (*e.g.*, constraints on the availability of nuclear and renewables).[o] Second, the socio-economic trajectories associated with a 550 ppm CO_2e concentration scenario are not derived from an assessment of what policy is optimal from a benefit-cost standpoint. Rather, it is indicative of one possible future outcome. The emission trajectories underlying some BAU scenarios (*e.g.*, MESSAGE's 612 ppm) also are consistent with some modest policy action to address climate change.[p] We chose not to include socio-economic trajectories that achieve even lower GHG concentrations at this time, given the difficulty many models had in converging to meet these targets.

For comparison purposes, the Energy Information Agency in its 2009 *Annual Energy Outlook* projected that global CO_2 emissions will grow to 30.8, 35.6, and 40.4 gigatons in 2010, 2020, and 2030, respectively, while world GDP is projected to be \$51.8, \$71.0 and \$93.9 trillion (2005\$ using market exchange rates) in 2010, 2020, and 2030, respectively. These projections are consistent with one or more EMF-22 scenarios. Likewise, the United Nations' 2008 Population Prospect projects population will grow from 6.1 billion people in 2000 to 9.1 billion people in 2050, which is close to the population trajectories for the IMAGE, MiniCAM, and MERGE models.

In addition to fossil and industrial CO_2 emissions, each EMF scenario provides projections of methane, nitrous oxide, fluorinated greenhouse gases, and net land use CO_2 emissions out to 2100. These assumptions also are used in the three models while retaining the default radiative forcings due to other factors (*e.g.*, aerosols and other gases). See the Appendix for greater detail.

[o] For instance, in the MESSAGE model's reference case total primary energy production from nuclear, biomass, and non-biomass renewables is projected to increase from about 15 percent of total primary energy in 2000 to 54 percent in 2100. In comparison, the MiniCAM reference case shows 10 percent in 2000 and 21 percent in 2100.

[p] For example, MiniCAM projects if all non-US OECD countries reduce CO_2 emissions to 83 percent below 2005 levels by 2050 (per the G-8 agreement) but all other countries continue along a BAU path CO_2 concentrations in 2100 would drop from 794 ppmv in its reference case to 762 ppmv.

14A.4.6 Discount Rate

The choice of a discount rate, especially over long periods of time, raises highly contested and exceedingly difficult questions of science, economics, philosophy, and law. Although it is well understood that the discount rate has a large influence on the current value of future damages, there is no consensus about what rates to use in this context. Because CO_2 emissions are long-lived, subsequent damages occur over many years. In calculating the SCC, we first estimate the future damages to agriculture, human health, and other market and non-market sectors from an additional unit of CO_2 emitted in a particular year in terms of reduced consumption (or consumption equivalents) due to the impacts of elevated temperatures, as represented in each of the three IAMs. Then we discount the stream of future damages to its present value in the year when the additional unit of emissions was released using the selected discount rate, which is intended to reflect society's marginal rate of substitution between consumption in different time periods.

For rules with both intra- and intergenerational effects, agencies traditionally employ constant discount rates of both 3 percent and 7 percent in accordance with OMB Circular A-4. As Circular A-4 acknowledges, however, the choice of discount rate for intergenerational problems raises distinctive problems and presents considerable challenges. After reviewing those challenges, Circular A-4 states, "If your rule will have important intergenerational benefits or costs you might consider a further sensitivity analysis using a lower but positive discount rate in addition to calculating net benefits using discount rates of 3 and 7 percent." For the specific purpose of developing the SCC, we adapt and revise that approach here.

Arrow *et al.* (1996) outlined two main approaches to determine the discount rate for climate change analysis, which they labeled "descriptive" and "prescriptive." The descriptive approach reflects a positive (non-normative) perspective based on observations of people's actual choices—*e.g.*, savings versus consumption decisions over time, and allocations of savings among more and less risky investments. Advocates of this approach generally call for inferring the discount rate from market rates of return "because of a lack of justification for choosing a social welfare function that is any different than what decision makers [individuals] actually use" (Arrow *et al*. 1996).

One theoretical foundation for the cost-benefit analyses in which the social cost of carbon will be used—the Kaldor-Hicks potential-compensation test—also suggests that market rates should be used to discount future benefits and costs, because it is the market interest rate that would govern the returns potentially set aside today to compensate future individuals for climate damages that they bear (*e.g.*, Just *et al*. 2004). As some have noted, the word "potentially" is an important qualification; there is no assurance that such returns will actually be set aside to provide compensation, and the very idea of compensation is difficult to define in the intergenerational context. On the other hand, societies provide compensation to future generations through investments in human capital and the resulting increase in knowledge, as well as infrastructure and other physical capital.

The prescriptive approach specifies a social welfare function that formalizes the normative judgments that the decision-maker wants explicitly to incorporate into the policy evaluation—*e.g.*, how inter-personal comparisons of utility should be made, and how the welfare of future generations should be weighed against that of the present generation. Ramsey (1928), for example, has argued that it is "ethically indefensible" to apply a positive pure rate of time preference to discount values across generations, and many agree with this view.

Other concerns also motivate making adjustments to descriptive discount rates. In particular, it has been noted that the preferences of future generations with regard to consumption versus environmental amenities may not be the same as those today, making the current market rate on consumption an inappropriate metric by which to discount future climate-related damages. Others argue that the discount rate should be below market rates to correct for market distortions and uncertainties or inefficiencies in intergenerational transfers of wealth, which in the Kaldor-Hicks logic are presumed to compensate future generations for damage (a potentially controversial assumption, as noted above; Arrow *et al*. 1996, Weitzman 1999).

Further, a legitimate concern about both descriptive and prescriptive approaches is that they tend to obscure important heterogeneity in the population. The utility function that underlies the prescriptive approach assumes a representative agent with perfect foresight and no credit constraints. This is an artificial rendering of the real world that misses many of the frictions that characterize individuals' lives and indeed the available descriptive evidence supports this. For instance, many individuals smooth consumption by borrowing with credit cards that have relatively high rates. Some are unable to access traditional credit markets and rely on payday lending operations or other high cost forms of smoothing consumption. Whether one puts greater weight on the prescriptive or descriptive approach, the high interest rates that credit-constrained individuals accept suggest that some account should be given to the discount rates revealed by their behavior.

We draw on both approaches but rely primarily on the descriptive approach to inform the choice of discount rate. With recognition of its limitations, we find this approach to be the most defensible and transparent given its consistency with the standard contemporary theoretical foundations of benefit-cost analysis and with the approach required by OMB's existing guidance. The logic of this framework also suggests that market rates should be used for discounting future consumption-equivalent damages. Regardless of the theoretical approach used to derive the appropriate discount rate(s), we note the inherent conceptual and practical difficulties of adequately capturing consumption trade-offs over many decades or even centuries. While relying primarily on the descriptive approach in selecting specific discount rates, the interagency group has been keenly aware of the deeply normative dimensions of both the debate over discounting in the intergenerational context and the consequences of selecting one discount rate over another.

14A.4.6.1 Historically Observed Interest Rates

In a market with no distortions, the return to savings would equal the private return on investment, and the market rate of interest would be the appropriate choice for the social discount rate. In the real world risk, taxes, and other market imperfections drive a wedge between the risk-free rate of return on capital and the consumption rate of interest. Thus, the literature recognizes two conceptual discount concepts—the consumption rate of interest and the opportunity cost of capital.

According to OMB's Circular A-4, it is appropriate to use the rate of return on capital when a regulation is expected to displace or alter the use of capital in the private sector. In this case, OMB recommends Agencies use a discount rate of 7 percent. When regulation is expected to primarily affect private consumption—for instance, via higher prices for goods and services—a lower discount rate of 3 percent is appropriate to reflect how private individuals trade-off current and future consumption.

The interagency group examined the economics literature and concluded that the consumption rate of interest is the correct concept to use in evaluating the benefits and costs of a marginal change in carbon emissions (Lind 1990, Arrow *et al*. 1996, Arrow 2000). The consumption rate of interest also is appropriate when the impacts of a regulation are measured in consumption (-equivalent) units, as is done in the three integrated assessment models used for estimating the SCC.

Individuals use a variety of savings instruments that vary with risk level, time horizon, and tax characteristics. The standard analytic framework used to develop intuition about the discount rate typically assumes a representative agent with perfect foresight and no credit constraints. The risk-free rate is appropriate for discounting certain future benefits or costs, but the benefits calculated by IAMs are uncertain. To use the risk-free rate to discount uncertain benefits, these benefits first must be transformed into "certainty equivalents," *i.e.*, the maximum certain amount that we would exchange for the uncertain amount. However, the calculation of the certainty-equivalent requires first estimating the correlation between the benefits of the policy and baseline consumption.

If the IAM projections of future impacts represent expected values (not certainty-equivalent values), then the appropriate discount rate generally does not equal the risk-free rate. If the benefits of the policy tend to be high in those states of the world in which consumption is low, then the certainty-equivalent benefits will be higher than the expected benefits (and vice versa). Since many (though not necessarily all) of the important impacts of climate change will flow through market sectors such as agriculture and energy, and since willingness to pay for environmental protections typically increases with income, we might expect a positive (though not necessarily perfect) correlation between the net benefits from climate policies and market returns. This line of reasoning suggests that the proper discount rate would exceed the riskless rate. Alternatively, a negative correlation between the returns to climate policies and market returns would imply that a discount rate below the riskless rate is appropriate.

This discussion suggests that both the post-tax riskless and risky rates can be used to capture individuals' consumption-equivalent interest rate. As a measure of the post-tax riskless rate, we calculate the average real return from Treasury notes over the longest time period available (those from Newell and Pizer 2003) and adjust for Federal taxes (the average marginal rate from tax years 2003 through 2006 is around 27 percent).[q] This calculation produces a real interest rate of about 2.7 percent, which is roughly consistent with Circular A-4's

[q] The literature argues for a risk-free rate on government bonds as an appropriate measure of the consumption rate of interest. Arrow (2000) suggests that it is roughly 3-4 percent. OMB cites evidence of a 3.1 percent pre-tax rate for 10-year Treasury notes in the A-4 guidance. Newell and Pizer (2003) find real interest rates between 3.5 and 4 percent for 30-year Treasury securities.

recommendation to use 3 percent to represent the consumption rate of interest.[r] A measure of the post-tax risky rate for investments whose returns are positively correlated with overall equity market returns can be obtained by adjusting pre-tax rates of household returns to risky investments (approximately 7 percent) for taxes yields a real rate of roughly 5 percent.[s]

14A.4.6.2 The Ramsey Equation

Ramsey discounting also provides a useful framework to inform the choice of a discount rate. Under this approach, the analyst applies either positive or normative judgments in selecting values for the key parameters of the Ramsey equation: η (coefficient of relative risk aversion or elasticity of the marginal utility of consumption) and ρ (pure rate of time preference).[t] These are then combined with g (growth rate of per-capita consumption) to equal the interest rate at which future monetized damages are discounted: $\rho + \eta \cdot g$.[u] In the simplest version of the Ramsey model, with an optimizing representative agent with perfect foresight, what we are calling the "Ramsey discount rate," $\rho + \eta \cdot g$, will be equal to the rate of return to capital, *i.e.*, the market interest rate.

A review of the literature provides some guidance on reasonable parameter values for the Ramsey discounting equation, based on both prescriptive and descriptive approaches.

- η. Most papers in the climate change literature adopt values for η in the range of 0.5 to 3 (Weitzman cites plausible values as those ranging from 1 to 4), although not all authors articulate whether their choice is based on prescriptive or descriptive

[r] The positive approach reflects how individuals make allocation choices across time, but it is important to keep in mind that we wish to reflect preferences for society as a whole, which generally has a longer planning horizon.
[s] Cambell *et al*. (2001) estimates that the annual real return from stocks for 1900-1995 was about 7 percent. The annual real rate of return for the S&P 500 from 1950–2008 was about 6.8 percent. In the absence of a better way to population-weight the tax rates, we use the middle of the 20–40 percent range to derive a post-tax interest rate (Kotlikoff and Rapson 2006).
[t] The parameter ρ measures the *pure rate of time preference*: people's behavior reveals a preference for an increase in utility today versus the future. Consequently, it is standard to place a lower weight on utility in the future. The parameter η captures *diminishing marginal utility*: consumption in the future is likely to be higher than consumption today, so diminishing marginal utility of consumption implies that the same monetary damage will cause a smaller reduction of utility for wealthier individuals, either in the future or in current generations. If $\eta = 0$, then a one dollar increase in income is equally valuable regardless of level of income; if $\eta = 1$, then a one percent increase in income is equally valuable no matter the level of income; and if $\eta > 1$, then a one percent increase in income is less valuable to wealthier individuals.
[u] In this case, g could be taken from the selected EMF socioeconomic scenarios or alternative assumptions about the rate of consumption growth.

reasoning.[v] Dasgupta (2008) argues that η should be greater than 1 and may be as high as 3, since η equal to 1 suggests savings rates that do not conform to observed behavior.

- ρ. With respect to the pure rate of time preference, most papers in the climate change literature adopt values for ρ in the range of 0 to 3 percent per year. The very low rates tend to follow from moral judgments involving intergenerational neutrality. Some have argued that to use any value other than $\rho = 0$ would unjustly discriminate against future generations (*e.g.*, Arrow *et al*. 1996, Stern 2006). However, even in an intergenerational setting, it may make sense to use a small positive pure rate of time preference because of the small probability of unforeseen cataclysmic events (Stern 2006).

- g. A commonly accepted approximation is around 2 percent per year. For the socioeconomic scenarios used for this exercise, the EMF models assume that g is about 1.5–2 percent to 2100.

Some economists and non-economists have argued for constant discount rates below 2 percent based on the prescriptive approach. When grounded in the Ramsey framework, proponents of this approach have argued that a ρ of zero avoids giving preferential treatment to one generation over another. The choice of η has also been posed as an ethical choice linked to the value of an additional dollar in poorer countries compared to wealthier ones. Stern (2006) applies this perspective through his choice of $\rho = 0.1$ percent per year, $\eta = 1$ and $g = 1.3$ percent per year, which yields an annual discount rate of 1.4 percent. In the context of permanent income savings behavior, however, Stern's assumptions suggest that individuals would save 93 percent of their income.[w]

Recently, Stern (2008) revisited the values used in Stern (2006), stating that there is a case to be made for raising η due to the amount of weight lower values place on damages far in the future (over 90 percent of expected damages occur after 2200 with $\eta = 1$). Using Stern's assumption that $\rho = 0.1$ percent, combined with a η of 1.5 to 2 and his original growth rate, yields a discount rate greater 2 percent.

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[v] Empirical estimates of η span a wide range of values. A benchmark value of 2 is near the middle of the range of values estimated or used by Szpiro (1986), Hall and Jones (2007), Arrow (2007), Dasgupta (2006, 2008), Weitzman (2007, 2009), and Nordhaus (2008). However, Chetty (2006) developed a method of estimating η using data on labor supply behavior. He shows that existing evidence of the effects of wage changes on labor supply imposes a tight upper bound on the curvature of utility over wealth (CRRA < 2) with the mean implied value of 0.71 and concludes that the standard expected utility model cannot generate high levels of risk aversion without contradicting established facts about labor supply. Recent work has jointly estimated the components of the Ramsey equation. Evans and Sezer (2005) estimate $\eta = 1.49$ for 22 OECD countries. They also estimate $\rho = 1.08$ percent per year using data on mortality rates. Anthoff *et al*. (2009b) estimate $\eta = 1.18$, and $\rho = 1.4$ percent. When they multiply the bivariate probability distributions from their work and Evans and Sezer (2005) together, they find $\eta = 1.47$, and $\rho = 1.07$.

[w] Stern (2008) argues that building in a positive rate of exogenous technical change over time reduces the implied savings rate and that η at or above 2 are inconsistent with observed behavior with regard to equity. (At the same time, adding exogenous technical change—all else equal—would increase g as well.)

We conclude that arguments made under the prescriptive approach can be used to justify discount rates between roughly 1.4 and 3.1 percent. In light of concerns about the most appropriate value for η, we find it difficult to justify rates at the lower end of this range under the Ramsey framework.

14A.4.6.3 Accounting for Uncertainty in the Discount Rate

While the consumption rate of interest is an important driver of the benefits estimate, it is uncertain over time. Ideally, we would formally model this uncertainty, just as we do for climate sensitivity. Weitzman (1998, 2001) showed theoretically and Newell and Pizer (2003) and Panipoulou *et al.* (2004) confirm empirically that discount rate uncertainty can have a large effect on net present values. A main result from these studies is that if there is a persistent element to the uncertainty in the discount rate (*e.g.*, the rate follows a random walk), then it will result in an effective (or certainty-equivalent) discount rate that declines over time. Consequently, lower discount rates tend to dominate over the very long term (Weitzman 1998, 1999, 2001; Newell and Pizer 2003; Panipoulou *et al.* (2004); Gollier 2008; Summers and Zeckhauser 2008; and Gollier and Weitzman 2009).

The proper way to model discount rate uncertainty remains an active area of research. Newell and Pizer (2003) employ a model of how long-term interest rates change over time to forecast future discount rates. Their model incorporates some of the basic features of how interest rates move over time, and its parameters are estimated based on historical observations of long-term rates. Subsequent work on this topic, most notably Panipoulou *et al.* (2004), uses more general models of interest rate dynamics to allow for better forecasts. Specifically, the volatility of interest rates depends on whether rates are currently low or high and variation in the level of persistence over time.

While Newell and Pizer (2003) and Panipoulou *et al.* (2004) attempt formally to model uncertainty in the discount rate, others argue for a declining scale of discount rates applied over time (*e.g.*, Weitzman 2001, and the UK's "Green Book" for regulatory analysis). This approach uses a higher discount rate initially, but applies a graduated scale of lower discount rates further out in time.[x] A key question that has emerged with regard to both of these approaches is the trade-off between potential time inconsistency and giving greater weight to far future outcomes (see the EPA Science Advisory Board's recent comments on this topic as part of its review of their *Guidelines for Economic Analysis*).[y]

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[x] For instance, the UK applies a discount rate of 3.5 percent to the first 30 years; 3 percent for years 31–75; 2.5 percent for years 76–125; 2 percent for years 126–200; 1.5 percent for years 201–300; and 1 percent after 300 years. As a sensitivity, it recommends a discount rate of 3 percent for the first 30 years, also decreasing over time.

[y] Uncertainty in future damages is distinct from uncertainty in the discount rate. Weitzman (2008) argues that Stern's choice of a low discount rate was "right for the wrong reasons." He demonstrates how the damages from a low probability, catastrophic event far in the future dominate the effect of the discount rate in a present value calculation and result in an infinite willingness-to-pay for mitigation today. Newbold and Daigneault, (2009) and Nordhaus (2009) find that Weitzman's result is sensitive to the functional forms chosen for climate sensitivity, utility, and consumption. Summers and Zeckhauser (2008) argue that uncertainty in future damages can also work in the other direction by increasing the benefits of waiting to learn the appropriate level of mitigation required.

14A.4.6.4 The Discount Rates Selected for Estimating SCC

In light of disagreement in the literature on the appropriate market interest rate to use in this context and uncertainty about how interest rates may change over time, we use three discount rates to span a plausible range of certainty-equivalent constant discount rates: 2.5, 3, and 5 percent per year. Based on the review in the previous sections, the interagency workgroup determined that these three rates reflect reasonable judgments under both descriptive and prescriptive approaches.

The central value (3 percent) is consistent with estimates provided in the economics literature and OMB's Circular A-4 guidance for the consumption rate of interest. As previously mentioned, the consumption rate of interest is the correct discounting concept to use when future damages from elevated temperatures are estimated in consumption-equivalent units. Further, 3 percent roughly corresponds to the after-tax riskless interest rate. The upper value of 5 percent is included to represent the possibility that climate damages are positively correlated with market returns. Additionally, this discount rate may be justified by the high interest rates that many consumers use to smooth consumption across periods.

The low value (2.5 percent) is included to incorporate the concern that interest rates are highly uncertain over time. It represents the average certainty-equivalent rate using the mean-reverting and random walk approaches from Newell and Pizer (2003) starting at a discount rate of 3 percent. Using this approach, the certainty equivalent is about 2.2 percent using the random walk model and 2.8 percent using the mean reverting approach.[z] Without giving preference to a particular model, the average of the two rates is 2.5 percent. Further, a rate below the riskless rate would be justified if climate investments are negatively correlated with the overall market rate of return. Use of this lower value also responds to certain judgments using the prescriptive or normative approach and to ethical objections that have been raised about rates of 3 percent or higher.

14A.5 REVISED SCC ESTIMATES

Our general approach to estimating SCC values is to run the three integrated assessment models (FUND, DICE, and PAGE) using the following inputs agreed upon by the interagency group:

- A Roe and Baker distribution for the climate sensitivity parameter bounded between 0 and 10 with a median of 3 °C and a cumulative probability between 2 and 4.5 °C of two-thirds.
- Five sets of GDP, population and carbon emissions trajectories based on EMF-22.
- Constant annual discount rates of 2.5, 3, and 5 percent.

[z] Calculations done by Pizer *et al*. using the original simulation program from Newell and Pizer (2003).

Because the climate sensitivity parameter is modeled probabilistically, and because PAGE and FUND incorporate uncertainty in other model parameters, the final output from each model run is a distribution over the SCC in year *t*.

For each of the IAMS, the basic computational steps for calculating the SCC in a particular year *t* are:

1) Input the path of emissions, GDP, and population from the selected EMF-22 scenarios, and the extrapolations based on these scenarios for post-2100 years.

2) Calculate the temperature effects and (consumption-equivalent) damages in each year resulting from the baseline path of emissions.

    a) In PAGE, the consumption-equivalent damages in each period are calculated as a fraction of the EMF GDP forecast, depending on the temperature in that period relative to the pre-industrial average temperature in each region.

    b) In FUND, damages in each period depend on both the level and the rate of temperature change in that period.

    c) In DICE, temperature affects both consumption and investment, so we first adjust the EMF GDP paths as follows: Using the Cobb-Douglas production function with the DICE2007 parameters, we extract the path of exogenous technical change implied by the EMF GDP and population paths, then we recalculate the baseline GDP path taking into account climate damages resulting from the baseline emissions path.

3) Add an additional unit of carbon emissions in year *t*. (The exact unit varies by model.)

4) Recalculate the temperature effects and damages expected in all years beyond *t* resulting from this adjusted path of emissions, as in step 2.

5) Subtract the damages computed in step 2 from those in step 4 in each year. (DICE is run in 10 year time steps, FUND in annual time steps, while the time steps in PAGE vary.)

6) Discount the resulting path of marginal damages back to the year of emissions using the agreed upon fixed discount rates.

7) Calculate the SCC as the net present value of the discounted path of damages computed in step 6, divided by the unit of carbon emissions used to shock the models in step 3.

8) Multiply by 12/44 to convert from dollars per ton of carbon to dollars per ton of CO_2 (2007 dollars) in DICE and FUND. (All calculations are done in tons of CO_2 in PAGE).

The steps above were repeated in each model for multiple future years to cover the time horizons anticipated for upcoming rulemaking analysis. To maintain consistency across the three IAMs, climate damages are calculated as lost consumption in each future year.

It is important to note that each of the three models has a different default end year. The default time horizon is 2200 for PAGE, 2595 for DICE, and 3000 for the latest version of FUND. This is an issue for the multi-model approach because differences in SCC estimates may arise simply due to the model time horizon. Many consider 2200 too short a time horizon because it could miss a significant fraction of damages under certain assumptions about the growth of marginal damages and discounting, so each model is run here through 2300. This step required a small adjustment in the PAGE model only. This step also required assumptions about GDP, population, and greenhouse gas emission trajectories after 2100, the last year for which these data are available from the EMF-22 models. (A more detailed discussion of these assumptions is included in the Appendix.)

This exercise produces 45 separate distributions of the SCC for a given year, the product of 3 models, 3 discount rates, and 5 socioeconomic scenarios. This is clearly too many separate distributions for consideration in a regulatory impact analysis.

To produce a range of plausible estimates that still reflects the uncertainty in the estimation exercise, the distributions from each of the models and scenarios are equally weighed and combined to produce three separate probability distributions for SCC in a given year, one for each assumed discount rate. These distributions are then used to define a range of point estimates for the global SCC. In this way, no integrated assessment model or socioeconomic scenario is given greater weight than another. Because the literature shows that the SCC is quite sensitive to assumptions about the discount rate, and because no consensus exists on the appropriate rate to use in an intergenerational context, we present SCCs based on the average values across models and socioeconomic scenarios for each discount rate.

The interagency group selected four SCC values for use in regulatory analyses. Three values are based on the average SCC across models and socio-economic and emissions scenarios at the 2.5-, 3-, and 5-percent discount rates. The fourth value is included to represent the higher-than-expected economic impacts from climate change further out in the tails of the SCC distribution. For this purpose, we use the SCC value for the 95th percentile at a 3-percent discount rate. (The full set of distributions by model and scenario combination is included in the Appendix.) As noted above, the 3-percent discount rate is the central value, and so the central value that emerges is the average SCC across models at the 3-percent discount rate. For purposes of capturing the uncertainties involved in regulatory impact analysis, we emphasize the importance and value of considering the full range.

As previously discussed, low probability, high impact events are incorporated into the SCC values through explicit consideration of their effects in two of the three models as well as the use of a probability density function for equilibrium climate sensitivity. Treating climate sensitivity probabilistically results in more high temperature outcomes, which in turn lead to higher projections of damages. Although FUND does not include catastrophic damages (in contrast to the other two models), its probabilistic treatment of the equilibrium climate sensitivity parameter will directly affect the non-catastrophic damages that are a function of the rate of temperature change.

In Table 14A.5.1**,** we begin by presenting SCC estimates for 2010 by model, scenario, and discount rate to illustrate the variability in the SCC across each of these input parameters. As expected, higher discount rates consistently result in lower SCC values, while lower discount rates result in higher SCC values for each socioeconomic trajectory. It is also evident that there are differences in the SCC estimated across the three main models. For these estimates, FUND produces the lowest estimates, while PAGE generally produces the highest estimates.

Table 14A.5.1 Disaggregated Social Cost of CO_2 Values by Model, Socio-Economic Trajectory, and Discount Rate for 2010 (2007$)

	Discount Rate:	**5%**	**3%**	**2.5%**	**3%**
Model	**Scenario**	**Avg**	**Avg**	**Avg**	**95th**
DICE	IMAGE	10.8	35.8	54.2	70.8
	MERGE	7.5	22.0	31.6	42.1
	Message	9.8	29.8	43.5	58.6
	MiniCAM	8.6	28.8	44.4	57.9
	550 Average	8.2	24.9	37.4	50.8
PAGE	IMAGE	8.3	39.5	65.5	142.4
	MERGE	5.2	22.3	34.6	82.4
	Message	7.2	30.3	49.2	115.6
	MiniCAM	6.4	31.8	54.7	115.4
	550 Average	5.5	25.4	42.9	104.7
FUND	IMAGE	-1.3	8.2	19.3	39.7
	MERGE	-0.3	8.0	14.8	41.3
	Message	-1.9	3.6	8.8	32.1
	MiniCAM	-0.6	10.2	22.2	42.6
	550 Average	-2.7	-0.2	3.0	19.4

These results are not surprising when compared to the estimates in the literature for the latest versions of each model. For example, adjusting the values from the literature that were used to develop interim SCC values to 2007 dollars for the year 2010 (assuming, as we did for the interim process, that SCC grows at 3 percent per year), FUND yields SCC estimates at or near zero for a 5-percent discount rate and around $9 per ton for a 3-percent discount rate. There are far fewer estimates using the latest versions of DICE and PAGE in the literature: Using similar adjustments to generate 2010 estimates, we calculate a SCC from DICE (based on Nordhaus 2008) of around $9 per ton for a 5-percent discount rate, and a SCC from PAGE (based on Hope 2006, 2008) close to $8 per ton for a 4-percent discount rate. Note that these comparisons are only approximate since the literature generally relies on Ramsey discounting, while we have assumed constant discount rates.[aa]

[aa] Nordhaus (2008) runs DICE2007 with $\rho = 1.5$ and $\eta = 2$. The default approach in PAGE2002 (version 1.4epm) treats ρ and η as random parameters, specified using a triangular distribution such that the min, mode, and max = 0.1, 1, and 2 for ρ, and 0.5, 1, and 2 for η, respectively. The FUND default value for η is 1, and Tol generates SCC estimates for values of $\rho = 0$, 1, and 3 in many recent papers (*e.g.*, Anthoff *et al*. 2009). The path of per-capita consumption growth, g, varies over time but is treated deterministically in two of the three models. In DICE, g is endogenous. Under Ramsey discounting, as economic growth slows in the future, the large damages from climate change that occur far out in the future are discounted at a lower rate than impacts that occur in the nearer term.

The SCC estimates from FUND are sensitive to differences in emissions paths but relatively insensitive to differences in GDP paths across scenarios, while the reverse is true for DICE and PAGE. This likely occurs because of several structural differences among the models. Specifically in DICE and PAGE, the fraction of economic output lost due to climate damages increases with the level of temperature alone, whereas in FUND the fractional loss also increases with the rate of temperature change. Further, in FUND increases in income over time decrease vulnerability to climate change (a form of adaptation), whereas this does not occur in DICE and PAGE. These structural differences among the models make FUND more sensitive to the path of emissions and less sensitive to GDP compared to DICE and PAGE.

Figure 14A.5.1 shows that IMAGE has the highest GDP in 2100 while MERGE Optimistic has the lowest. The ordering of global GDP levels in 2100 directly corresponds to the rank ordering of SCC for PAGE and DICE. For FUND, the correspondence is less clear, a result that is to be expected given its less direct relationship between its damage function and GDP.

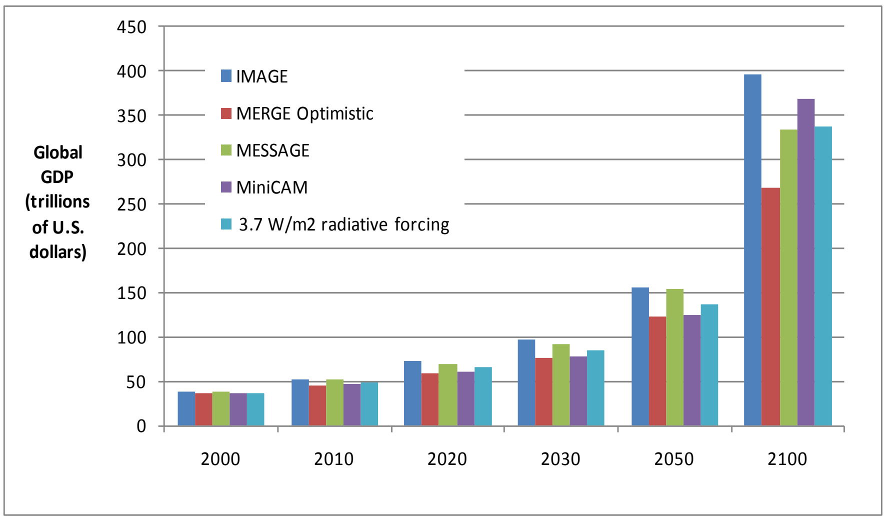

Figure 14A.5.1 Level of Global GDP Across EMF Scenarios

Table 14A.5.2 shows the four selected SCC values in 5-year increments from 2010 to 2050. Values for 2010, 2020, 2040, and 2050 are calculated by first combining all outputs (10,000 estimates per model run) from all scenarios and models for a given discount rate. Values for the years in between are calculated using a simple linear interpolation.

Table 14A.5.2 Social Cost of CO_2, 2010–2050 (2007$)

Discount Rate	5%	3%	2.5%	3%
Year	**Avg**	**Avg**	**Avg**	**95th**
2010	4.7	21.4	35.1	64.9
2015	5.7	23.8	38.4	72.8
2020	6.8	26.3	41.7	80.7
2025	8.2	29.6	45.9	90.4
2030	9.7	32.8	50.0	100.0
2035	11.2	36.0	54.2	109.7
2040	12.7	39.2	58.4	119.3
2045	14.2	42.1	61.7	127.8
2050	15.7	44.9	65.0	136.2

The SCC increases over time because future emissions are expected to produce larger incremental damages as physical and economic systems become more stressed in response to greater climatic change. Note that this approach allows us to estimate the growth rate of the SCC directly using DICE, PAGE, and FUND rather than assuming a constant annual growth rate as was done for the interim estimates (using 3 percent). This helps to ensure that the estimates are internally consistent with other modeling assumptions. Table 14A.5.3 illustrates how the growth rate for these four SCC estimates varies over time. The full set of annual SCC estimates between 2010 and 2050 is reported in the Appendix.

Table 14A.5.3 Changes in the Average Annual Growth Rates of SCC Estimates between 2010 and 2050

Average Annual Growth Rate	5%	3%	2.5%	3.0%
Year Range	**Avg**	**Avg**	**Avg**	**95th**
2010–2020	3.6	2.1	1.7	2.2
2020–2030	3.7	2.2	1.8	2.2
2030–2040	2.7	1.8	1.6	1.8
2040–2050	2.1	1.4	1.1	1.3

While the SCC estimate grows over time, the future monetized value of emissions reductions in each year (the SCC in year *t* multiplied by the change in emissions in year *t*) must be discounted to the present to determine its total net present value for use in regulatory analysis. Damages from future emissions should be discounted at the same rate as that used to calculate the SCC estimates themselves to ensure internal consistency—*i.e.*, future damages from climate change, whether they result from emissions today or emissions in a later year, should be discounted using the same rate. For example, climate damages in 2020 that are calculated using a SCC based on a 5-percent discount rate also should be discounted back to the analysis year using a 5-percent discount rate.[bb]

14A.6 LIMITATIONS OF THE ANALYSIS

As noted, any estimate of the SCC must be taken as provisional and subject to further refinement (and possibly significant change) in accordance with evolving scientific, economic, and ethical understandings. During the course of our modeling, it became apparent that there are several areas in particular need of additional exploration and research. These caveats and additional observations in the following section are necessary to consider when interpreting and applying the SCC estimates.

Incomplete treatment of non-catastrophic damages. The impacts of climate change are expected to be widespread, diverse, and heterogeneous. In addition, the exact magnitude of these impacts is uncertain because of the inherent complexity of climate processes, the economic behavior of current and future populations, and our inability to accurately forecast technological change and adaptation. Current IAMs do not assign value to all of the important physical, ecological, and economic impacts of climate change recognized in the climate change literature

[bb] However, it is possible that other benefits or costs of proposed regulations unrelated to CO_2 emissions will be discounted at rates that differ from those used to develop the SCC estimates.

(some of which are discussed above) because of lack of precise information on the nature of damages and because the science incorporated into these models understandably lags behind the most recent research. Our ability to quantify and monetize impacts will undoubtedly improve with time. It is also likely that even in future applications, a number of potentially significant damage categories will remain non-monetized. (Ocean acidification is one example of a potentially large damage from CO_2 emissions not quantified by any of the three models. Species and wildlife loss is another example that is exceedingly difficult to monetize.)

Incomplete treatment of potential catastrophic damages. There has been considerable recent discussion of the risk of catastrophic impacts and how best to account for extreme scenarios, such as the collapse of the Atlantic Meridional Overturning Circulation or the West Antarctic Ice Sheet, or large releases of methane from melting permafrost and warming oceans. Weitzman (2009) suggests that catastrophic damages are extremely large—so large, in fact, that the damages from a low probability, catastrophic event far in the future dominate the effect of the discount rate in a present value calculation and result in an infinite willingness-to-pay for mitigation today. However, Nordhaus (2009) concluded that the conditions under which Weitzman's results hold "are limited and do not apply to a wide range of potential uncertain scenarios."

Using a simplified IAM, Newbold and Daigneault (2009) confirmed the potential for large catastrophe risk premiums but also showed that the aggregate benefit estimates can be highly sensitive to the shapes of both the climate sensitivity distribution and the damage function at high temperature changes. Pindyck (2009) also used a simplified IAM to examine high-impact low-probability risks, using a right-skewed gamma distribution for climate sensitivity as well as an uncertain damage coefficient, but in most cases found only a modest risk premium. Given this difference in opinion, further research in this area is needed before its practical significance can be fully understood and a reasonable approach developed to account for such risks in regulatory analysis. (The next section discusses the scientific evidence on catastrophic impacts in greater detail.)

Uncertainty in extrapolation of damages to high temperatures. The damage functions in these IAMs are typically calibrated by estimating damages at moderate temperature increases (*e.g.*, DICE was calibrated at 2.5 °C) and extrapolated to far higher temperatures by assuming that damages increase as some power of the temperature change. Hence, estimated damages are far more uncertain under more extreme climate change scenarios.

Incomplete treatment of adaptation and technological change. Each of the three integrated assessment models used here assumes a certain degree of low- or no-cost adaptation. For instance, Tol assumes a great deal of adaptation in FUND, including widespread reliance on air conditioning, so much so that the largest single benefit category in FUND is the reduced electricity costs from not having to run air conditioning as intensively (NRC 2009).

Climate change also will increase returns on investment to develop technologies that allow individuals to cope with adverse climate conditions, and IAMs to do not adequately account for this directed technological change.[cc] For example, scientists may develop crops that are better able to withstand higher and more variable temperatures. Although DICE and FUND have both calibrated their agricultural sectors under the assumption that farmers will change land use practices in response to climate change (Mastrandrea 2009), they do not take into account technological changes that lower the cost of this adaptation over time. On the other hand, the calibrations do not account for increases in climate variability, pests, or diseases, which could make adaptation more difficult than assumed by the IAMs for a given temperature change. Hence, models do not adequately account for potential adaptation or technical change that might alter the emissions pathway and resulting damages. In this respect, it is difficult to determine whether the incomplete treatment of adaptation and technological change in these IAMs under or overstate the likely damages.

Risk aversion. A key question unanswered during this interagency process is what to assume about relative risk aversion with regard to high-impact outcomes. These calculations do not take into account the possibility that individuals may have a higher willingness to pay to reduce the likelihood of low-probability, high-impact damages than they do to reduce the likelihood of higher-probability but lower-impact damages with the same expected cost. (The inclusion of the 95th percentile estimate in the final set of SCC values was largely motivated by this concern.) If individuals do show such a higher willingness to pay, a further question is whether that fact should be taken into account for regulatory policy. Even if individuals are not risk-averse for such scenarios, it is possible that regulatory policy should include a degree of risk-aversion.

Assuming a risk-neutral representative agent is consistent with OMB's Circular A-4, which advises that the estimates of benefits and costs used in regulatory analysis are usually based on the average or the expected value and that "emphasis on these expected values is appropriate as long as society is 'risk neutral' with respect to the regulatory alternatives. While this may not always be the case, [analysts] should in general assume 'risk neutrality' in [their] analysis."

Nordhaus (2008) points to the need to explore the relationship between risk and income in the context of climate change across models and to explore the role of uncertainty regarding various parameters in the results. Using FUND, Anthoff *et al.* (2009) explored the sensitivity of the SCC to Ramsey equation parameter assumptions based on observed behavior. They conclude that "the assumed rate of risk aversion is at least as important as the assumed rate of time preference in determining the social cost of carbon." Since Circular A-4 allows for a different assumption on risk preference in regulatory analysis if it is adequately justified, we plan to continue investigating this issue.

[cc] However these research dollars will be diverted from whatever their next best use would have been in the absence of climate change (so productivity/GDP would have been still higher).

14A.7 A FURTHER DISCUSSION OF CATASTROPHIC IMPACTS AND DAMAGE FUNCTIONS

As noted above, the damage functions underlying the three IAMs used to estimate the SCC may not capture the economic effects of all possible adverse consequences of climate change and may therefore lead to underestimates of the SCC (Mastrandrea 2009). In particular, the models' functional forms may not adequately capture: (1) potentially discontinuous "tipping point" behavior in Earth systems; (2) inter-sectoral and inter-regional interactions, including global security impacts of high-end warming; and (3) limited near-term substitutability between damage to natural systems and increased consumption.

It is the hope of the interagency group that over time researchers and modelers will work to fill these gaps and that the SCC estimates used for regulatory analysis by the Federal government will continue to evolve with improvements in modeling. In the meantime, we discuss some of the available evidence.

14A.7.1 Extrapolation of Climate Damages to High Levels of Warming

The damage functions in the models are calibrated at moderate levels of warming and should therefore be viewed cautiously when extrapolated to the high temperatures found in the upper end of the distribution. Recent science suggests that there are a number of potential climatic "tipping points" at which the Earth system may exhibit discontinuous behavior with potentially severe social and economic consequences (*e.g.*, Lenton *et al.* 2008, Kriegler *et al.* 2009). These tipping points include the disruption of the Indian Summer Monsoon, dieback of the Amazon Rainforest and boreal forests, collapse of the Greenland Ice Sheet and the West Antarctic Ice Sheet, reorganization of the Atlantic Meridional Overturning Circulation, strengthening of El Niño-Southern Oscillation, and the release of methane from melting permafrost. Many of these tipping points are estimated to have thresholds between about 3 °C and 5 °C (Lenton *et al.* 2008). Probabilities of several of these tipping points were assessed through expert elicitation in 2005–2006 by Kriegler *et al.* (2009); results from this study are highlighted in Table 14A.7.1. Ranges of probability are averaged across core experts on each topic.

Table 14A.7.1 Probabilities of Various Tipping Points from Expert Elicitation

Possible Tipping Points	Duration before effect is fully realized *years*	Additional Warming by 2100 %		
		0.5–1.5 C	**1.5–3.0 C**	**3–5 C**
Reorganization of Atlantic Meridional Overturning Circulation	about 100	0–18	6–39	18–67
Greenland Ice Sheet Collapse	at least 300	8–39	33–73	67–96
West Antarctic Ice Sheet Collapse	at least 300	5–41	10–63	33–88
Dieback of Amazon Rainforest	about 50	2–46	14–84	41–94
Strengthening of El Niño-Southern Oscillation	about 100	1–13	6–32	19–49
Dieback of Boreal Forests	about 50	13–43	20–81	34–91
Shift in Indian Summer Monsoon	about 1	not formally assessed		
Release of Methane from Melting Permafrost	less than 100	not formally assessed		

As previously mentioned, FUND does not include potentially catastrophic effects. DICE assumes a small probability of catastrophic damages that increases with increased warming, but the damages from these risks are incorporated as expected values (*i.e.*, ignoring potential risk aversion). PAGE models catastrophic impacts in a probabilistic framework (Figure 14A.4.1), so the high-end output from PAGE potentially offers the best insight into the SCC if the world were to experience catastrophic climate change. For instance, at the 95th percentile and a 3-percent discount rate, the SCC estimated by PAGE across the five socio-economic and emission trajectories of \$113 per ton of CO_2 is almost double the value estimated by DICE, \$58 per ton in 2010. We cannot evaluate how well the three models account for catastrophic or non-catastrophic impacts, but this estimate highlights the sensitivity of SCC values in the tails of the distribution to the assumptions made about catastrophic impacts.

PAGE treats the possibility of a catastrophic event probabilistically, while DICE treats it deterministically (*i.e.*, by adding the expected value of the damage from a catastrophe to the aggregate damage function). In part, this results in different probabilities being assigned to a catastrophic event across the two models. For instance, PAGE places a probability near zero on a catastrophe at 2.5 °C warming, while DICE assumes a 4 percent probability of a catastrophe at 2.5 °C. By comparison, Kriegler *et al.* (2009) estimate a probability of at least 16–36 percent of crossing at least one of their primary climatic tipping points in a scenario with temperatures about 2–4 °C warmer than pre-Industrial levels in 2100.

It is important to note that crossing a climatic tipping point will not necessarily lead to an economic catastrophe in the sense used in the IAMs. A tipping point is a critical threshold across which some aspect of the Earth system starts to shifts into a qualitatively different state (for instance, one with dramatically reduced ice sheet volumes and higher sea levels). In the IAMs, a catastrophe is a low-probability environmental change with high economic impact.

14A.7.2 Failure to Incorporate Inter-Sectoral and Inter-Regional Interactions

The damage functions do not fully incorporate either inter-sectoral or inter-regional interactions. For instance, while damages to the agricultural sector are incorporated, the effects of changes in food supply on human health are not fully captured and depend on the modeler's choice of studies used to calibrate the IAM. Likewise, the effects of climate damages in one region of the world on another region are not included in some of the models (FUND includes the effects of migration from sea level rise). These inter-regional interactions, though difficult to quantify, are the basis for climate-induced national and economic security concerns (*e.g.*, Campbell *et al.* 2007; U.S. Department of Defense 2010) and are particularly worrisome at higher levels of warming. High-end warming scenarios, for instance, project water scarcity affecting 4.3–6.9 billion people by 2050, food scarcity affecting about 120 million additional people by 2080, and the creation of millions of climate refugees (Easterling *et al.* 2007; Campbell *et al*. 2007).

14A.7.3 Imperfect Substitutability of Environmental Amenities

Data from the geological record of past climate changes suggests that 6 °C of warming may have severe consequences for natural systems. For instance, during the Paleocene-Eocene Thermal Maximum about 55.5 million years ago, when the Earth experienced a geologically rapid release of carbon associated with an approximately 5 °C increase in global mean temperatures, the effects included shifts of about 400–900 miles in the range of plants (Wing *et al.* 2005), and dwarfing of both land mammals (Gingerich 2006) and soil fauna (Smith *et al.* 2009).

The three IAMs used here assume that it is possible to compensate for the econoic consequences of damages to natural systems through increased consumption of non-climate goods, a common assumption in many economic models. In the context of climate change, however, it is possible that the damages to natural systems could become so great that no increase in consumption of non-climate goods would provide complete compensation (Levy *et al.* 2005). For instance, as water supplies become scarcer or ecosystems become more fragile and less bio-diverse, the services they provide may become increasingly more costly to replace. Uncalibrated attempts to incorporate the imperfect substitutability of such amenities into IAMs (Sterner and Persson 2008) indicate that the optimal degree of emissions abatement can be considerably greater than is commonly recognized.

14A.8 CONCLUSION

The interagency group selected four SCC estimates for use in regulatory analyses. For 2010, these estimates are \$4.7, \$21.4, \$35.1, and \$64.9 (2007\$). The first three estimates are based on the average SCC across models and socio-economic and emissions scenarios at the 5-, 3-, and 2.5-percent discount rates, respectively. The fourth value is included to represent the higher-than-expected impacts from temperature change further out in the tails of the SCC distribution. For this purpose, we use the SCC value for the 95th percentile at a 3-percent discount rate. The central value is the average SCC across models at the 3-percent discount rate. For purposes of capturing the uncertainties involved in regulatory impact analysis, we emphasize the importance and value of considering the full range. These SCC estimates also grow over time. For instance, the central value increases to \$24 per ton of CO_2 in 2015 and \$26 per ton of CO_2 in 2020.

We noted a number of limitations to this analysis, including the incomplete way in which the integrated assessment models capture catastrophic and non-catastrophic impacts, their incomplete treatment of adaptation and technological change, uncertainty in the extrapolation of damages to high temperatures, and assumptions regarding risk aversion. The limited amount of research linking climate impacts to economic damages makes this modeling exercise even more difficult. It is the hope of the interagency group that over time researchers and modelers will work to fill these gaps and that the SCC estimates used for regulatory analysis by the Federal government will continue to evolve with improvements in modeling.

14A.9 REFERENCES

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14A.10 ANNEX

This Annex provides additional technical information about the non-CO_2 emission projections used in the modeling and the method for extrapolating emissions forecasts through 2300, and shows the full distribution of 2010 SCC estimates by model and scenario combination. Annual SCC values for the next 40 years are provided in Table 14A.10.1.

Table 14A.10.1 Annual SCC Values: 2010–2050 (2007$)

Discount Rate	5%	3%	2.5%	3%
Year	Avg	Avg	Avg	95th
2010	4.7	21.4	35.1	64.9
2011	4.9	21.9	35.7	66.5
2012	5.1	22.4	36.4	68.1
2013	5.3	22.8	37.0	69.6
2014	5.5	23.3	37.7	71.2
2015	5.7	23.8	38.4	72.8
2016	5.9	24.3	39.0	74.4
2017	6.1	24.8	39.7	76.0
2018	6.3	25.3	40.4	77.5
2019	6.5	25.8	41.0	79.1
2020	6.8	26.3	41.7	80.7
2021	7.1	27.0	42.5	82.6
2022	7.4	27.6	43.4	84.6
2023	7.7	28.3	44.2	86.5
2024	7.9	28.9	45.0	88.4
2025	8.2	29.6	45.9	90.4
2026	8.5	30.2	46.7	92.3
2027	8.8	30.9	47.5	94.2
2028	9.1	31.5	48.4	96.2
2029	9.4	32.1	49.2	98.1
2030	9.7	32.8	50.0	100.0
2031	10.0	33.4	50.9	102.0
2032	10.3	34.1	51.7	103.9
2033	10.6	34.7	52.5	105.8
2034	10.9	35.4	53.4	107.8
2035	11.2	36.0	54.2	109.7
2036	11.5	36.7	55.0	111.6
2037	11.8	37.3	55.9	113.6
2038	12.1	37.9	56.7	115.5
2039	12.4	38.6	57.5	117.4
2040	12.7	39.2	58.4	119.3
2041	13.0	39.8	59.0	121.0
2042	13.3	40.4	59.7	122.7
2043	13.6	40.9	60.4	124.4
2044	13.9	41.5	61.0	126.1
2045	14.2	42.1	61.7	127.8
2046	14.5	42.6	62.4	129.4
2047	14.8	43.2	63.0	131.1
2048	15.1	43.8	63.7	132.8
2049	15.4	44.4	64.4	134.5
2050	15.7	44.9	65.0	136.2

14A.10.1Other (Non-CO_2) Gases

In addition to fossil and industrial CO_2 emissions, each EMF scenario provides projections of methane (CH_4), nitrous oxide (N_2O), fluorinated gases, and net land use CO_2 emissions to 2100. These assumptions are used in all three IAMs while retaining each model's default radiative forcings (RF) due to other factors (*e.g.*, aerosols and other gases). Specifically, to obtain the RF associated with the non-CO_2 EMF emissions only, we calculated the RF associated with the EMF atmospheric CO_2 concentrations and subtracted them from the EMF total RF.[dd] This approach respects the EMF scenarios as much as possible and at the same time takes account of those components not included in the EMF projections. Since each model treats non-CO_2 gases differently (*e.g.*, DICE lumps all other gases into one composite exogenous input), this approach was applied slightly differently in each of the models.

FUND: Rather than relying on RF for these gases, the actual emissions from each scenario were used in FUND. The model default trajectories for CH_4, N_2O, SF_6, and the CO_2 emissions from land were replaced with the EMF values.

PAGE: PAGE models CO_2, CH_4, sulfur hexafluoride (SF_6), and aerosols and contains an "excess forcing" vector that includes the RF for everything else. To include the EMF values, we removed the default CH_4 and SF_6 factors,[ee] decomposed the excess forcing vector, and constructed a new excess forcing vector that includes the EMF RF for CH_4, N_2O, and fluorinated gases, as well as the model default values for aerosols and other factors. Net land use CO_2 emissions were added to the fossil and industrial CO_2 emissions pathway.

DICE: DICE presents the greatest challenge because all forcing due to factors other than industrial CO_2 emissions is embedded in an exogenous non-CO_2 RF vector. To decompose this exogenous forcing path into EMF non-CO_2 gases and other gases, we relied on the references in DICE2007 to the Intergovernmental Panel on Climate Change's (IPCC) Fourth Assessment Report (AR4) and the discussion of aerosol forecasts in the IPCC's Third Assessment Report (TAR) and in AR4, as explained below. In DICE2007, Nordhaus assumes that exogenous forcing from all non-CO_2 sources is -0.06 W/m^2 in 2005, as reported in AR4, and increases linearly to 0.3 W/m^2 in 2105, based on GISS projections, and then stays constant after that time.

According to AR4, the RF in 2005 from CH_4, N_20, and halocarbons (approximately similar to the F-gases in the EMF-22 scenarios) was 0.48 + 0.16 + 0.34 = 0.98 W/m^2 and RF from total aerosols was -1.2 W/m^2. Thus, the -.06 W/m^2 non-CO_2 forcing in DICE can be decomposed into: 0.98 W/m^2 due to the EMF non-CO_2 gases, -1.2 W/m^2 due to aerosols, and the remainder, 0.16 W/m^2, due to other residual forcing.

[dd] Note EMF did not provide CO_2 concentrations for the IMAGE reference scenario. Thus, for this scenario, we fed the fossil, industrial and land CO_2 emissions into MAGICC (considered a "neutral arbiter" model, which is tuned to emulate the major global climate models) and the resulting CO_2 concentrations were used. Note also that MERGE assumes a neutral biosphere so net land CO_2 emissions are set to zero for all years for the MERGE Optimistic reference scenario, and for the MERGE component of the average 550 scenario (*i.e.*, we add up the land use emissions from the other three models and divide by 4).

[ee] Both the model default CH_4 emissions and the initial atmospheric CH_4 is set to zero to avoid double counting the effect of past CH_4 emissions.

For subsequent years, we calculated the DICE default RF from aerosols and other non-CO_2 gases based on the following two assumptions:

(1) RF from aerosols declines linearly from 2005 to 2100 at the rate projected by the TAR and then stays constant thereafter, and

(2) With respect to RF from non-CO_2 gases not included in the EMF-22 scenarios, the share of non-aerosol RF matches the share implicit in the AR4 summary statistics cited above and remains constant over time.

Assumption (1) means that the RF from aerosols in 2100 equals 66 percent of that in 2000, which is the fraction of the TAR projection of total RF from aerosols (including sulfates, black carbon, and organic carbon) in 2100 vs. 2000 under the A1B SRES emissions scenario. Since the SRES marker scenarios were not updated for the AR4, the TAR provides the most recent IPCC projection of aerosol forcing. We rely on the A1B projection from the TAR because it provides one of the lower aerosol forecasts among the SRES marker scenarios and is more consistent with the AR4 discussion of the post-SRES literature on aerosols:

> Aerosols have a net cooling effect and the representation of aerosol and aerosol precursor emissions, including sulphur dioxide, black carbon and organic carbon, has improved in the post-SRES scenarios. Generally, these emissions are projected to be lower than reported in SRES. {WGIII 3.2, TS.3, SPM}.[ff]

Assuming a simple linear decline in aerosols from 2000 to 2100 also is more consistent with the recent literature on these emissions. For example, Figure 14A.10.1 shows that the sulfur dioxide emissions peak over the short-term of some SRES scenarios above the upper bound estimates of the more recent scenarios.[gg] Recent scenarios project sulfur emissions to peak earlier and at lower levels compared to the SRES in part because of new information about present and planned sulfur legislation in some developing countries, such as India and China.[hh] The lower bound projections of the recent literature have also shifted downward slightly compared to the SRES scenario (IPCC 2007).

With these assumptions, the DICE aerosol forcing changes from -1.2 in 2005 to -0.792 in 2105 W/m^2; forcing due to other non-CO_2 gases not included in the EMF scenarios declines from 0.160 to 0.153 W/m^2.

[ff] AR4 Synthesis Report, p. 44, http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr.pdf
[gg] See Smith, S.J., R. Andres, E. Conception, and J. Lurz. 2004. "Historical sulfur dioxide emissions, 1850-2000: methods and results." Joint Global Research Institute, College Park, 14 pp.
[hh] See Carmichael, G., D. Streets, G. Calori, M. Amann, M. Jacobson, J. Hansen, and H. Ueda. 2002. "Changing trends in sulphur emissions in Asia: implications for acid deposition, air pollution, and climate." *Environmental Science and Technology* 36(22):4707- 4713; Streets, D., K. Jiang, X. Hu, J. Sinton, X.-Q. Zhang, D. Xu, M. Jacobson, and J. Hansen. 2001. "Recent reductions in China's greenhouse gas emissions." *Science* 294(5548):1835–1837.

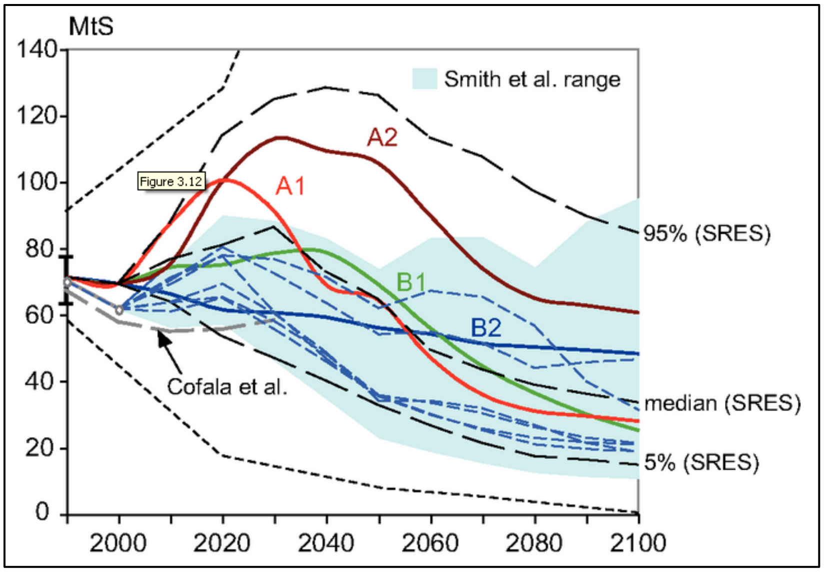

Figure 14A.10.1 Sulphur Dioxide Emission Scenarios

Notes: Thick colored lines depict the four SRES marker scenarios and black dashed lines show the median, 5th and 95th percentile of the frequency distribution for the full ensemble of 40 SRES scenarios. The blue area (and the thin dashed lines in blue) illustrates individual scenarios and the range of Smith *et al.* (2004). Dotted lines indicate the minimum and maximum of SO_2 emissions scenarios developed pre-SRES.
Source: IPCC (2007), AR4 WGIII 3.2, http://www.ipcc.ch/publications_and_data/ar4/wg3/en/ch3-ens3-2-2-4.html.

Although other approaches to decomposing the DICE exogenous forcing vector are possible, initial sensitivity analysis suggests that the differences among reasonable alternative approaches are likely to be minor. For example, adjusting the TAR aerosol projection above to assume that aerosols will be maintained at 2000 levels through 2100 reduces average SCC values (for 2010) by approximately 3 percent (or less than $2); assuming all aerosols are phased out by 2100 increases average 2010 SCC values by 6–7 percent (or $0.50–$3), depending on the discount rate. These differences increase slightly for SCC values in later years but are still well within 10 percent of each other as far out as 2050.

Finally, as in PAGE, the EMF net land use CO_2 emissions are added to the fossil and industrial CO_2 emissions pathway.

14A.10.2Extrapolating Emissions Projections to 2300

To run each model through 2300 requires assumptions about GDP, population, greenhouse gas emissions, and radiative forcing trajectories after 2100, the last year for which these projections are available from the EMF-22 models. These inputs were extrapolated from 2100 to 2300 as follows:

1. Population growth rate declines linearly, reaching zero in 2200.
2. GDP/per capita growth rate declines linearly, reaching zero in 2300.
3. The decline in the fossil and industrial carbon intensity (CO2/GDP) growth rate over 2090-2100 is maintained from 2100 through 2300.
4. Net land use CO_2 emissions decline linearly, reaching zero in 2200.

5. Non-CO_2 radiative forcing remains constant after 2100.

Long run stabilization of GDP per capita was viewed as a more realistic simplifying assumption than a linear or exponential extrapolation of the pre-2100 economic growth rate of each EMF scenario. This is based on the idea that increasing scarcity of natural resources and the degradation of environmental sinks available for assimilating pollution from economic production activities may eventually overtake the rate of technological progress. Thus, the overall rate of economic growth may slow over the very long run. The interagency group also considered allowing an exponential decline in the growth rate of GDP per capita. However, since this would require an additional assumption about how close to zero the growth rate would get by 2300, the group opted for the simpler and more transparent linear extrapolation to zero by 2300.

The population growth rate is also assumed to decline linearly, reaching zero by 2200. This assumption is reasonably consistent with the United Nations long run population forecast, which estimates global population to be fairly stable after 2150 in the medium scenario (UN 2004).[ii] The resulting range of EMF population trajectories (Table 14A.10.2) also encompass the UN medium scenario forecasts through 2300 – global population of 8.5 billion by 2200, and 9 billion by 2300.

Maintaining the decline in the 2090–2100 carbon intensity growth rate (*i.e.*, CO_2 per dollar of GDP) through 2300 assumes that technological improvements and innovations in the areas of energy efficiency and other carbon reducing technologies (possibly including currently unavailable methods) will continue to proceed at roughly the same pace that is projected to occur towards the end of the forecast period for each EMF scenario. This assumption implies that total cumulative emissions in 2300 will be between 5,000 and 12,000 GtC, which is within the range of the total potential global carbon stock estimated in the literature.

Net land use CO_2 emissions are expected to stabilize in the long run, so in the absence of any post 2100 projections, the group assumed a linear decline to zero by 2200. Given no a priori reasons for assuming a long run increase or decline in non-CO_2 radiative forcing, it is assumed to remain at the 2100 levels for each EMF scenario through 2300.

Figure 14A.10.2 through Figure 14A.10.8 show the paths of global population, GDP, fossil and industrial CO_2 emissions, net land CO_2 emissions, non-CO_2 radiative forcing, and CO_2 intensity (fossil and industrial CO_2 emissions/GDP) resulting from these assumptions.

[ii] United Nations. 2004. *World Population to 2300*. http://www.un.org/esa/population/publications/longrange2/WorldPop2300final.pdf.

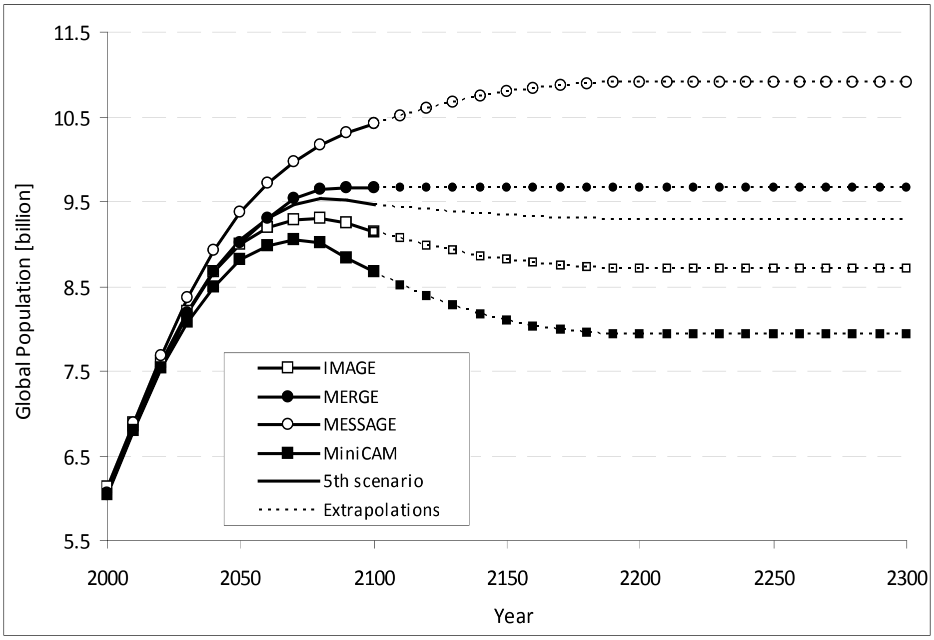

Figure 14A.10.2 Global Population, 2000–2300 (post-2100 extrapolations assume the population growth rate changes linearly to reach a zero growth rate by 2200)

Note: In the fifth scenario, 2000–2100 population is equal to the average of the population under the 550 ppm CO_2e, full-participation, not-to-exceed scenarios considered by each of the four models.

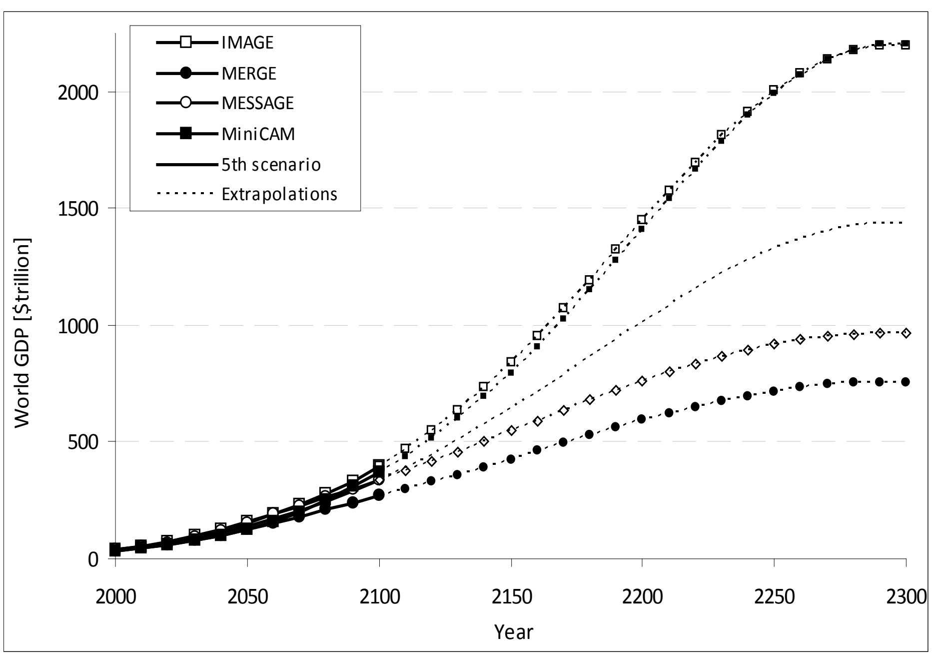

Figure 14A.10.3 World GDP, 2000-2300 (post-2100 extrapolations assume GDP per capita growth declines linearly, reaching zero in 2300)

Note: In the fifth scenario, 2000–2100 GDP is equal to the average of the GDP under the 550 ppm CO_2e, full-participation, not-to-exceed scenarios considered by each of the four models.

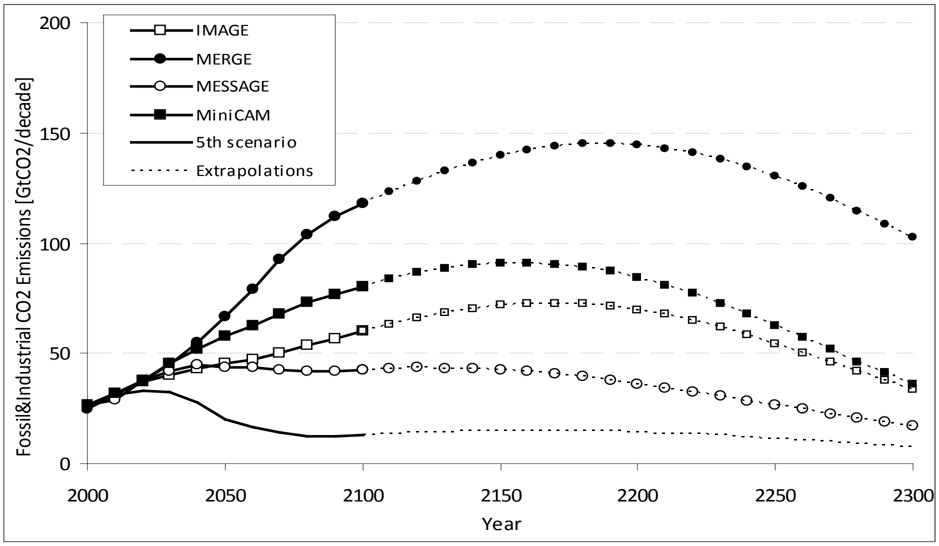

Figure 14A.10.4 Global Fossil and Industrial CO_2 Emissions, 2000-2300 (post-2100 extrapolations assume growth rate of CO_2 intensity (CO_2/GDP) over 2090–2100 is maintained through 2300)

Note: In the fifth scenario, 2000–2100 emissions are equal to the average of the emissions under the 550 ppm CO2e, full-participation, not-to-exceed scenarios considered by each of the four models.

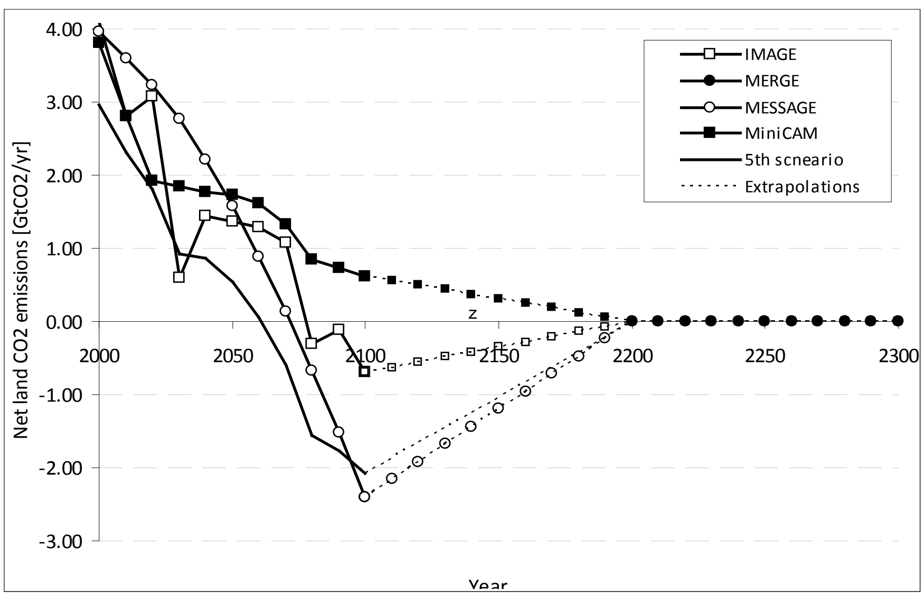

Figure 14A.10.5 Global Net Land Use CO_2 Emissions, 2000–2300 (post-2100 extrapolations assume emissions decline linearly, reaching zero in 2200)[jj]

Note: In the fifth scenario, 2000–2100 emissions are equal to the average of the emissions under the 550 ppm CO2e, full-participation, not-to-exceed scenarios considered by each of the four models.

[jj] MERGE assumes a neutral biosphere so net land CO_2 emissions are set to zero for all years for the MERGE Optimistic reference scenario, and for the MERGE component of the average 550 scenario (*i.e.*, we add up the land use emissions from the other three models and divide by 4).

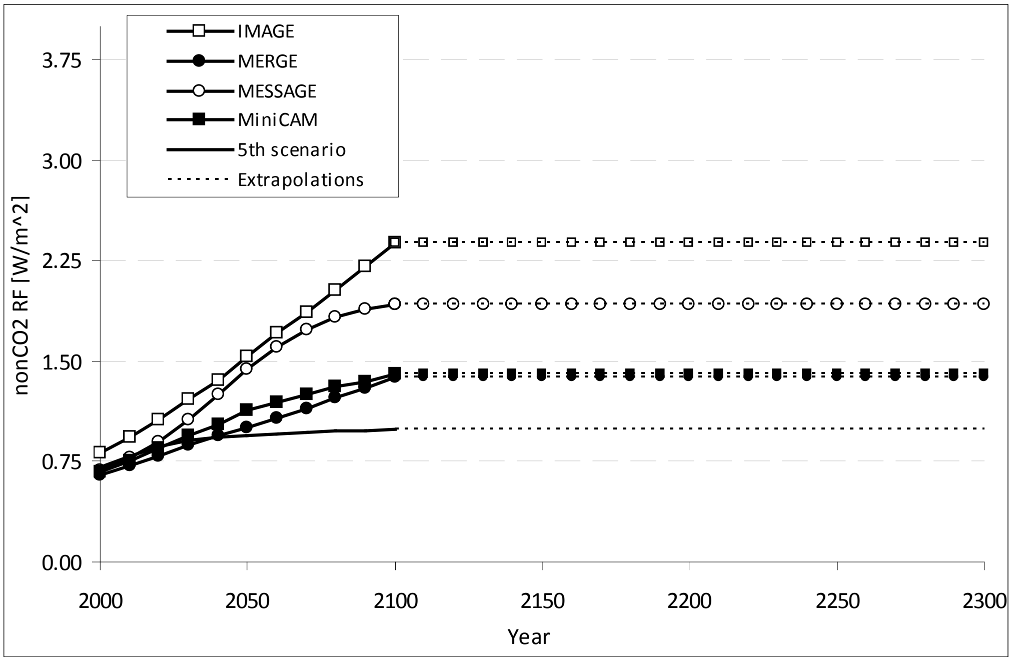

Figure 14A.10.6 Global Non-CO_2 Radiative Forcing, 2000–2300 (post-2100 extrapolations assume constant non-CO_2 radiative forcing after 2100)

Note: In the fifth scenario, 2000–2100 emissions are equal to the average of the emissions under the 550 ppm CO2e, full-participation, not-to-exceed scenarios considered by each of the four models.

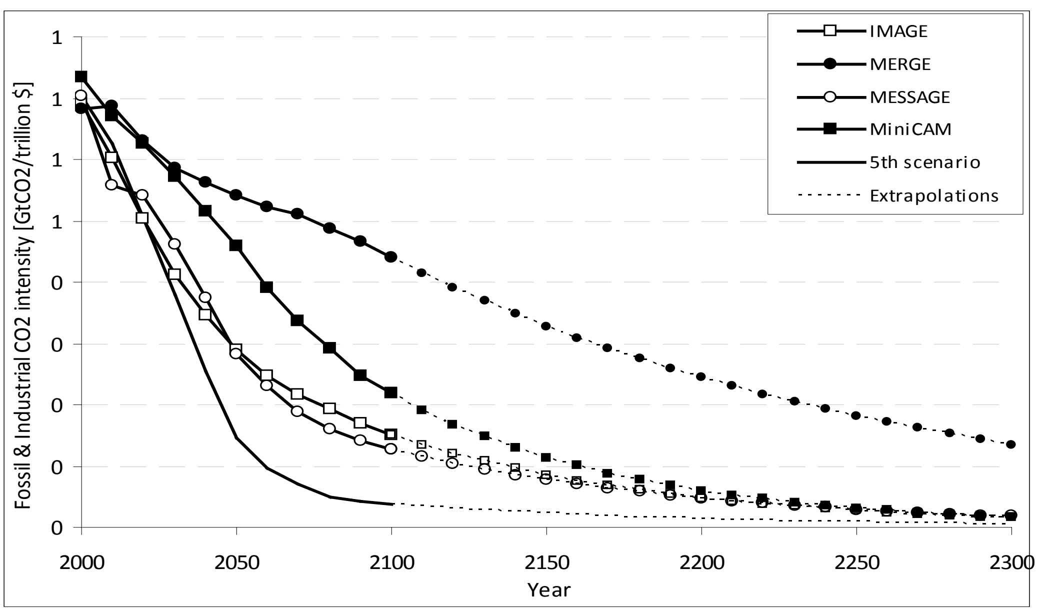

Figure 14A.10.7 Global CO_2 Intensity (fossil & industrial CO_2 emissions/GDP), 2000–2300 (post-2100 extrapolations assume decline in CO_2/GDP growth rate over 2090–2100 is maintained through 2300)

Note: In the fifth scenario, 2000–2100 emissions are equal to the average of the emissions under the 550 ppm CO_2e, full-participation, not-to-exceed scenarios considered by each of the four models.

Table 14A.10.2 2010 Global SCC Estimates at 2.5-Percent Discount Rate (2007$/ton CO_2)

Percentile	1st	5th	10th	25th	50th	Avg	75th	90th	95th	99th
Scenario	PAGE									
IMAGE	3.3	5.9	8.1	13.9	28.8	65.5	68.2	147.9	239.6	563.8
MERGE optimistic	1.9	3.2	4.3	7.2	14.6	34.6	36.2	79.8	124.8	288.3
Message	2.4	4.3	5.8	9.8	20.3	49.2	50.7	114.9	181.7	428.4
MiniCAM base	2.7	4.6	6.4	11.2	22.8	54.7	55.7	120.5	195.3	482.3
5th scenario	2.0	3.5	4.7	8.1	16.3	42.9	41.5	103.9	176.3	371.9
Scenario	DICE									
IMAGE	16.4	21.4	25	33.3	46.8	54.2	69.7	96.3	111.1	130.0
MERGE optimistic	9.7	12.6	14.9	19.7	27.9	31.6	40.7	54.5	63.5	73.3
Message	13.5	17.2	20.1	27	38.5	43.5	55.1	75.8	87.9	103.0
MiniCAM base	13.1	16.7	19.8	26.7	38.6	44.4	56.8	79.5	92.8	109.3
5th scenario	10.8	14	16.7	22.2	32	37.4	47.7	67.8	80.2	96.8
Scenario	FUND									
IMAGE	-33.1	-18.9	-13.3	-5.5	4.1	19.3	18.7	43.5	67.1	150.7
MERGE optimistic	-33.1	-14.8	-10	-3	5.9	14.8	20.4	43.9	65.4	132.9
Message	-32.5	-19.8	-14.6	-7.2	1.5	8.8	13.8	33.7	52.3	119.2
MiniCAM base	-31.0	-15.9	-10.7	-3.4	6	22.2	21	46.4	70.4	152.9
5th scenario	-32.2	-21.6	-16.7	-9.7	-2.3	3	6.7	20.5	34.2	96.8

Table 14A.10.3 2010 Global SCC Estimates at 3-Percent Discount Rate (2007$/ton CO_2)

Percentile	1st	5th	10th	25th	50th	Avg	75th	90th	95th	99th
Scenario	PAGE									
IMAGE	2.0	3.5	4.8	8.1	16.5	39.5	41.6	90.3	142.4	327.4
MERGE optimistic	1.2	2.1	2.8	4.6	9.3	22.3	22.8	51.3	82.4	190.0
Message	1.6	2.7	3.6	6.2	12.5	30.3	31	71.4	115.6	263.0
MiniCAM base	1.7	2.8	3.8	6.5	13.2	31.8	32.4	72.6	115.4	287.0
5th scenario	1.3	2.3	3.1	5	9.6	25.4	23.6	62.1	104.7	222.5
Scenario	DICE									
IMAGE	11.0	14.5	17.2	22.8	31.6	35.8	45.4	61.9	70.8	82.1
MERGE optimistic	7.1	9.2	10.8	14.3	19.9	22	27.9	36.9	42.1	48.8
Message	9.7	12.5	14.7	19	26.6	29.8	37.8	51.1	58.6	67.4
MiniCAM base	8.8	11.5	13.6	18	25.2	28.8	36.9	50.4	57.9	67.8
5th scenario	7.9	10.1	11.8	15.6	21.6	24.9	31.8	43.7	50.8	60.6
Scenario	FUND									
IMAGE	-25.2	-15.3	-11.2	-5.6	0.9	8.2	10.4	25.4	39.7	90.3
MERGE optimistic	-24.0	-12.4	-8.7	-3.6	2.6	8	12.2	27	41.3	85.3
Message	-25.3	-16.2	-12.2	-6.8	-0.5	3.6	7.7	20.1	32.1	72.5
MiniCAM base	-23.1	-12.9	-9.3	-4	2.4	10.2	12.2	27.7	42.6	93.0
5th scenario	-24.1	-16.6	-13.2	-8.3	-3	-0.2	2.9	11.2	19.4	53.6

Table 14A.10.4 2010 Global SCC Estimates at 5-Percent Discount Rate (2007$/ton CO_2)

Percentile	1st	5th	10th	25th	50th	Avg	75th	90th	95th	99th
Scenario	PAGE									
IMAGE	0.5	0.8	1.1	1.8	3.5	8.3	8.5	19.5	31.4	67.2
MERGE optimistic	0.3	0.5	0.7	1.2	2.3	5.2	5.4	12.3	19.5	42.4
Message	0.4	0.7	0.9	1.6	3	7.2	7.2	17	28.2	60.8
MiniCAM base	0.3	0.6	0.8	1.4	2.7	6.4	6.6	15.9	24.9	52.6
5th scenario	0.3	0.6	0.8	1.3	2.3	5.5	5	12.9	22	48.7
Scenario	DICE									
IMAGE	4.2	5.4	6.2	7.6	10	10.8	13.4	16.8	18.7	21.1
MERGE optimistic	2.9	3.7	4.2	5.3	7	7.5	9.3	11.7	12.9	14.4
Message	3.9	4.9	5.5	7	9.2	9.8	12.2	15.4	17.1	18.8
MiniCAM base	3.4	4.2	4.7	6	7.9	8.6	10.7	13.5	15.1	16.9
5th scenario	3.2	4	4.6	5.7	7.6	8.2	10.2	12.8	14.3	16.0
Scenario	FUND									
IMAGE	-11.7	-8.4	-6.9	-4.6	-2.2	-1.3	0.7	4.1	7.4	17.4
MERGE optimistic	-10.6	-7.1	-5.6	-3.6	-1.3	-0.3	1.6	5.4	9.1	19.0
Message	-12.2	-8.9	-7.3	-4.9	-2.5	-1.9	0.3	3.5	6.5	15.6
MiniCAM base	-10.4	-7.2	-5.8	-3.8	-1.5	-0.6	1.3	4.8	8.2	18.0
5th scenario	-10.9	-8.3	-7	-5	-2.9	-2.7	-0.8	1.4	3.2	9.2

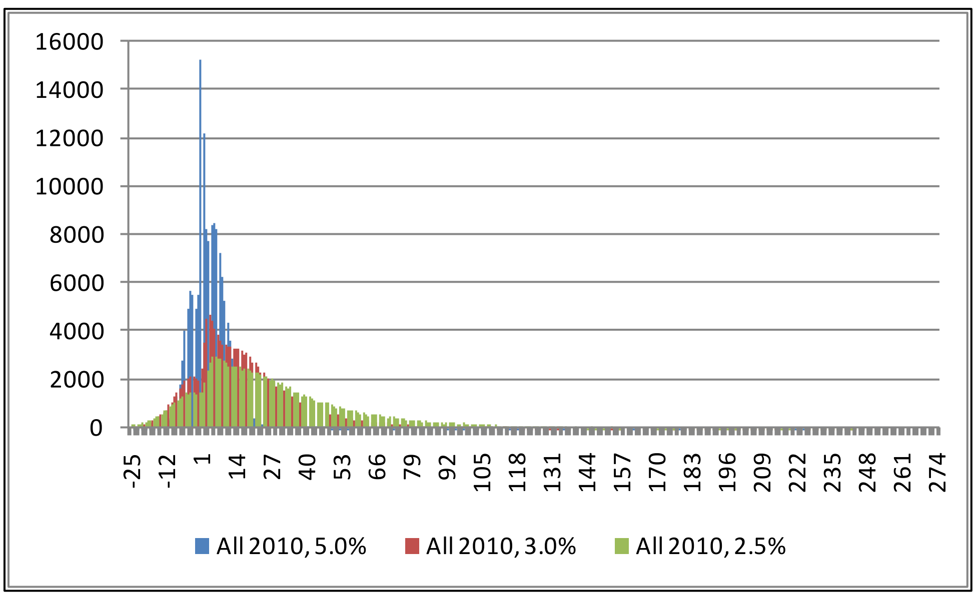

Figure 14A.10.8 Histogram of Global SCC Estimates in 2010 (2007$/ton CO_2), by Discount Rate*

* The distribution of SCC values ranges from -$5,192 to $66,116, but the X-axis has been truncated at approximately the 1st and 99th percentiles to better show the data.

Table 14A.10.5 Additional Summary Statistics of 2010 Global SCC Estimates

Discount Rate	5%				3%				2.5%			
Scenario	Mean	Variance	Skewness	Kurtosis	Mean	Variance	Skewness	Kurtosis	Mean	Variance	Skewness	Kurtosis
DICE	9.0	13.1	0.8	0.2	28.3	209.8	1.1	0.9	42.2	534.9	1.2	1.1
PAGE	6.5	136.0	6.3	72.4	29.8	3,383.7	8.6	151.0	49.3	9,546.0	8.7	143.8
FUND	-1.3	70.1	28.2	1,479.0	6.0	16,382.5	128.0	18,976.5	13.6	150,732.6	149.0	23,558.3

APPENDIX 14B. TECHNICAL UPDATE OF SOCIAL COST OF CARBON FOR REGULATORY IMPACT ANALYSIS UNDER EXECUTIVE ORDER 12866

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APPENDIX 14B. TECHNICAL UPDATE OF SOCIAL COST OF CARBON FOR REGULATORY IMPACT ANALYSIS UNDER EXECUTIVE ORDER 12866

14B.1 PREFACE

The following text is reproduced almost verbatim from the May 2013 report (revised July 2015) of the Interagency Working Group on the Social Cost of Carbon of the United States Government. Minor changes were made to the report's format to make it more consistent with the rest of this technical support document.

14B.2 EXECUTIVE SUMMARY

Under Executive Order 12866, agencies are required, to the extent permitted by law, "to assess the costs and the benefits of the intended regulation and, recognizing that some costs and benefits are difficult to quantify, propose or adopt a regulation only upon a reasoned determination that the benefits of the intended regulation justify its costs." The purpose of the "social cost of carbon" (SCC) estimates presented here is to allow agencies to incorporate the social benefits of reducing carbon dioxide (CO_2) emissions into cost-benefit analyses of regulatory actions that impact cumulative global emissions. The SCC is an estimate of the monetized damages associated with an incremental increase in carbon emissions in a given year. It is intended to include (but is not limited to) changes in net agricultural productivity, human health, property damages from increased flood risk, and the value of ecosystem services due to climate change.

The interagency process that developed the original U.S. government's SCC estimates is described in the 2010 interagency technical support document (TSD) (Interagency Working Group on Social Cost of Carbon 2010). Through that process the interagency group selected four SCC values for use in regulatory analyses. Three values are based on the average SCC from three integrated assessment models (IAMs), at discount rates of 2.5, 3, and 5 percent. The fourth value, which represents the 95th percentile SCC estimate across all three models at a 3 percent discount rate, is included to represent higher-than-expected impacts from temperature change further out in the tails of the SCC distribution.

While acknowledging the continued limitations of the approach taken by the interagency group in 2010, this document provides an update of the SCC estimates based on new versions of each IAM (DICE, PAGE, and FUND). It does not revisit other interagency modeling decisions (e.g., with regard to the discount rate, reference case socioeconomic and emission scenarios, or equilibrium climate sensitivity). Improvements in the way damages are modeled are confined to those that have been incorporated into the latest versions of the models by the developers themselves in the peer-reviewed literature.

The SCC estimates using the updated versions of the models are higher than those reported in the 2010 TSD. By way of comparison, the four 2020 SCC estimates reported in the 2010 TSD were $7, $26, $42 and $81 (2007$). The corresponding four updated SCC estimates for 2020 are $12, $43, $64, and $128 (2007$). The model updates that are relevant to the SCC estimates include: an explicit representation of sea level rise damages in the DICE and PAGE models; updated adaptation assumptions, revisions to ensure damages are constrained by GDP, updated regional scaling of damages, and a revised treatment of potentially abrupt shifts in climate damages in the PAGE model; an updated carbon cycle in the DICE model; and updated damage functions for sea level rise impacts, the agricultural sector, and reduced space heating requirements, as well as changes to the transient response of temperature to the buildup of GHG concentrations and the inclusion of indirect effects of methane emissions in the FUND model. The SCC estimates vary by year, and the following table summarizes the revised SCC estimates from 2010 through 2050.

Table 14B.2.1 Revised Social Cost of CO_2, 2010 – 2050 (in 2007 dollars per ton of CO_2)

Discount Rate Year	5.0% Avg	3.0% Avg	2.5% Avg	3.0% 95th
2010	10	31	50	86
2015	11	36	56	105
2020	12	42	62	123
2025	14	46	68	138
2030	16	50	73	152
2035	18	55	78	168
2040	21	60	84	183
2045	23	64	89	197
2050	26	69	95	212

14B.3 PURPOSE

The purpose of this document is to update the schedule of social cost of carbon (SCC) [a] estimates from the 2010 interagency technical support document (TSD) (Interagency Working Group on Social Cost of Carbon 2010).[1] E.O. 13563 commits the Administration to regulatory decision making "based on the best available science."[b] Additionally, the interagency group recommended in 2010 that the SCC estimates be revisited on a regular basis or as model updates that reflect the growing body of scientific and economic knowledge become available.[c] New versions of the three integrated assessment models used by the U.S. government to estimate the SCC (DICE, FUND, and PAGE), are now available and have been published in the peer reviewed literature. While acknowledging the continued limitations of the approach taken by the interagency group in 2010 (documented in the original 2010 TSD), this document provides an update of the SCC estimates based solely on the latest peer-reviewed version of the models, replacing model versions that were developed up to ten years ago in a rapidly evolving field. It does not revisit other assumptions with regard to the discount rate, reference case socioeconomic and emission scenarios, or equilibrium climate sensitivity. Improvements in the way damages are modeled are confined to those that have been incorporated into the latest versions of the models

[a] In this document, we present all values of the SCC as the cost per metric ton of CO_2 emissions. Alternatively, one could report the SCC as the cost per metric ton of carbon emissions. The multiplier for translating between mass of CO_2 and the mass of carbon is 3.67.
[b] http://www.whitehouse.gov/sites/default/files/omb/inforeg/eo12866/eo13563_01182011.pdf
[c] See p. 1, 3, 4, 29, and 33 (Interagency Working Group on Social Cost of Carbon 2010).[1]

by the developers themselves in the peer-reviewed literature. The Environmental Protection Agency (EPA), in collaboration with other Federal agencies such as the Department of Energy (DOE), continues to investigate potential improvements to the way in which economic damages associated with changes in CO_2 emissions are quantified.

Section 14B.4 summarizes the major updates relevant to SCC estimation that are contained in the new versions of the integrated assessment models released since the 2010 interagency report. Section 14B.5 presents the updated schedule of SCC estimates for 2010 – 2050 based on these versions of the models.

14B.4 SUMMARY OF MODEL UPDATES

This section briefly summarizes changes integrated into the most recent versions of the three integrated assessment models (IAMs) used by the interagency group in 2010. We focus on describing those model updates that are relevant to estimating the social cost of carbon. For example, both the DICE and PAGE models now include an explicit representation of sea level rise damages. Other revisions to PAGE include: updated adaptation assumptions, revisions to ensure damages are constrained GDP, updated regional scaling of damages, and a revised treatment of potentially abrupt shifts in climate damages. In the most recent version of DICE, the model's simple carbon cycle has been updated to be more consistent with a relatively more complex climate model. The FUND model includes updated damage functions for sea level rise impacts, the agricultural sector, and reduced space heating requirements, as well as changes to the response of temperature to the buildup of GHG concentrations and the inclusion of indirect effects of methane emissions. Changes made to parts of the models that are superseded by the interagency working group's modeling assumptions – regarding climate sensitivity, discounting, and socioeconomic variables – are not discussed.

Table 14B.4.1 Summary of Key Model Revisions Relevant to the Interagency SCC

IAM	Version used in 2010 Interagency Analysis	New Version	Key Changes Relevant to Interagency SCC
DICE	2007	2010	Updated calibration of the carbon cycle model and explicit representation of seal level rise (SLR) and associated damages.
FUND	3.5 (2009)	3.8 (2012)	Updated damage functions for space heating, SLR, agricultural impacts, changes to transient response of temperature to buildup of GHG concentrations, and inclusion of indirect climate effects of methane.
PAGE	2002	2009	Explicit representation of SLR damages, revisions to damage function to ensure damages do not exceed 100% of GDP, change in regional scaling of damages, revised treatment of potential abrupt damages, and updated adaptation assumptions.

14B.4.1 DICE

Changes in the DICE model relevant for the SCC estimates developed by the interagency working group include: 1) updated parameter values for the carbon cycle model, 2) an explicit representation of sea level dynamics, and 3) a re-calibrated damage function that includes an explicit representation of economic damages from sea level rise. Changes were also made to other parts of the DICE model—including the equilibrium climate sensitivity parameter, the rate of change of total factor productivity, and the elasticity of the marginal utility of consumption—but these components of DICE are superseded by the interagency working group's assumptions and so will not be discussed here. More details on DICE2007 can be found in Nordhaus (2008)[2] and on DICE2010 in Nordhaus (2010)[3] and the associated on-line appendix containing supplemental information.

14B.4.1.1 Carbon Cycle Parameters

DICE uses a three-box model of carbon stocks and flows to represent the accumulation and transfer of carbon among the atmosphere, the shallow ocean and terrestrial biosphere, and the deep ocean. These parameters are "calibrated to match the carbon cycle in the Model for the Assessment of Greenhouse Gas Induced Climate Change (MAGICC)" (Nordhaus 2008 p 44).[2d] Carbon cycle transfer coefficient values in DICE2010 are based on re-calibration of the model to match the newer version of MAGICC (Nordhaus 2010 p 2).[3] For example, in DICE2010 in each decade, 12 percent of the carbon in the atmosphere is transferred to the shallow ocean, 4.7 percent of the carbon in the shallow ocean is transferred to the atmosphere, 94.8 percent remains in the shallow ocean, and 0.5 percent is transferred to the deep ocean. For comparison, in DICE 2007, 18.9 percent of the carbon in the atmosphere is transferred to the shallow ocean each decade, 9.7 percent of the carbon in the shallow ocean is transferred to the atmosphere, 85.3 percent remains in the shallow ocean, and 5 percent is transferred to the deep ocean.

The implication of these changes for DICE2010 is in general a weakening of the ocean as a carbon sink and therefore a higher concentration of carbon in the atmosphere than in DICE2007, for a given path of emissions. All else equal, these changes will generally increase the level of warming and therefore the SCC estimates in DICE2010 relative to those from DICE2007.

14B.4.1.2 Sea Level Dynamics

A new feature of DICE2010 is an explicit representation of the dynamics of the global average sea level anomaly to be used in the updated damage function (discussed below). This section contains a brief description of the sea level rise (SLR) module; a more detailed description can be found on the model developer's website.[e] The average global sea level anomaly is modeled as the sum of four terms that represent contributions from: 1) thermal expansion of the oceans, 2) melting of glaciers and small ice caps, 3) melting of the Greenland ice sheet, and 4) melting of the Antarctic ice sheet.

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[d] MAGICC is a simple climate model initially developed within the U.S. National Center for Atmospheric Research that has been used heavily by the Intergovernmental Panel on Climate Change (IPCC) to emulate projections from much more sophisticated state of the art earth system simulation models (Randall et al. 2007).[4]

[e] Documentation on the new sea level rise module of DICE is available on William Nordhaus' website at: http://nordhaus.econ.yale.edu/documents/SLR_021910.pdf.

The parameters of the four components of the SLR module are calibrated to match consensus results from the IPCC's Fourth Assessment Report.[4,f] The rise in sea level from thermal expansion in each time period (decade) is 2 percent of the difference between the sea level in the previous period and the long run equilibrium sea level, which is 0.5 meters per degree Celsius (°C) above the average global temperature in 1900. The rise in sea level from the melting of glaciers and small ice caps occurs at a rate of 0.008 meters per decade per °C above the average global temperature in 1900.

The contribution to sea level rise from melting of the Greenland ice sheet is more complex. The equilibrium contribution to SLR is 0 meters for temperature anomalies less than 1 °C and increases linearly from 0 meters to a maximum of 7.3 meters. The contribution to SLR in each period is proportional to the difference between the previous period's sea level anomaly and the equilibrium sea level anomaly, where the constant of proportionality increases with the temperature anomaly in the current period.

The contribution to SLR from the melting of the Antarctic ice sheet is -0.001 meters per decade when the temperature anomaly is below 3 °C and increases linearly to a maximum rate of 0.025 meters per decade at a temperature anomaly of 6 °C.

14B.4.1.3 Re-calibrated Damage Function

Economic damages from climate change in the DICE model are represented by a fractional loss of gross economic output in each period. A portion of the remaining economic output in each period (net of climate change damages) is consumed and the remainder is invested in the physical capital stock to support future production, so each period's climate damages will reduce consumption in that period and in all future periods due to the lost investment. The fraction of output in each period that is lost due to climate change impacts is represented as one minus a fraction, which is one divided by a quadratic function of the temperature anomaly, producing a sigmoid ("S"-shaped) function. The loss function in DICE2010 has been expanded by adding a quadratic function of SLR to the quadratic function of temperature. In DICE2010 the temperature anomaly coefficients have been recalibrated to avoid double-counting damages from sea level rise that were implicitly included in these parameters in DICE2007.

The aggregate damages in DICE2010 are illustrated by Nordhaus (2010 p 3),[3] who notes that "…damages in the uncontrolled (baseline) (*i.e.*, reference) case … in 2095 are \$12 trillion, or 2.8 percent of global output, for a global temperature increase of 3.4 °C above 1900 levels." This compares to a loss of 3.2 percent of global output at 3.4 °C in DICE2007. However, in DICE2010 (as downloaded from the homepage of William Nordhaus), annual damages are lower in most of the early periods but higher in later periods of the time horizon than would be calculated using the DICE2007 damage function. Specifically, the percent difference between damages in the base run of DICE2010 and those that would be calculated using the DICE2007 damage function starts at +7 percent in 2005, decreases to a low of -14 percent in 2065, then continuously increases to +20 percent by 2300 (the end of the interagency analysis time horizon), and to +160 percent by the end of the model time horizon in 2595. The large increases in the far

[f] For a review of post-IPCC AR4 research on sea level rise, see Nicholls et al. (2011)[5] and NAS (2011).[6]

future years of the time horizon are due to the permanence associated with damages from sea level rise, along with the assumption that the sea level is projected to continue to rise long after the global average temperature begins to decrease. The changes to the loss function generally decrease the interagency working group SCC estimates slightly, all else equal.

14B.4.2 FUND

FUND version 3.8 includes a number of changes over the previous version 3.5 used in the interagency report. Documentation supporting FUND and the model's source code for all versions of the model is available from the model authors.[g] Notable changes, due to their impact on the estimates of expected SCC, are adjustments to the space heating, agriculture, and sea level rise damage functions in addition to changes to the temperature response function and the inclusion of indirect effects from methane emissions.[h] We discuss each of these in turn.

14B.4.2.1 Space Heating

In FUND, the damages associated with the change in energy needs for space heating are based on the estimated impact due to one degree of warming. These baseline damages are scaled based on the forecasted temperature anomaly's deviation from the one degree benchmark and adjusted for changes in vulnerability due to economic and energy efficiency growth. In FUND 3.5, the function that scales the base year damages adjusted for vulnerability allows for the possibility that in some simulations the benefits associated with reduced heating needs may be an unbounded convex function of the temperature anomaly. In FUND 3.8, the form of the scaling has been modified to ensure that the function is everywhere concave, meaning that for every simulation there will exist an upper bound on the benefits a region may receive from reduced space heating needs. The new formulation approaches a value of two in the limit as the temperature anomaly increases, or in other words, assuming no decrease in vulnerability, the reduced expenditures on space heating at any level of warming will not exceed two times the reductions experienced at one degree of warming. Since the reduced need for space heating represents a benefit of climate change in the model, or a negative damage, this change will increase the estimated SCC. This update accounts for a significant portion of the difference in the expected SCC estimates reported by the two versions of the model when run probabilistically.

14B.4.2.2 Sea Level Rise and Land Loss

The FUND model explicitly includes damages associated with the inundation of dry land due to sea level rise. The amount of land lost within a region is dependent upon the proportion of the coastline being protected by adequate sea walls and the amount of sea level rise. In FUND 3.5 the function defining the potential land lost in a given year due to sea level rise is linear in the rate of sea level rise for that year. This assumption implicitly assumes that all regions are well represented by a homogeneous coastline in length and a constant uniform slope moving

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[g] http://www.fund-model.org/. This report uses version 3.8 of the FUND model, which represents a modest update to the most recent version of the model to appear in the literature (version 3.7) (Anthoff and Tol, 2013).[7] For the purpose of computing the SCC, the relevant changes are associated with improving consistency with IPCC AR4 by adjusting the atmospheric lifetimes of CH4 and N2O and incorporating the indirect forcing effects of CH4, along with making minor stability improvements in the sea wall construction algorithm.

[h] The other damage sectors (water resources, space cooling, land loss, migration, ecosystems, human health, and extreme weather) were not the subject of significant updates.

inland. In FUND 3.8 the function defining the potential land lost has been changed to be a non-linear function of sea level rise, thereby assuming that the slope of the shore line is not constant moving inland, with a positive first derivative. The effect of this change is to typically reduce the vulnerability of some regions to sea level rise based land loss, therefore having an effect of lowering the expected SCC estimate. The model has also been updated to assume that the value of dry land at risk of inundation is not uniform across a region but will be a decreasing function of protection measure, thereby implicitly assuming that the most valuable land will be protected first.

14B.4.2.3 Agriculture

In FUND, the damages associated with the agricultural sector are measured as proportional to the sector's value. The fraction is made up of three additively separable components that represent the effects from carbon fertilization, the rate of temperature change, and the level of the temperature anomaly. In both FUND 3.5 and FUND 3.8, the fraction of the sector's value lost due to the level of the temperature anomaly is modeled as a quadratic function with an intercept of zero. In FUND 3.5, the linear and quadratic coefficients are modeled as the ratio of two normal distributions. Within this specification, as draws from the distribution in the denominator approached zero the share of the sector's value "lost" approaches (+/-) infinity independent of the temperature anomaly itself. In FUND 3.8, the linear and quadratic coefficients are drawn directly from truncated normal distributions so that they remain in the range $[0,\infty)$ and $(-\infty,0]$, respectively, where the means for the new distributions are set equal to the ratio of the means from the normal distributions used in the previous version. In general the impact of this change has been to increase the likelihood that increases in the temperature level will have either larger positive or negative effects on the agricultural sector relative to the previous version (through eliminating simulations in which the "lost" value approached (+/-) infinity). The net effect of this change on the SCC estimates is difficult to predict.

14B.4.2.4 Temperature Response Model

The temperature response model translates changes in global levels of radiative forcing into the current expected temperature anomaly. In FUND, a given year's increase in the cumulative temperature anomaly is based on a mean reverting function where the mean equals the equilibrium temperature anomaly that would eventually be reached if that year's level of radiative forcing were sustained. The rate of mean reversion defines the rate at which the transient temperature approaches the equilibrium. In FUND 3.5, the rate of temperature response is defined as a decreasing linear function of equilibrium climate sensitivity to capture the fact that the progressive heat uptake of the deep ocean causes the rate to slow at higher values of the equilibrium climate sensitivity. In FUND 3.8, the rate of temperature response has been updated to a quadratic function of the equilibrium climate sensitivity. This change reduces the sensitivity of the rate of temperature response to the level of the equilibrium climate sensitivity. Therefore in FUND 3.8, the temperature response will typically be faster than in the previous version. The overall effect of this change is likely to increase estimates of the SCC as higher temperatures are reached during the timeframe analyzed and as the same damages experienced in the previous version of the model are now experienced earlier and therefore discounted less.

14B.4.2.5 Methane

The IPCC notes a series of indirect effects of methane emissions, and has developed methods for proxying such effects when computing the global warming potential of methane (Forster et al. 2007).[8] FUND 3.8 now includes the same methods for incorporating the indirect effects of methane emissions. Specifically, the average atmospheric lifetime of methane has been set to 12 years to account for the feedback of CH4 emissions on its own lifetime. The radiative forcing associated with atmospheric methane has also been increase by 40% to account for its net impact on ozone production and increase in stratospheric water vapor. The general effect of this increased radiative forcing will be to increase the estimated SCC values, where the degree to which this occurs will be dependent upon the relative curvature of the damage functions with respect to the temperature anomaly.

14B.4.3 PAGE

PAGE09 (Hope 2012)[9] includes a number of changes from PAGE2002, the version used in the 2009 SCC interagency report. The changes that most directly affect the SCC estimates include: explicitly modeling the impacts from sea level rise, revisions to the damage function to ensure damages are constrained by GDP, a change in the regional scaling of damages, a revised treatment for the probability of a discontinuity within the damage function, and revised assumptions on adaptation. The model also includes revisions to the carbon cycle feedback and the calculation of regional temperatures. More details on PAGE2009 can be found in three working papers (Hope 2011a, 2011b, 2011c).[10, 11, 12] A description of PAGE2002 can be found in Hope (2006).[13]

14B.4.3.1 Sea Level Rise

While PAGE2002 aggregates all damages into two categories – economic and non-economic impacts - PAGE2009 adds a third explicit category: damages from sea level rise. In the previous version of the model, damages from sea level rise were subsumed by the other damage categories. PAGE09 models damages from sea level rise as increasing less than linearly with sea level based on the assumption that low-lying shoreline areas will be associated with higher damages than current inland areas. Damages from the economic and non-economic sector were adjusted to account for the introduction of this new category.

14B.4.3.2 Revised Damage Function to Account for Saturation

In PAGE09, small initial economic and non-economic benefits (negative damages) are modeled for small temperature increases, but all regions eventually experience positive economic damages from climate change, where damages are the sum of additively separable polynomial functions of temperature and sea level rise. Damages transition from this polynomial function to a logistic path once they exceed a certain proportion of remaining Gross Domestic Product (GDP) to ensure that damages do not exceed 100 percent of GDP. This differs from PAGE2002, which allowed Eastern Europe to potentially experience large benefits from temperature increases, and which also did not bound the possible damages that could be experienced.

14B.4.3.3 Regional Scaling Factors

As in the previous version of PAGE, the PAGE09 model calculates the damages for the European Union (EU) and then, assumes that damages for other regions are proportional based on a given scaling factor. The scaling factor in PAGE09 is based on the length of a region's coastline relative to the EU (Hope 2011b).[11] Because of the long coastline in the EU, other regions are, on average, less vulnerable than the EU for the same sea level and temperature increase, but all regions have a positive scaling factor. PAGE2002 based its scaling factors on four studies reported in the IPCC's third assessment report, and allowed for benefits from temperature increase in Eastern Europe, smaller impacts in developing countries, and higher damages in developing countries.

14B.4.3.4 Probability of a Discontinuity

In PAGE2002, the damages associated with a "discontinuity" were modeled as an expected value. That is, additional damages from an extreme event, such as extreme melting of the Greenland ice sheet, were multiplied by the probability of the event occurring and added to the damage estimate. In PAGE09, the probability of "discontinuity" is treated as a discrete event for each year in the model. The damages for each model run are estimated with or without a discontinuity occurring, rather than as an expected value. A large-scale discontinuity becomes possible when the temperature rises beyond some threshold value between 2 and 4°C. The probability that a discontinuity will occur beyond this threshold then increases by between 10 and 30 percent for every 1°C rise in temperature beyond the threshold. If a discontinuity occurs, the EU loses an additional 5 to 25 percent of its GDP (drawn from a triangular distribution with a mean of 15 percent) in addition to other damages, and other regions lose an amount determined by the regional scaling factor. The threshold value for a possible discontinuity is lower than in PAGE2002, while the rate at which the probability of a discontinuity increases with the temperature anomaly and the damages that result from a discontinuity are both higher than in PAGE2002. The model assumes that only one discontinuity can occur and that the impact is phased in over a period of time, but once it occurs, its effect is permanent.

14B.4.3.5 Adaptation

As in PAGE2002, adaptation is available to increase the tolerable level of temperature change and can help mitigate any climate change impacts that still occur. In PAGE this adaptation is the same regardless of the temperature change or sea level rise and is therefore akin to what is more commonly considered a reduction in vulnerability. It is modeled by modifying the temperature change and sea level rise used in the damage function or by reducing the damages by some percentage. PAGE09 assumes a smaller decrease in vulnerability than the previous version of the model and assumes that it will take longer for this change in vulnerability to be realized. In the aggregated economic sector, at the time of full implementation, this adaptation will mitigate all damages up to a temperature increase of 1°C, and for temperature anomalies between 1°C and 3°C, it will reduce damages by 15-30 percent (depending on the region). However, it takes 20 years to fully implement this adaptation. In PAGE2002, adaptation was assumed to reduce economic sector damages up to 3°C by 50-90 percent after 20 years. Beyond 3°C, no adaptation is assumed to be available to mitigate the impacts of climate change. For the non-economic sector, in PAGE09 adaptation is available to reduce 15 percent of the damages due to a temperature increase between 0°C and 2°C and is assumed to take 40 years to fully implement, instead of 25 percent of the damages over 20 years assumed in PAGE2002. Similarly, adaptation is assumed to alleviate 25-50 percent of the damages from the first 0.20 to 0.25 meters of sea level rise but is assumed to be ineffective thereafter. Hope (2011c)[12] estimates that the less optimistic assumptions regarding the ability to offset impacts of temperature and sea level rise via adaptation increase the SCC by approximately 30 percent.

14B.4.3.6 Other Noteworthy Changes

Two other changes in the model are worth noting. A revised carbon cycle feedback is introduced to simulate decreased CO_2 absorption by the terrestrial biosphere and ocean as the temperature rises. This feedback is linear in the average global and annual temperature anomaly but is capped at a maximum value. In the previous version of PAGE, an additional amount was added to the CO_2 emissions each period to account for a decrease in ocean absorption and a loss of soil carbon. Also updated is the method by which the average global and annual temperature anomaly is downscaled to determine annual average regional temperature anomalies to be used in the regional damage functions. In the previous version of PAGE, the scaling was determined solely based on regional difference in emissions of sulfate aerosols. In PAGE09, this regional temperature anomaly is further adjusted using an additive factor that is based on the average absolute latitude of a region relative to the area weighted average absolute latitude of the Earth's landmass.

14B.5 REVISED SCC ESTIMATES

The updated versions of the three integrated assessment models were run using the same methodology detailed in the 2010 TSD.[1] The approach along with the inputs for the socioeconomic emissions scenarios, equilibrium climate sensitivity distribution, and discount rate remains the same. This includes the five reference scenarios based on the EMF-22 modeling exercise, the Roe and Baker equilibrium climate sensitivity distribution calibrated to the Fourth Assessment Report of the IPCC, and three constant discount rates of 2.5, 3, and 5 percent.

As was previously the case, the use of three models, three discount rates, and five scenarios produces 45 separate distributions for the SCC. The approach laid out in the TSD applied equal weight to each model and socioeconomic scenario in order to reduce the dimensionality down to three separate distributions representative of the three discount rates. The interagency group selected four values from these distributions for use in regulatory analysis. Three values are based on the average SCC across models and socio-economic-emissions scenarios at the 2.5, 3, and 5 percent discount rates, respectively. The fourth value was chosen to represent the higher-than-expected economic impacts from climate change further out in the tails of the SCC distribution. For this purpose, the 95th percentile of the SCC estimates at a 3 percent discount rate was chosen. (A detailed set of percentiles by model and scenario combination is available in the Annex.) As noted in the original TSD, "the 3 percent discount rate is the central value, and so the central value that emerges is the average SCC across models at the 3 percent discount rate" (TSD, p. 25). However, for purposes of capturing the uncertainties involved in regulatory impact analysis, the interagency group emphasizes the importance and value of including all four SCC values.

Table 14B.5.1 shows the four selected SCC estimates in five year increments from 2010 to 2050. Values for 2010, 2020, 2030, 2040, and 2050 are calculated by first combining all outputs (10,000 estimates per model run) from all scenarios and models for a given discount rate. Values for the years in between are calculated using basic linear interpolation. The full set of annual SCC estimates between 2010 and 2050 is reported in the Annex.

Table 14B.5.1 Revised Social Cost of CO_2, 2010 – 2050 (in 2007 dollars per ton of CO_2)

Discount Rate Year	5.0% Avg	3.0% Avg	2.5% Avg	3.0% 95th
2010	10	31	50	86
2015	11	36	56	105
2020	12	42	62	123
2025	14	46	68	138
2030	16	50	73	152
2035	18	55	78	168
2040	21	60	84	183
2045	23	64	89	197
2050	26	69	95	212

The SCC estimates using the updated versions of the models are higher than those reported in the TSD due to the changes to the models outlined in the previous section. Figure 14B.5.1 illustrates where the four SCC values for 2020 fall within the full distribution for each discount rate based on the combined set of runs for each model and scenario (150,000 estimates in total for each discount rate). In general, the distributions are skewed to the right and have long tails. The Figure also shows that the lower the discount rate, the longer the right tail of the distribution.

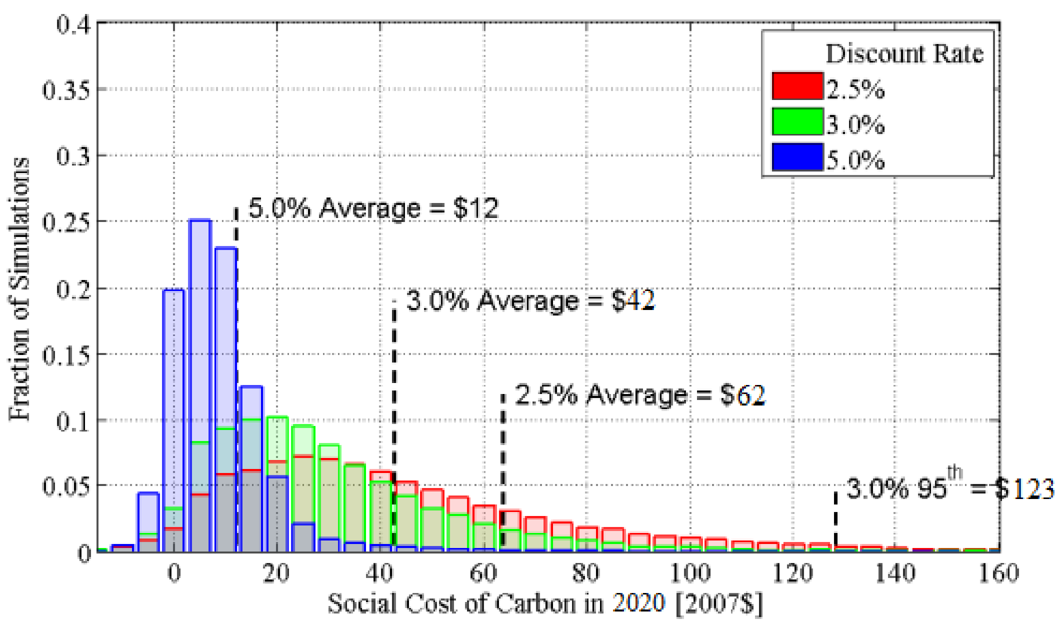

Figure 14B.5.1 Distribution of SCC Estimates for 2010 (in 2007$ per ton CO_2)

As was the case in the original TSD, the SCC increases over time because future emissions are expected to produce larger incremental damages as physical and economic systems become more stressed in response to greater climatic change. The approach taken by the interagency group is to allow the growth rate to be determined endogenously by the models through running them for a set of perturbation years out to 2050. Table 14B.5.2 illustrates how the growth rate for these four SCC estimates varies over time.

Table 14B.5.2 Average Annual Growth Rates of SCC Estimates between 2010 and 2050

Average Annual Growth Rate (%)	5.0% Avg	3.0% Avg	2.5% Avg	3.0% 95th
2010-2020	1.2%	3.2%	2.4%	4.4%
2020-2030	3.4%	2.1%	1.7%	2.3%
2030-2040	3.0%	1.9%	1.5%	2.0%
2040-2050	2.6%	1.6%	1.3%	1.6%

The future monetized value of emission reductions in each year (the SCC in year *t* multiplied by the change in emissions in year *t*) must be discounted to the present to determine its total net present value for use in regulatory analysis. As previously discussed in the original TSD, damages from future emissions should be discounted at the same rate as that used to calculate the SCC estimates themselves to ensure internal consistency – *i.e.*, future damages from climate change, whether they result from emissions today or emissions in a later year, should be discounted using the same rate.

14B.6 OTHER MODEL LIMITATIONS OR RESEARCH GAPS

The 2010 interagency SCC technical support report discusses a number of important limitations for which additional research is needed. In particular, the document highlights the need to improve the quantification of both non-catastrophic and catastrophic damages, the treatment of adaptation and technological change, and the way in which inter-regional and inter-sectoral linkages are modeled. It also discusses the need to more carefully assess the implications of risk aversion for SCC estimation as well as the inability to perfectly substitute between climate and non-climate goods at higher temperature increases, both of which have implications for the discount rate used. EPA, DOE, and other agencies continue to engage in long-term research work on modeling and valuation of climate impacts that we expect will inform improvements in SCC estimation in the future.

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14B.7 ANNEX A

Table 14B.7.1 Annual SCC Values: 2010-2050 (2007$/ton CO_2)

Discount Rate Year	5.0% Avg	3.0% Avg	2.5% Avg	3.0% 95th
2010	10	31	50	86
2011	11	32	51	90
2012	11	33	53	93
2013	11	34	54	97
2014	11	35	55	101
2015	11	36	56	105
2016	11	38	57	108
2017	11	39	59	112
2018	12	40	60	116
2019	12	41	61	120
2020	12	42	62	123
2021	12	42	63	126
2022	13	43	64	129
2023	13	44	65	132
2024	13	45	66	135
2025	14	46	68	138
2026	14	47	69	141
2027	15	48	70	149
2028	15	49	71	146
2029	15	49	72	149
2030	16	50	73	152
2031	16	51	74	155
2032	17	52	75	158
2033	17	53	76	161
2034	18	54	77	164
2035	18	55	78	168
2036	19	56	79	171
2037	19	57	81	174
2038	20	58	82	177
2039	20	59	83	180
2040	21	60	84	183
2041	21	61	85	186
2042	22	61	86	189
2043	22	62	87	192
2044	23	63	88	194
2045	23	64	89	197
2046	24	65	90	200
2047	24	66	92	203
2048	25	67	93	206
2049	25	68	94	209
2050	26	69	95	212

Table 14B.7.2 202 Global SCC Estimates at 2.5 Percent Discount Rate (2007$/ton CO_2)

Percentile	1st	5th	10th	25th	50th	Avg	75th	90th	95th	99th
Scenario					**PAGE**					
IMAGE	6	10	15	26	55	123	133	313	493	949
MERGE Optimistic	4	6	8	15	32	75	79	188	304	621
MESSAGE	4	7	10	19	41	104	103	266	463	879
MiniCAM Base	5	8	12	21	45	102	108	255	412	835
5th Scenario	2	4	6	11	24	81	66	192	371	915
Scenario					**DICE**					
IMAGE	25	31	37	47	64	72	92	123	139	161
MERGE Optimistic	14	18	20	26	36	40	50	65	74	85
MESSAGE	20	24	28	37	51	58	71	95	109	221
MiniCAM Base	20	25	29	38	53	61	76	102	117	135
5th Scenario	17	22	25	33	45	52	65	91	106	126
Scenario					**FUND**					
IMAGE	-14	-2	4	15	31	39	55	86	107	157
MERGE Optimistic	-6	1	6	14	27	35	46	70	87	141
MESSAGE	-16	-5	1	11	24	31	43	67	83	126
MiniCAM Base	-7	2	7	16	32	39	55	83	103	158
5th Scenario	-29	-13	-6	4	16	21	32	53	69	103

Table 14B.7.3 SCC Estimates at 3 Percent Discount Rate (2007$/ton CO2)

Percentile	1st	5th	10th	25th	50th	Avg	75th	90th	95th	99th
Scenario					**PAGE**					
IMAGE	4	7	9	17	36	87	91	228	369	696
MERGE Optimistic	2	4	6	10	22	54	55	136	222	461
MESSAGE	3	5	7	13	28	72	71	188	316	614
MiniCAM Base	3	5	7	13	29	70	72	177	288	597
5th Scenario	1	3	4	7	16	55	46	130	252	632
Scenario					**DICE**					
IMAGE	16	21	24	32	43	48	60	79	90	102
MERGE Optimistic	10	13	15	19	25	28	35	44	50	58
MESSAGE	14	18	20	26	35	40	49	64	73	83
MiniCAM Base	13	17	20	26	35	39	49	65	73	85
5th Scenario	12	15	17	22	30	34	43	58	67	79
Scenario					**FUND**					
IMAGE	-13	-4	0	8	18	23	33	51	65	99
MERGE Optimistic	-7	-1	2	8	17	21	29	45	57	95
MESSAGE	-14	-6	-2	5	14	18	26	41	52	82
MiniCAM Base	-7	-1	3	9	19	23	33	50	63	101
5th Scenario	-22	-11	-6	1	8	11	18	31	40	62

Table 14B.7.4 2020 Global SCC Estimates at 5 Percent Discount Rate (2007$/ton CO_2)

Percentile	1st	5th	10th	25th	50th	Avg	75th	90th	95th	99th
Scenario	**PAGE**									
IMAGE	1	2	2	4	10	27	26	68	118	234
MERGE Optimistic	1	1	2	3	6	17	17	43	72	149
MESSAGE	1	1	2	4	8	23	22	58	102	207
MiniCAM Base	1	1	2	3	8	20	20	52	90	182
5th Scenario	0	1	1	2	5	17	14	39	75	199
Scenario	**DICE**									
IMAGE	6	8	9	11	14	15	18	22	25	27
MERGE Optimistic	4	5	6	7	9	10	12	15	16	18
MESSAGE	6	7	8	10	12	13	16	20	22	25
MiniCAM Base	5	6	7	8	11	12	14	18	20	22
5th Scenario	5	6	6	8	10	11	14	17	19	21
Scenario	**FUND**									
IMAGE	-9	-5	-4	-1	2	3	6	10	14	24
MERGE Optimistic	-6	-4	-2	0	3	4	6	11	15	26
MESSAGE	-10	-6	-4	-1	1	2	5	9	12	21
MiniCAM Base	-7	-4	-2	0	3	4	6	11	14	25
5th Scenario	-11	-7	-5	-3	0	0	3	5	7	13

Table 14B.7.5 Additional Summary Statistics of 2020 Global SCC Estimates

Discount Rate Statistic:	5.0%				3.0%				2.5%			
	Mean	Variance	Skewness	Kurtosis	Mean	Variance	Skewness	Kurtosis	Mean	Variance	Skewness	Kurtosis
DICE	12	26	2	15	38	409	3	24	57	1097	3	30
PAGE	21	1481	5	32	68	13712	4	22	97	26878	4	23
FUND	3	41	5	179	19	1452	-42	8727	33	6154	-73	14931

14B.8 ANNEX B

The November 2013 revision of this technical support document is based on two corrections to the runs based on the FUND model. First, the potential dry land loss in the algorithm that estimates regional coastal protections was misspecified in the model's computer code. This correction is covered in an erratum to Anthoff and Tol (2013) published in the same journal (Climatic Change) in October 2013 (Anthoff and Tol (2013b)). Second, the equilibrium climate sensitivity distribution was inadvertently specified as a truncated Gamma distribution (the default in FUND) as opposed to the truncated Roe and Baker distribution as was intended. The truncated Gamma distribution used in the FUND runs had approximately the same mean and upper truncation point, but lower variance and faster decay of the upper tail, as compared to the intended specification based on the Roe and Baker distribution. The difference between the original estimates reported in the May 2013 version of this technical support document and this revision are generally one dollar or less.

The July 2015 revision of this technical support document is based on two corrections. First, the DICE model had been run up to 2300 rather than through 2300, as was intended, thereby leaving out the marginal damages in the last year of the time horizon. Second, due to an indexing error, the results from the PAGE model were in 2008 U.S. dollars rather than 2007 U.S. dollars, as was intended. In the current revision, all models have been run through 2300, and all estimates are in 2007 U.S. dollars. On average the revised SCC estimates are one dollar less than the mean SCC estimates reported in the November 2013 version of this technical support document. The difference between the 95th percentile estimates with a 3% discount rate is slightly larger, as those estimates are heavily influenced by results from the PAGE model.

CHAPTER 15. UTILITY IMPACT ANALYSIS

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CHAPTER 15. UTILITY IMPACT ANALYSIS

15.1 INTRODUCTION

In the utility impact analysis, U.S. Department of Energy (DOE) analyzes the changes in electric installed capacity and generation that result for each trial standard level (TSL).

The utility impact analysis uses a variant of the DOE Energy Information Administration's (EIA)'s National Energy Modeling System (NEMS).[a] NEMS is a public domain, multi-sectored, partial equilibrium model of the U.S. energy sector. Each year, DOE/EIA uses NEMS to produce an energy forecast for the United States, the *Annual Energy Outlook* (AEO). The EIA publishes a Reference case, which incorporates all existing energy-related policies at the time of publication, and a variety of side cases, which analyze the impact of different policies, energy price, and market trends. DOE is using a new methodology based on results published for the *Annual Energy Outlook 2015 (AEO2015)* Reference case and a set of the side cases that implement a variety of efficiency-related policies.[1]

The new approach retains key aspects of DOE's previous methodology and provides some improvements:

- The assumptions used in the AEO Reference case and side cases are fully documented and receive detailed public scrutiny.
- NEMS is updated each year, with each edition of the *AEO*, to reflect changes in energy prices, supply trends, regulations, *etc.*
- The comprehensiveness of NEMS permits the modeling of interactions among the various energy supply and demand sectors.
- Using EIA published side cases to estimate the utility impacts enhances the transparency of DOE's analysis.
- The variability in impacts estimates from one edition of *AEO* to the next will be reduced under the new approach.

The methodology is presented in appendix 15A. The methodology is described in more detail in K. Coughlin, *Utility Sector Impacts of Reduced Electricity Demand*.[2]

This chapter presents the results for commercial water heating (CWH) equipment.

15.2 METHODOLOGY

DOE estimates the marginal impacts of reduction in energy demand on the energy supply sector. In principle, marginal values should provide a better estimate of the actual impact of energy conservation standards. DOE represents these marginal impacts using time series of *impact factors*.

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[a] For more information on NEMS, refer to the DOE EIA documentation. A useful summary is *National Energy Modeling System: An Overview*. www.eia.gov/oiaf/aeo/overview/

The impact factors are calculated based on output from NEMS for the *AEO2015*. NEMS uses predicted growth in demand for each end use to build up a projection of the total electric system load growth. The system load shapes are converted internally to load duration curves, which are then used to estimate the most cost-effective additions to capacity. When electricity demand deviates from the *AEO* Reference case, in general there are three inter-related effects: the annual generation (TWh) from the stock of electric generating capacity changes, the total generation capacity itself (GW) may change, and the mix of capacity types and technologies may change. Technology changes lead to a change in the proportion of fuel consumption to electricity generated (referred to as the heat rate). Each of these effects can vary for different types of end use. The change in total generating capacity is sensitive to the degree to which the end-use is peak coincident, while the capacity mix is sensitive to the hourly load shape associated with the end use. Changes in generation by fuel type lead in turn to changes in total power sector emissions of sulfur dioxide (SO_2), nitrogen oxides (NO_x), mercury (Hg), and carbon dioxide (CO_2).

DOE defined impact factors describing the change in emissions, installed capacity, and fuel consumption per unit reduction of site electricity demand. The impact factors vary by sector and end-use, as well as by year. DOE multiplied the impact factors by the stream of site energy savings calculated in the national impact analysis (NIA) (chapter 10) to produce estimates of the utility impacts. The utility impact factors are presented in appendix 15A. For CWH equipment, DOE used the impact factors for water heating.

15.3 UTILITY IMPACT RESULTS

15.3.1 Installed Capacity

Figure 15.3.1 through Figure 15.3.6 show the changes in U.S. electricity installed capacity for each TSL by major plant type for selected years. The changes have been calculated based on the impact factors for capacity presented in appendix 15A. Units are megawatts of capacity per gigawatt-hour of site electricity use (MW/GWh).[b]

[b] These units are identical to GW/TWh.

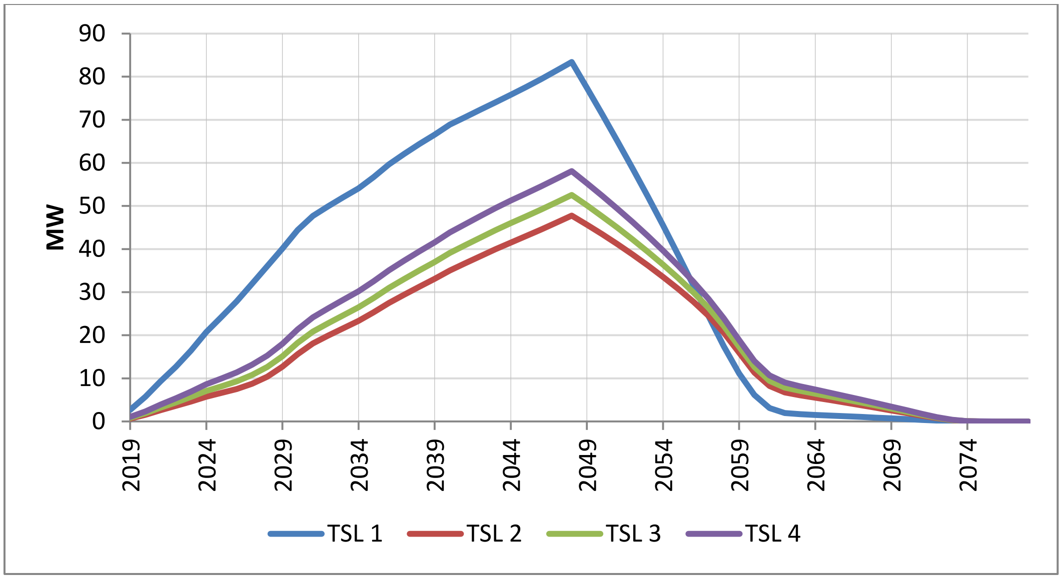

Figure 15.3.1 CWH Equipment: Total Capacity Reduction

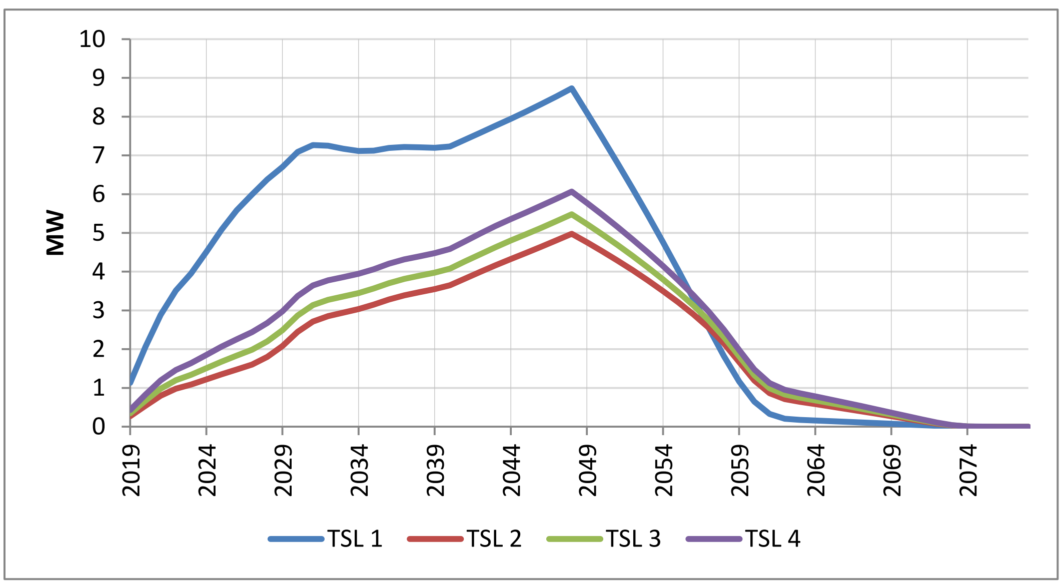

Figure 15.3.2 CWH Equipment: Coal Capacity Reduction

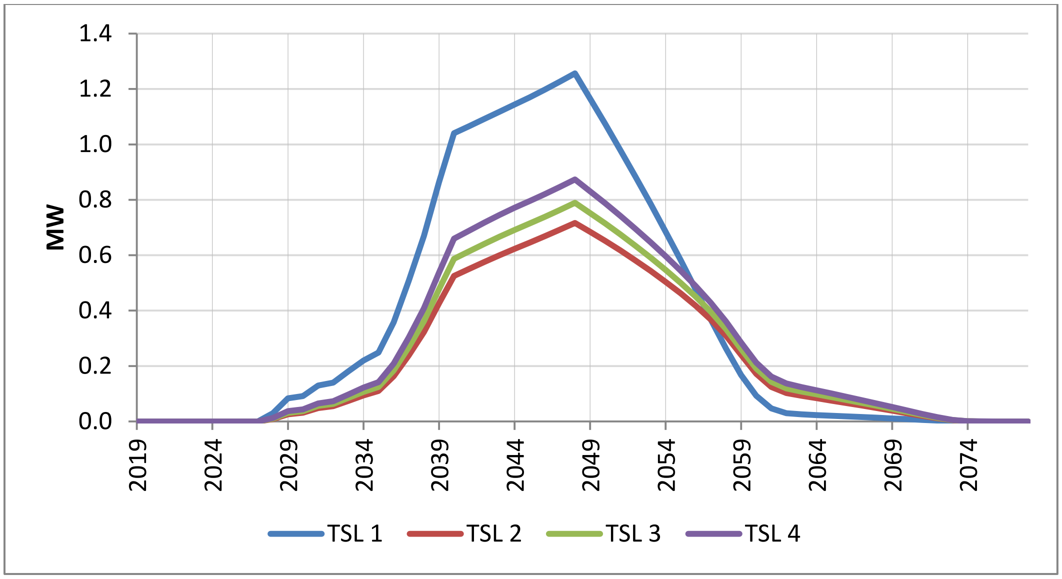

Figure 15.3.3 CWH Equipment: Nuclear Capacity Reduction

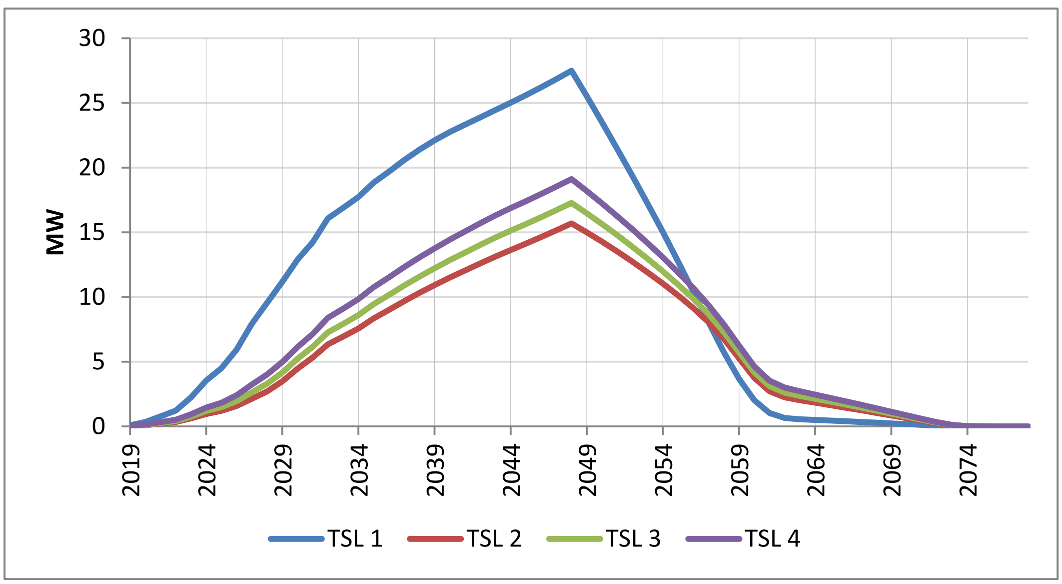

Figure 15.3.4 CWH Equipment: Gas Combined Cycle Capacity Reduction

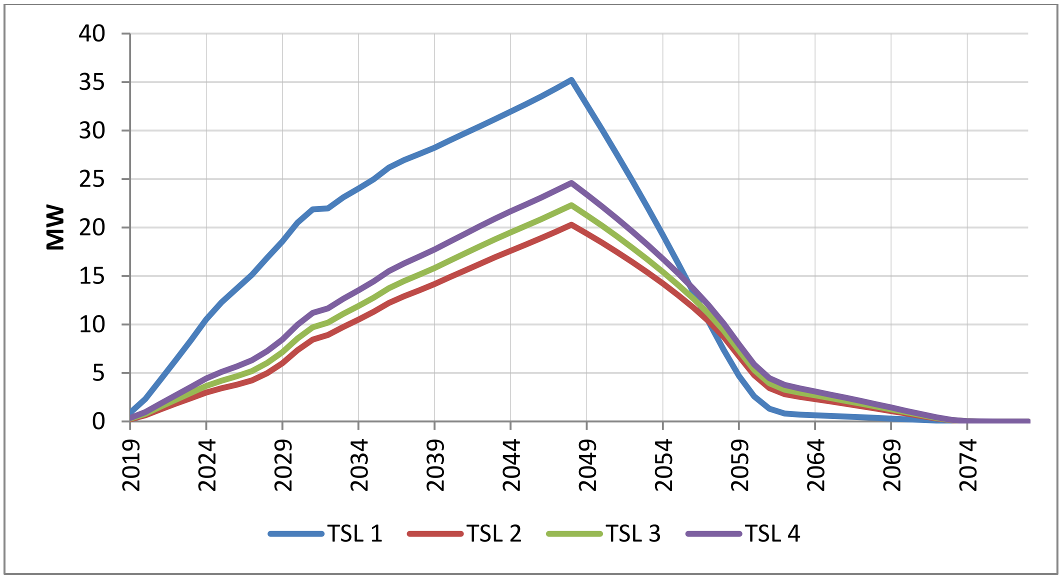

Figure 15.3.5 CWH Equipment: Peaking Capacity Reduction

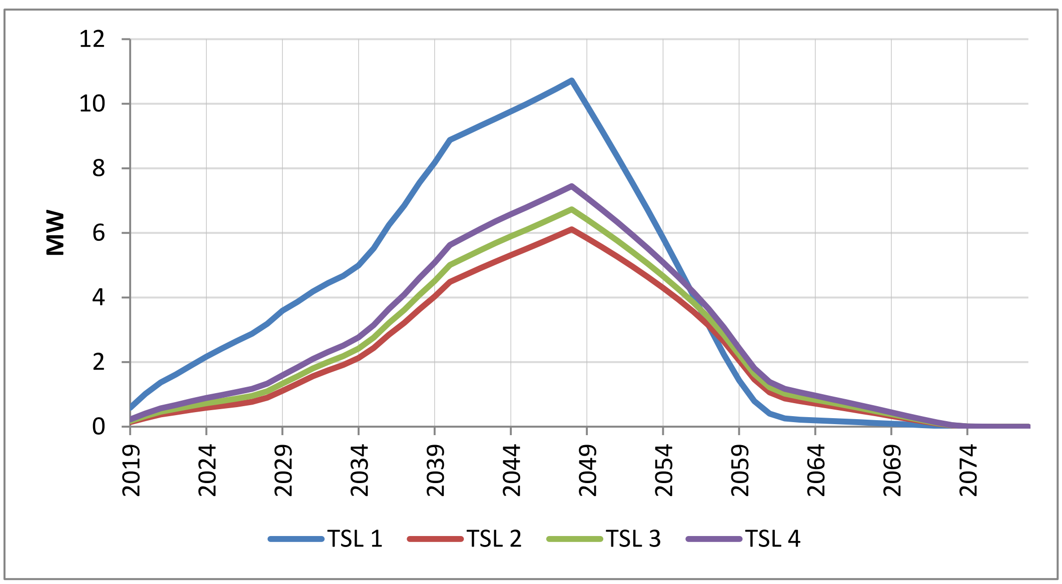

Figure 15.3.6 CWH Equipment: Renewables Capacity Reduction

15.3.2 Electricity Generation

Figure 15.3.7 through Figure 15.3.12 show the annual change in electricity generation for each TSL by fuel type. The change by fuel type has been calculated based on factors calculated as described in appendix 15A.

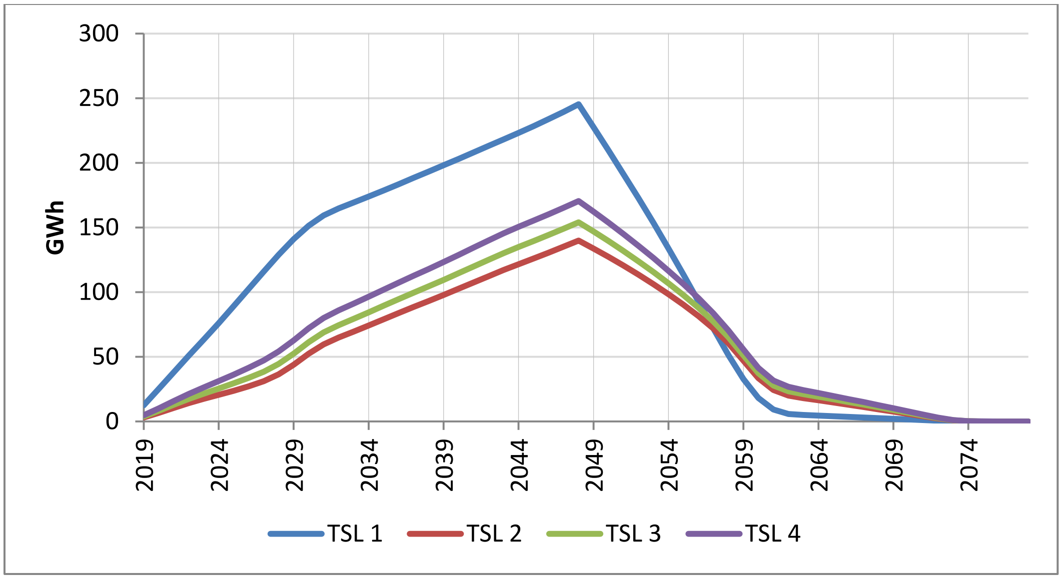

Figure 15.3.7 CWH Equipment: Total Generation Reduction

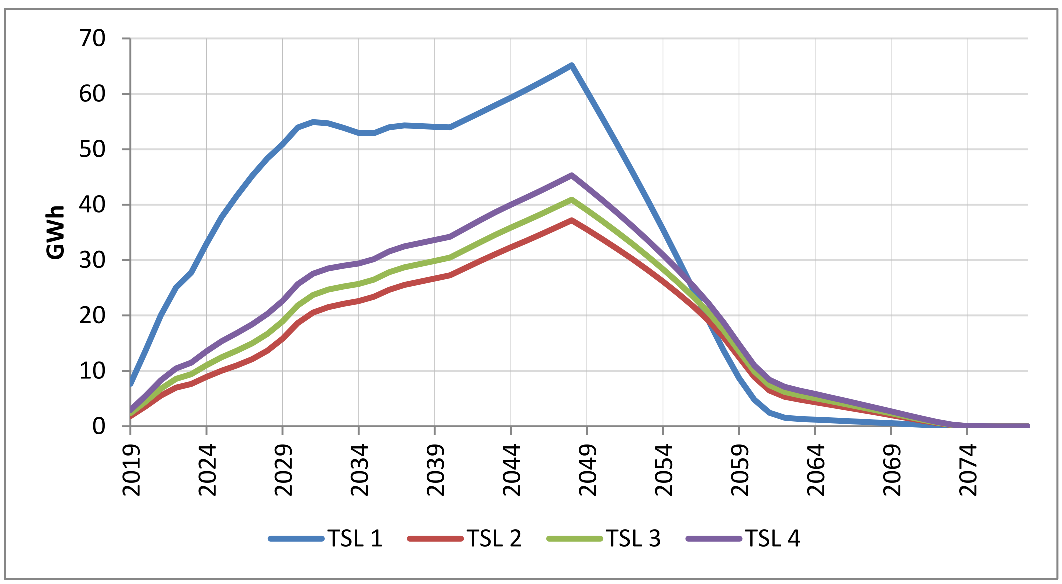

Figure 15.3.8 CWH Equipment: Coal Generation Reduction

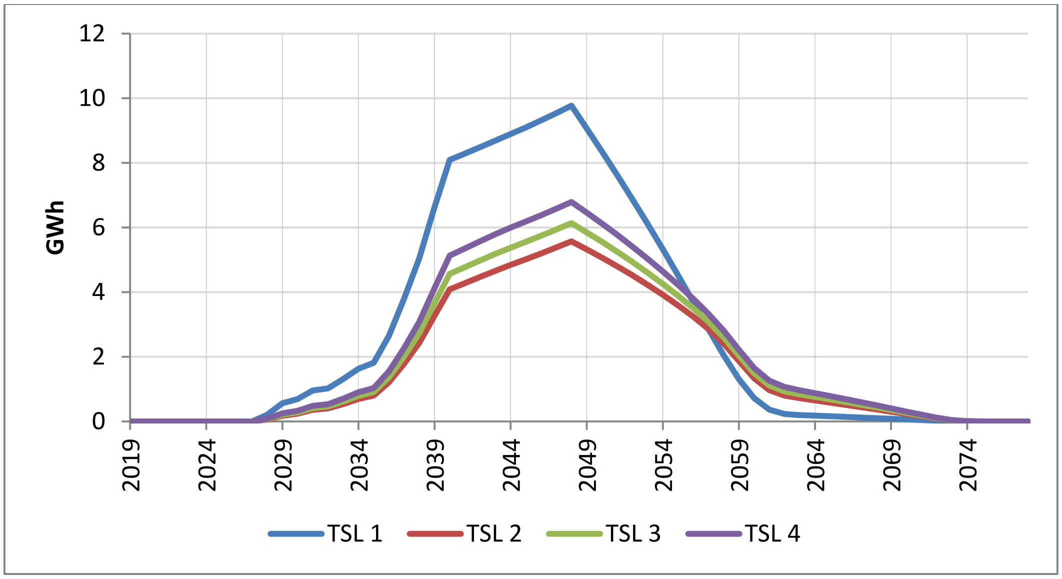

Figure 15.3.9 CWH Equipment: Nuclear Generation Reduction

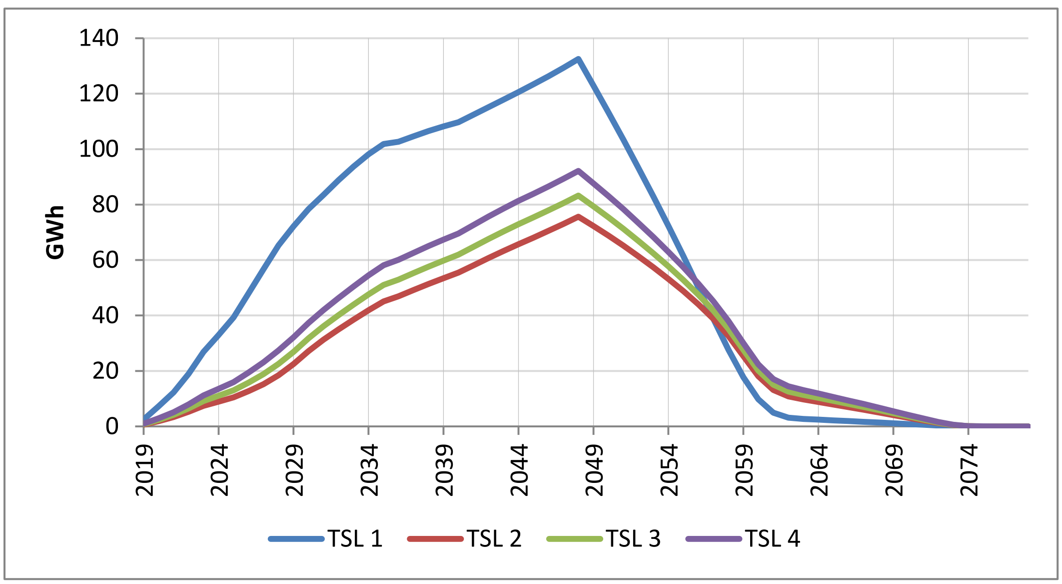

Figure 15.3.10 CWH Equipment: Gas Combined Cycle Generation Reduction

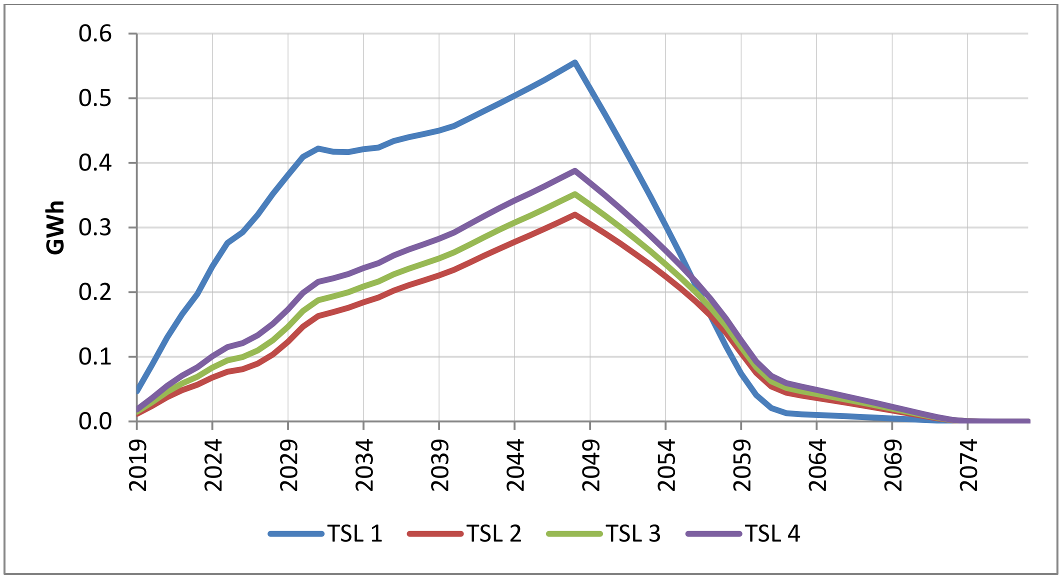

Figure 15.3.11 CWH Equipment: Oil Generation Reduction

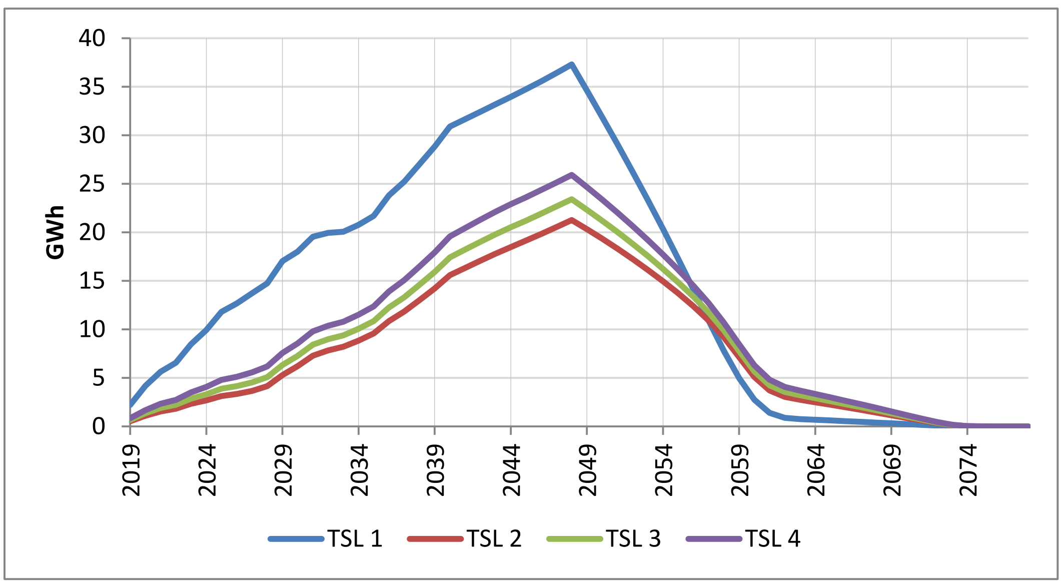

Figure 15.3.12 CWH Equipment: Renewables Generation Reduction

15.3.3 Results Summary

Table 15.3.1 presents a summary of the utility impact results for CWH equipment.

Table 15.3.1 CWH Equipment: Summary of Utility Impact Results

	Trial Standard Level (TSL)			
	1	**2**	**3**	**4**
Installed Capacity Reduction (MW)				
2020	5.74	1.53	1.90	2.33
2025	24.28	6.61	8.17	9.98
2030	44.44	15.63	18.25	21.36
2035	56.71	25.35	28.66	32.55
2040	68.90	35.03	39.10	43.85
Electricity Generation Reduction (GWh)				
2020	25.18	6.60	8.21	10.12
2025	89.17	23.76	29.48	36.24
2030	151.47	52.41	61.36	72.10
2035	178.67	79.07	89.50	101.94
2040	203.10	102.62	114.66	128.83

REFERENCES

1. U.S. Department of Energy–Energy Information Administration. *Annual Energy Outlook 2015 with Projections to 2040*. 2015. Washington, DC. DOE/EIA-0383(2015). Available at www.eia.gov/forecasts/aeo/.

2. Coughlin, K. *Utility Sector Impacts of Reduced Electricity Demand*. 2014. Lawrence Berkeley National Laboratory. Report No. LBNL-6864E. www.osti.gov/scitech/biblio/1165372/.

APPENDIX 15A. UTILITY IMPACT ANALYSIS METHODOLOGY

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APPENDIX 15A. UTILITY IMPACT ANALYSIS METHODOLOGY

15A.1 INTRODUCTION

In the utility impact analysis, the U.S. Department of Energy (DOE) analyzes the changes in electric installed capacity and power generation that result for each trial standard level (TSL). These changes are estimated by multiplying the site savings of electricity by a set of impact factors that measure the corresponding change in generation by fuel type, installed capacity, and power sector emissions. This appendix describes the methods that DOE used to calculate these impact factors. The methodology is more fully described in Coughlin (2014).[1]

DOE's analysis uses output of the DOE/Energy Information Administration (EIA)'s *Annual Energy Outlook* (*AEO*). The *AEO* includes a Reference case and a set of side cases that implement a variety of economic and policy scenarios. In 2015, EIA announced the adoption of a 2-year release cycle for the *AEO*, alternating between a full set of scenarios and a shorter edition containing only five scenarios. The *AEO2015* is a shorter edition.[2] DOE adapts its calculation methodology according to the *AEO* publication type, as described in this document.

15A.2 METHODOLOGY

Marginal reductions in electricity demand lead to marginal reductions in power sector generation, emissions, and installed capacity. DOE quantifies these reductions using marginal impact factors, which are time series defining the change in some power sector quantity that results from a unit change in site electricity demand. Because load shapes affect the mix of generation types on the margin, these impact factors depend on end-use and sector.

DOE's approach examines a series of *AEO* side cases related to efficiency policy to estimate the relationship between marginal demand reductions and power sector variables. With EIA's 2-year release cycle, the most recent full set of side cases is for *AEO2014*. The relevant scenarios from that publication are as follows:

- 2013 Technology (leaves all technologies at 2013 efficiencies),
- Best Available Technology (highest efficiency irrespective of cost),
- High Technology (higher penetration rates for efficiency and demand management),
- Extended Policies (includes efficiency standards that are not in the reference).

The *AEO2015* is a shorter publication. To update the impact factors for short publication years, DOE uses a two-step approach. First, DOE uses the scenarios available in both *AEO2014* and *AEO2015* to calculate scaling factors for each power sector variable. These scaling factors account for differences in the projected fuel mix in the two publication years. Second, DOE applies the scaling factors to the impact factors calculated using *AEO2014*. These rescaled values are used as the impact factors for analyses based on *AEO2015*.

For years that the *AEO* has the full set of scenarios, DOE uses seven steps to develop end-use dependent impact factors from results for the efficiency policy scenarios listed above. The steps are as follows:

1) Supply-side data on generation, capacity, and emissions and demand-side data on electricity use by sector and end-use are extracted from each side case. The data are converted to differences relative to the *AEO* Reference case.

2) The changes in electricity use on the demand-side data are allocated to one of three categories: on-peak, shoulder, and off-peak. These categories are used in the utility sector to correlate end-use consumption with supply types. For each of the end-uses that are modeled explicitly in the National Energy Modeling System (NEMS), load shape information is used to identify the fraction of annual electricity use assigned to each category. On-peak hours are defined as 12:00 noon to 5:00 p.m. Monday through Saturday, June through September. Off-peak hours are 9 p.m. to 6 a.m. and Sundays. All other hours are assigned to the shoulder period.

3) For each year and each side case, the demand-side reductions to on-peak, off-peak, and shoulder-period electricity use are matched on the supply-side to reductions in generation by fuel type. The fuel types are petroleum fuels, natural gas, renewables, nuclear, and coal. The allocation is based on the following rules:

   a) All petroleum-based generation is allocated to peak periods;

   b) Natural gas generation is allocated to any remaining peak reduction; this is consistent with the fact that oil and gas steam units are used in NEMS to meet peak demand;

   c) Base-load generation (nuclear and coal) is allocated proportionally to all periods;

   d) The remaining generation of all types is allocated to the remaining off-peak and shoulder reductions proportionally.

4) The output of Step 3 defines fuel-share weights giving the fraction of energy demand in each load category that is met by each fuel type, per unit of electricity demand added or subtracted at the margin, as a function of time. DOE also calculates fuel-specific marginal heat rates, equal to the primary energy (heat content) consumed per unit of electricity generated at the margin for that fuel (presented in appendix 10D). The product of the fuel-share weight and the marginal heat rate defines coefficients that allocate a marginal reduction in end-use electricity demand to a reduction in quads of fuel use for each of the five fuel types.

5) For the power sector pollutants tabulated in the *AEO* (CO_2, Hg, NO_X, SO_2). DOE uses a regression model to relate reductions in fuel consumption by fuel type to reductions in emissions of each pollutant type. The model produces a time series of coefficients defining the marginal emissions intensity for each fuel type, defined as the change in mass of pollutant emitted per unit change in fuel consumption. These coefficients are combined with the weights calculated in Step 4 to produce coefficients that relate emissions changes to changes in end-use demand. For power sector pollutants not tabulated in *AEO* (CH_4 and N_2O), DOE cannot define marginal emissions intensities, and instead uses U.S. Environmental Protection Agency estimates of the average

emissions intensity by fuel type.[3] These are then combined with the fuel-share weights to define the impact factor time series.

6) A regression model is used to relate reductions in generation by fuel type to reductions in installed capacity. The categories used for installed capacity are the same as for generation except for peak: NEMS uses two peak capacity types (combustion turbine/diesel and oil and gas steam) that are combined here into a single "peak" category. The model produces coefficients that define the change in total installed capacity of a given type resulting from a unit change in total annual generation for the corresponding fuel type. These coefficients are combined with the weights calculated in Step 4 to produce the annual impact factors relating installed capacity changes to changes in end-use demand.

7) The impact factor time-series for fuel share, pollutant emissions, and capacity for the appropriate end use are multiplied by the stream of energy savings calculated in the national impact analysis (NIA) to produce estimates of the utility impacts.

This analysis ignores pumped storage, fuel cells, and distributed generation, as these generation types are not affected by the policy changes modeled in the EIA side cases. The methodology is described in more detail in K. Coughlin, *Utility Sector Impacts of Reduced Electricity Demand*.[1]

In the shorter *AEO,* efficiency-related scenarios are not published. For the scenarios that are published, the approach outlined above can be used to define marginal fuel-specific heat rates, to relate changes in fuel use to changes in pollutant emissions, and to relate changes in generation to changes in capacity. However, the results depend on the scenarios used as input, as the detailed evolution of the electricity sector depends both on demand and on other factors such as economic growth that affect the supply side more directly.

To deal with this issue, DOE developed a set of scaling factors derived from scenarios that are available in both *AEO2014* and *AEO2015* (High Economic Growth, Low Economic Growth, High Oil Price, and High Resource). Because the scaling factors are calculated using the same set of scenarios, they should be insensitive to how the scenarios are defined and should capture the effects that depend only on how the projected fuel mix for electricity generation differs between the two publication years. The scaling factors are calculated as follows:

1) For both *AEO2014* and *AEO2015* supply-side data on generation, capacity, and emissions are collected for the side cases that are published in both years. The data are converted to differences relative to the appropriate *AEO* Reference case.

2) For each *AEO*, time series of fuel-specific marginal heat rates are defined as the ratio of change in fuel consumption to change in generation by fuel type. The values are averaged across scenarios to produce a single time series for each *AEO* edition.

3) For each *AEO*, time series of fuel-specific emissions intensities are defined as the ratio of change in pollutant emissions to change in fuel consumption for each fossil fuel type. The values are averaged across scenarios to produce a single time series for each *AEO* edition.

4) For each *AEO*, time series of fuel-specific capacity factors are defined as the ratio of change in installed capacity to change in generation by fuel type. The values are averaged across scenarios to produce a single time series for each *AEO* edition.

5) For each of the time series generated in Steps 2–4, a scaling factor is defined as the ratio of the cumulative impact factor for *AEO2015* divided by the cumulative impact factor for *AEO2014*. The cumulative impact factor is defined as the sum of the annual impact factors for the years 2019–2040.

6) The scaling factors are used to rescale the marginal heat rates, emissions intensities, and capacity coefficients developed in the *AEO2014* analysis, and generate impact factors corresponding to *AEO2015*.

15A.3 MODEL RESULTS

This section summarizes the impact factors for fuel share and capacity. The marginal heat rates are presented in appendix 10D.

15A.3.1 Electricity Generation

The data in Table 15A.3.1 show the distribution across fuel types of a unit reduction in electricity demand by sector and end-use, referred to in this document as fuel-share weights. The fuel types are coal, natural gas, petroleum, renewables, and nuclear. The values for cooling are representative of peaking loads, while the values for refrigeration are representative of flat loads.

Table 15A.3.1 Fuel-Share Weights by Sector and End-Use (Values for 2020 Shown)

End Use	Coal	Natural Gas	Nuclear	Oil	Renewables
Commercial Sector					
Cooking	53.7%	29.6%	0.0%	0.4%	16.6%
Lighting	54.1%	29.2%	0.0%	0.4%	16.6%
Office Equipment (Non-PC)	51.7%	31.5%	0.0%	0.6%	16.6%
Office Equipment (PC)	51.7%	31.5%	0.0%	0.6%	16.6%
Other Uses	52.4%	30.8%	0.0%	0.5%	16.6%
Refrigeration	56.2%	27.4%	0.0%	0.3%	16.4%
Space Cooling	48.9%	35.0%	0.0%	1.0%	15.4%
Space Heating	58.5%	24.9%	0.0%	0.0%	17.0%
Ventilation	56.4%	27.3%	0.0%	0.2%	16.5%
Water Heating	54.3%	29.2%	0.0%	0.4%	16.4%
Industrial Sector					
All Uses	52.4%	30.8%	0.0%	0.5%	16.6%
Residential Sector					
Clothes Dryers	55.0%	28.0%	0.0%	0.2%	17.1%
Cooking	54.1%	28.6%	0.0%	0.3%	17.3%
Freezers	56.1%	27.6%	0.0%	0.3%	16.4%
Lighting	56.9%	26.1%	0.0%	0.1%	17.2%
Other Uses	55.0%	27.9%	0.0%	0.2%	17.2%
Refrigeration	56.0%	27.6%	0.0%	0.3%	16.5%
Space Cooling	49.4%	34.3%	0.0%	0.9%	15.6%
Space Heating	58.1%	25.1%	0.0%	0.0%	17.1%
Water Heating	55.5%	27.2%	0.0%	0.2%	17.5%

15A.3.2 Installed Capacity

Table 15A.3.2 shows the total change in installed capacity (GW) per unit of site electricity demand reduction for the five principal capacity types: coal, natural gas, peaking, renewables, and nuclear. The peaking category is the sum of the two NEMS categories oil and gas steam and combustion turbine/diesel.

Table 15A.3.2 Capacity Impact Factors in GW per TWh of Reduced Site Electricity Demand (Values for 2020 shown)

End Use	Coal	Natural Gas	Nuclear	Peaking	Renewables
Commercial Sector					
Cooking	8.63E-02	1.49E-02	0.00E+00	1.19E-01	4.32E-02
Lighting	8.71E-02	1.47E-02	0.00E+00	1.11E-01	4.33E-02
Office Equipment (Non-PC)	8.31E-02	1.59E-02	0.00E+00	1.62E-01	4.33E-02
Office Equipment (PC)	8.31E-02	1.59E-02	0.00E+00	1.62E-01	4.33E-02
Other Uses	8.43E-02	1.55E-02	0.00E+00	1.46E-01	4.34E-02
Refrigeration	9.05E-02	1.38E-02	0.00E+00	7.29E-02	4.28E-02
Space Cooling	7.87E-02	1.76E-02	0.00E+00	2.73E-01	4.01E-02
Space Heating	9.41E-02	1.25E-02	0.00E+00	0.00E+00	4.44E-02
Ventilation	9.07E-02	1.37E-02	0.00E+00	6.89E-02	4.29E-02
Water Heating	8.74E-02	1.47E-02	0.00E+00	1.13E-01	4.28E-02
Industrial Sector					
All Uses	8.43E-02	1.55E-02	0.00E+00	1.46E-01	4.34E-02
Residential Sector					
Clothes Dryers	8.85E-02	1.41E-02	0.00E+00	7.02E-02	4.46E-02
Cooking	8.70E-02	1.44E-02	0.00E+00	7.97E-02	4.52E-02
Freezers	9.03E-02	1.39E-02	0.00E+00	7.70E-02	4.28E-02
Lighting	9.16E-02	1.32E-02	0.00E+00	2.57E-02	4.48E-02
Other Uses	8.84E-02	1.41E-02	0.00E+00	6.62E-02	4.49E-02
Refrigeration	9.02E-02	1.39E-02	0.00E+00	7.56E-02	4.29E-02
Space Cooling	7.95E-02	1.73E-02	0.00E+00	2.51E-01	4.07E-02
Space Heating	9.35E-02	1.26E-02	0.00E+00	2.70E-03	4.47E-02
Water Heating	8.93E-02	1.37E-02	0.00E+00	4.32E-02	4.55E-02

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CHAPTER 16. EMPLOYMENT IMPACT ANALYSIS

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16.1 INTRODUCTION

The U.S. Department of Energy's (DOE's) employment impact analysis is designed to estimate indirect national job creation or elimination resulting from proposed standards due to reallocation of associated expenditures for purchasing and operating commercial water heating (CWH) equipment. Job increases or decreases reported in this chapter are separate from the direct CWH sector employment impacts reported in chapter 12 and reflect the employment impact of efficiency standards on all other sectors of the economy.

16.2 ASSUMPTIONS

DOE expects amended energy conservation standards to decrease energy use and, therefore, reduce energy expenditures. The savings in energy expenditures may be spent on new investments or not spent at all (*i.e.*, they may remain "saved"). Amended standards may increase the purchase price of commercial water heaters, including the retail price plus sales tax, and could, in some cases, increase installation costs.

Using an input/output econometric model of the U.S. economy, this analysis estimated the short-term effect of these expenditure impacts on net economic output and employment. DOE intends this analysis to quantify the indirect employment impacts of these expenditure changes. DOE evaluated direct employment impacts at manufacturers' facilities in the manufacturer impact analysis (see chapter 12).

DOE notes that the Impact of Sector Energy Technologies (ImSET) model is not a general equilibrium-forecasting model and understands the uncertainties involved in projecting employment impacts, especially changes in the later years of the analysis.[1] Because ImSET does not incorporate price changes, the employment effects predicted by ImSET would overestimate the magnitude of actual job impacts over the long run for this rule. As input/output models do not allow prices to bring markets into equilibrium, they are best used for short-run analysis. Therefore, DOE included a qualitative discussion of how labor markets are likely to respond in the longer term. In future rulemakings, DOE may consider the use of other modeling approaches for examining long-run employment impacts.

16.3 METHODOLOGY

DOE based its analysis on an input/output model of the U.S. economy that estimates the effects of standards on major sectors of the economy related to buildings and the net impact of standards on jobs. Pacific Northwest National Laboratory (PNNL) developed the model using ImSET 3.1.1[2] as a successor to Impact of Building Energy Efficiency Programs (ImBuild),[3] a special purpose version of the Impact Analysis for Planning (IMPLAN)[4] national input/output model. ImSET estimates the employment and income effects of building energy technologies. Compared with simple economic multiplier approaches, ImSET allows for more complete and automated analysis of the economic impacts of energy-efficiency investments in buildings.

In an input/output model, the level of employment in an economy is determined by the relationships of different sectors of the economy and spending flows among them. Different sectors have different levels of labor intensity, and so changes in the level of spending (*e.g.*, due to the effects of an efficiency standard) in one sector of the economy will affect flows in other sectors, which affects the overall level of employment.

ImSET uses a 187-sector model of the national economy to predict the economic effects of residential and commercial buildings' technologies. ImSET collects estimates of initial investments, energy savings, and economic activity associated with spending the savings resulting from standards (*e.g.*, changes in final demand in personal consumption, business investment and spending, and government spending). It provides overall estimates of the change in national output for each input/output sector. The model applies estimates of employment and wage income per dollar of economic output for each sector and calculates impacts on national employment and wage income.

Energy-efficiency technology primarily affects the U.S. economy along three spending pathways. First, general investment funds are diverted to sectors that manufacture, install, and maintain energy-efficient equipment. The increased cost of equipment leads to higher employment in the equipment manufacturing sectors and lower employment in other economic sectors. Second, commercial firm and residential spending are redirected from utilities toward firms that supply production inputs. Third, utility sector investment funds are released for use in other sectors of the economy. When customers use less energy, electric and natural gas utilities experience relative reductions in demand, which leads to reductions in utility sector investment and employment.

DOE notes that the employment impacts estimated with ImSET for the entire economy differ from the employment impacts in the CWH manufacturing sector estimated in chapter 12 using the Government Regulatory Impact Model (GRIM). The methodologies used and the sectors analyzed in the ImSET and GRIM models are different.

16.4 SHORT-TERM RESULTS

The results in this section refer to impacts of CWH standards relative to the no-new-standards case. DOE disaggregated the impact of standards on employment into three component effects: increased capital investment costs, decreased energy costs, and changes in operations and maintenance costs.

Conceptually, one can consider the impact of the rule in its first year on three aggregate sectors: the CWH production sector, the energy utility sector, and the general consumer goods sector (as mentioned previously, ImSET's calculations are made at a much more disaggregate level). By raising energy efficiency, the proposed rule increases the purchase price of commercial water heaters; this increase in expenditures causes an increase in employment in this sector. At the same time, the improvements in energy efficiency reduce expenditures on electricity and natural gas. The reduction in electricity and gas demand causes reductions in employment in the utilities sectors. Finally, based on the net impact of increased expenditures on commercial water heaters and reduced expenditures on energy, expenditures on everything else are either positively or negatively affected, increasing or reducing jobs in that sector accordingly.

The model also captures any indirect jobs created or lost by changes in consumption due to changes in employment (*e.g.,* as more workers are hired, they consume more goods, which generates more employment; the converse is true for workers laid off).

Table 16.4.1 presents the modeled net employment impact from the rule in 2020 and 2025. As mentioned in chapter 12, 97 percent of commercial water heaters are produced domestically and 3 percent are imported. The U.S. trade deficit in recent years suggests that between 50 and 75 percent of the money spent on imported commercial water heaters is likely to return.

Table 16.4.1 Net Short-Term Change in Employment (Number of Employees)

Trial Standard Level	2020	2025
1	119–123	205–210
2	361–377	527–544
3	399–416	610–628
4	459–478	721–741

16.5 LONG-TERM RESULTS

Over the long term, DOE expects the energy savings to customers to increasingly dominate the increase in appliance costs, resulting in increased aggregate savings to customers. As a result, DOE expects demand for energy to decline over time and demand for other goods to increase. Because the energy sector is relatively capital intensive compared to the consumer goods sector, the net effect will be an increase in labor demand. In equilibrium, this should lead to upward pressure on wages and a shift in employment away from energy toward consumer goods. Note that in long-run equilibrium there is no net effect on total employment because wages adjust to bring the labor market into equilibrium. Nonetheless, even to the extent that markets are slow to adjust, DOE anticipates that net labor market impacts will be negligible over time due to the small magnitude of the short-term effects presented in Table 16.4.1.

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17.1 INTRODUCTION

Under the Process Rule (Procedures for Consideration of New or Revised Energy Conservation Standards for Consumer Products), 61 FR 36974 (July 15, 1996), the U.S. Department of Energy (DOE) is committed to continually explore non-regulatory alternatives to standards. DOE will prepare a draft regulatory impact analysis pursuant to E.O. 12866, Regulatory Planning and Review, which will be subject to review under the Executive Order by the Office of Management and Budget's Office of Information and Regulatory Affairs. 58 FR 51735 (Sept. 30, 1993).

DOE has identified five major alternatives to standards that represent feasible policy options to reduce commercial water heating (CWH) equipment energy consumption. DOE evaluated each alternative's ability to achieve significant energy savings at a reasonable cost and compared the effectiveness of each one to the effectiveness of the proposed standards rule.

The non-regulatory means of achieving energy savings that DOE proposes to analyze are listed in Table 17.1.1. In support of DOE's notice of proposed rulemaking, DOE includes a quantitative analysis of each alternative, the methodology for which is discussed briefly in this technical support document (TSD).

Table 17.1.1 Non-Regulatory Alternatives to Standards

No New Regulatory Action
Customer Rebates
Consumer Tax Credits
Voluntary Energy Efficiency Targets
Early Replacement

17.2 METHODOLOGY

DOE uses the national impact analysis (NIA) spreadsheet models to calculate the national energy savings (NES) and the net present value (NPV) corresponding to each non-regulatory alternative. The NIA model is discussed in chapter 10 of this TSD. To compare each alternative quantitatively to the proposed energy conservation standards, DOE quantifies the effect of each alternative on the purchase and use of energy-efficient CWH equipment. After quantifying each alternative, DOE makes the appropriate revisions to the inputs in the NIA models to estimate energy savings compared to the no-new-standards case scenario. Key inputs that DOE typically revises in these models include the following:

- energy prices and escalation factors,
- implicit market discount rates,
- business purchase prices and operating costs,
- purchase price-versus-efficiency relationships, and
- product stock data.

The key measures of the impact of each alternative include the following:

- Energy use reflects the cumulative energy use of the product from the effective date of the new standard to the year 2048.
- NES represents the cumulative national energy use from the base-case projection minus the alternative policy case projection, given in quadrillion British thermal units (quads).
- NPV represents the value in 2014$ (discounted to 2015) of net monetary savings from products bought during the period from the effective date of the policy (2019) through the end of the analysis period (2048).

17.3 NON-REGULATORY POLICIES

17.3.1 No New Regulatory Action

The no-new-standards case is the one in which no new regulatory action is taken with regard to the energy efficiency of CWH equipment, as described in the NIA (chapter 10 of this TSD). The no-new-standards case provides the basis of comparison for all other non-regulatory alternatives. By definition, no new regulatory action yields zero NES and an NPV of zero dollars.

17.3.2 Customer Rebates

Customer rebates cover a portion of the difference in incremental product price between products meeting baseline efficiency levels and those meeting higher efficiency levels, resulting in a higher percentage of consumers purchasing more efficacious models and decreased aggregated energy use compared to the no-new-standards case.

DOE surveyed the various rebate programs available in the United States in 2014 and 2015. Typically, local utility companies offer rebates to commercial customers (*i.e.*, business customers taking service through a commercial rate code) that replace their existing commercial water heater with an energy-efficient appliance. The Environmental Protection Agency (EPA) initiated an ENERGY STAR® voluntary program for Commercial Water Heaters on March 20, 2013. Equipment qualifying as energy efficient is frequently defined as ENERGY STAR compliant. The current ENERGY STAR Product Specification for Commercial Water Heaters[1] includes storage type gas-fired and electric heat pump water heaters, as well as gas-fired instantaneous type products. DOE notes that there are no commercially available commercial storage type heat pump water heater products that meet the ENERGY STAR program definitions: the ENERGY STAR program does not currently have efficiency metric for electric heat pump water heaters, and hence no certified products of this type are available on the ENERGY STAR Product Finder website.

For this investigation, DOE conducted internet research to identify representative rebates across the country. This research identifies 9 utility companies and an energy efficiency program that operate in 11 states: Maine, New Hampshire, Massachusetts, Wisconsin, Missouri, Iowa, Illinois, South Dakota, Nebraska, Washington, and California. Review of these entities identified that they offer various rebates for storage tank products and instantaneous products, typically based upon the efficiency level of the appliance.

Among these programs, Columbia Gas of Massachusetts[2] and Berkshire Gas,[3] which are both members of Gas Networks, offer $500 rebates on condensing standalone 75 to 300 M Btu/h with a thermal efficiency (E_t) of 95 percent or greater or $100 for ENERGY STAR-labeled storage water heaters. Unitil Energy,[4] also a member of Gas Networks, offers the same rebates for the same products. Focus on Energy,[5] Wisconsin's state program funded by investor-owned energy utilities, offers a $500 rebate for a natural gas storage water heater with a E_t of 90 percent and higher. MidAmerican Energy[6] offers a rebate of $125 for a natural gas storage water heater with a 60-gallon or larger storage capacity and a E_t greater than or equal to 82.5 percent.

During the research, different program structures were observed for various programs. The Sempra Energy Companies (Southern California Gas Company[7] and San Diego Gas & Electric[8]) offer a rebate structured around the input rating of the appliance with rates ranging between $1/1,000 British thermal unit per hour (Btu/h) and $5/1,000 Btu/h. Southern California Gas Company offers $1/1,000 Btu/h for products with a E_t of 83 percent, but less than 90 percent and $5/1,000 Btu/h for products with a E_t of 90 percent and higher. San Diego Gas & Electric offers a flat rate of $2/1,000 Btu/h for all products with an E_t of 84 percent and higher. Puget Sound Energy[9] offered a program focused upon commercial high-efficiency water heaters for use in restaurants and laundry applications. This rebate of $800 is for storage tank products with an E_t of 94 percent and higher.

Rebate programs for instantaneous commercial water heaters were found to be typically structured by a flat rate incremented for increasing efficiency ranges; an E_t of 0.82 ranges from a $200 to a $500 rebate, while an E_t of 0.94 and higher qualifies for a rebate of $800. The $800 rebate is offered by Unitil, Berkshire, and Columbia Gas of Massachusetts, all members of Gas Networks. It is interesting to note that Unitil also offered the lowest rebate identified for instantaneous commercial water heaters with an E_t of 0.67 qualifying for a $100 rebate. The Sempra Energy Companies (Southern California Gas Company and San Diego Gas & Electric) offer a rebate structured around the input rating of the appliance with rates ranging from $1/1,000 Btu/h for products with E_t of 80 percent but less than 90 percent, and $4/1,000 Btu/h for products with a E_t of 90 percent and higher.

DOE chose to model a scenario where customers are offered flat rebates for each of the product types based upon the average value of the rebates identified in the research. It is noted that the programs offering rebates were included in the analysis using 199,000 Btu/h input rates for storage tank products and 250,000 Btu/h input rates for instantaneous products. Based upon the data collected, the DOE assumes that storage tank products have an average rebate of $341 and instantaneous products have an average rebate of $465.

To estimate the market shares of efficiency levels (see chapter 10 of this TSD) that would result from such a rebate, DOE examined available information on efficiency choices in equipment classes covered by ENERGY STAR.[a] Available ENERY STAR shipment[10] information indicates that, on average, ENERGY STAR programs have a market penetration of 46.9 percent. Examining these data identifies that currently, ENERGY STAR has nine commercial product programs.[b] The commercial programs have an average market penetration of 42.8 percent. Therefore, DOE modeled the market penetration for rebates at 45 percent of total shipments in those equipment classes meeting or exceeding the ENERGY STAR level. For determining the potential impact of rebate programs targeting trial standard level (TSL) 3, DOE developed a shift scenario. In the shift scenario, market share was shifted upward such that the total market share of shipments at or above TSL 3 was 45 percent. To do this, DOE calculated the existing market shares of shipments above TSL 3, if any, and the remainder of 45 percent minus existing market shares was assigned to the TSL 3 efficiency level. Shipments below TSL 3 were distributed across efficiency levels in proportion to no-new-standards case efficiency distributions. In cases (if any) where the existing cumulative no-new-standards case market share at or above TSL 3 exceeded 45 percent, the distribution was left at the no-new-standards case distribution.[c]

Although the rebate program reduces the total installed cost to the customer, it is financed by tax revenues or by utility revenues. Therefore, from a societal perspective, the installed cost at any efficiency level does not change with the rebate program; rather, part of the cost is transferred from the customer to taxpayers/ratepayers as a whole. Consequently, DOE assumed that equipment costs in the rebates scenario were identical to the NIA no-new-standards case.

DOE assumed that rebates would remain in effect for the duration of the analysis period. Table 17.3.1 presents the NES and NPV values for the 45 percent rebate scenario and compares them against the NES and NPV values at TSL 3. NES and NPV are calculated for equipment purchased in the 2018–2047 analysis period and include energy savings, operation and maintenance costs, and savings extending for the life of equipment purchased in 2047.

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[a] The EPA initiated an ENERGY STAR Program for Commercial Water Heaters on March 20, 2013. The program defines commercial water heaters as products that utilize gas or electricity to heat potable water for use outside the heater upon demand, at a thermostatically controlled temperature. These products may be either storage tank or instantaneous, where a storage type product heats and stores water within the appliance at a thermostatically controlled temperature for delivery on demand and that is industrial equipment, including: i.) gas storage water heaters with an input rate greater than 75,000 British thermal units (Btu) per hour, and ii.) Electric heat pump water heaters designed to transfer thermal energy from one temperature level to a higher temperature level for the purpose of heating water, including both air-source and water-source units with an input rate greater than or equal to 1.6 kW.
[b] The nine Energy Star programs considered relevant to the current rulemaking include commercial dishwashers, commercial fryers, commercial griddles, commercial hot food holding cabinets, commercial ice machines, commercial ovens, commercial refrigerators and freezers, commercial steam cookers, and light commercial heating, ventilation, and air conditioning (HVAC).
[c] This analysis includes a market shift of commercial gas-fired instantaneous hot water supply boilers, although no specific rebate programs were identified for this type of product. This analysis therefore overestimates the impact of existing rebate programs by assuming expansion to cover the hot water supply boilers.

Table 17.3.1 Customer Rebate NES and NPV Comparison to TSL 3

Policy Alternative	Cumulative Primary Energy Savings* *quads*	Net Present Value** *billion 2014$*	
		7% Discount Rate	3% Discount Rate
No New Regulatory Action	0	0	0
Customer Rebates	0.187	0.302	0.797
Today's Standards at TSL 3	1.604	2.263	6.750

* Energy savings are in primary energy quads.
** Net present value is the value in the present of a time series of costs and savings.

17.3.3 Consumer Tax Credits

Consumer tax credits are considered a viable non-regulatory market transformation program, as shown by the inclusion of Federal consumer tax credits in the Energy Policy Act of 2005 (EPACT 2005; Pub L. 109-58, 119 Stat 1026 (2005)) for various residential appliances. From a consumer perspective, the most important difference between rebate and tax credit programs is that a rebate can be obtained relatively quickly, whereas receipt of tax credits is delayed until income taxes are filed or a tax refund is provided by the Internal Revenue Service.

During 2014, a $300 Federal tax credit was available for storage tank products with a E_t of 0.90 or greater. Commercial water heaters do not qualify for a 2015 Federal tax credit.

As with consumer rebates, DOE assumed that consumer tax credits paid the same amount towards the purchase of equipment ($341 for storage tank equipment and $456 for instantaneous equipment) but estimated a different response rate. The delay in reimbursement makes tax credits less attractive than rebates. Consequently, DOE estimated a response rate that is 80 percent of that for rebate programs (45 percent) and, therefore, a corresponding shift of 36 percent in market shares to or above TSL 3 with no change in total shipments. In cases (if any) where the existing cumulative no-new-standards case market share at or above TSL 3 exceeded 36 percent, the distribution was left at the no-new-standards case distribution.[d] DOE estimated NPV and NES values under these assumptions and the results are presented in Table 17.3.2.

From a societal perspective, tax credits (like rebates) do not change the installed cost of the equipment but rather transfer a portion of the cost from the consumer to taxpayers as a whole. DOE, therefore, assumed that equipment costs in the consumer tax credits scenario were identical to the NIA no-new-standards case.

DOE assumed that tax credits would remain in effect for the duration of the analysis period. Table 17.3.2 presents the NES and NPV values for the tax credit scenario and compares them against the NES and NPV values at TSL 3.

[d] This analysis includes a market shift of commercial gas-fired instantaneous water heaters and hot water supply boilers, although no specific tax incentive programs were identified for this type of product. This analysis therefore overestimates the impact of prior tax incentive programs by assuming expansion to cover boilers.

Table 17.3.2 Tax Credit NES and NPV Comparison to TSL 3

Policy Alternative	Cumulative Primary Energy Savings* *quads*	Net Present Value** *billion 2014$*	
		7% Discount Rate	3% Discount Rate
No New Regulatory Action	0	0	0
Consumer Tax Credits	0.103	0.166	0.438
Today's Standards at TSL 3	1.604	2.263	6.750

* Energy savings are in primary energy quads.
** Net present value is the value in the present of a time series of costs and savings.

17.3.4 Voluntary Energy Efficiency Programs

While voluntary programs for equipment could be effective, DOE lacks a quantitative basis to determine their effectiveness. As previously noted, the economic and social considerations in play are broader than simple economic return to the equipment purchaser. DOE lacks the data necessary to quantitatively project the degree to which such voluntary programs for more expensive, higher efficiency equipment like CWH equipment would modify the market.

17.3.5 Early Replacement

Early replacement refers to the replacement of equipment before the end of its useful life. The purpose of this policy is to retrofit or replace old, inefficient equipment with high-efficiency units. DOE considered the feasibility of a Federal program to promote early replacement of appliances and equipment under EPACT 1992. DOE identified Federal policy options for early replacement that include a direct national program, replacement of Federally owned equipment, promotion through equipment manufacturers, customer incentives, incentives to utilities, market behavior research, and building regulations.

While cost-effective opportunities to install more-efficient units exist, DOE determined that a Federal early replacement program is not economically justified because the market for commercial water heaters is relatively small, especially for Federally owned equipment, and distributed across a broad set of customers; thus, the savings would not be likely to be significant. Additionally, early retirement means that a unit may be replaced by an appliance less efficient than the eventual replacement would have been. Therefore, energy savings would be less than anticipated. Early replacement programs also could increase long-term sales volatility by encouraging a temporary increase in production, followed by a lull in demand. However, DOE recognizes that early replacement could be economical in localities subject to high energy costs or environmental constraints; when replacement appliances are much more efficient than existing stock; or when a major technology breakthrough has occurred, creating the need for a ready market.

For the reasons listed, DOE determined that for this analysis, early replacement would not be a significant alternative to regulatory action.

17.4 SUMMARY OF RESULTS FOR NON-REGULATORY ALTERNATIVES

Table 17.4.1 and Table 17.4.2 show the NES and NPV for the non-regulatory alternatives analyzed. The case in which no regulatory action is taken constitutes the no-new-standards case scenario. Because this is the no-new-standards case scenario, NES and NPV are zero by definition. For comparison, the tables include the results of the NES and NPV at TSL 3 associated with the proposed energy conservation standard.

As shown in Table 17.4.1 and Table 17.4.2, none of the policy alternatives DOE examined would achieve the amount of energy or monetary savings that could be realized under the proposed rule. In addition, implementing either tax credits or customer rebates would incur initial and/or administrative costs not considered in this analysis.

Table 17.4.1 Cumulative NES of Non-Regulatory Alternatives Compared to the Proposed Standard

Policy Alternative	Cumulative Primary Energy Savings* *quads*
No New Regulatory Action	0
Customer Rebates	0.187
Consumer Tax Credits	0.103
Voluntary Energy Efficiency Targets	0
Early Replacement	0
Today's Standards at TSL 3	1.604

* Energy savings are in primary energy quads.

Table 17.4.2 Cumulative NPV of Non-Regulatory Alternatives Compared to the Proposed Standard

Policy Alternative	Net Present Value* *billion 2014$*	
	7% Discount Rate	3% Discount Rate
No New Regulatory Action	0	0
Customer Rebates	0.302	0.797
Consumer Tax Credits	0.166	0.438
Voluntary Energy Efficiency Targets	0	0
Early Replacement	0	0
Today's Standards at TSL 3	2.263	6.750

* Net present value is the value in the present of a time series of costs and savings.

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