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

COMMERCIAL PACKAGED BOILERS

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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 notice of proposed rulemaking (NOPR) technical support document (TSD) is a stand-alone report that provides the technical analyses and results supporting the information presented in the NOPR for commercial packaged boilers (CPBs). This NOPR TSD reports on the NOPR activities and analyses conducted in the period preceding the final rule stage of this rulemaking.

1.2 SUMMARY OF THE BENEFITS

The U.S. Department of Energy's (DOE's) analyses indicate that the proposed standards would save a significant amount of energy. The lifetime energy savings amount to 0.39 quadrillion Btu (quads)[a] for commercial packaged boilers purchased in the 30-year period that begins in the anticipated first full year of compliance with amended standards (2019–2048), relative to the case without amended standards (referred to as the "no-new-standards case"). This represents a savings of 0.8 percent relative to the energy use of this equipment in the no-new-standards-case.[b]

The cumulative net present value (NPV) of total consumer costs and savings of the proposed standards for commercial packaged boilers ranges from \$0.414 billion (at a 7-percent discount rate) to \$1.687 billion (at a 3-percent discount rate). This NPV expresses the estimated total value of future operating-cost savings minus the estimated increased equipment and installation costs for commercial packaged boilers purchased in 2019–2048.

In addition, the proposed CPB standards would have significant environmental benefits. The energy savings described in this section are estimated to result in cumulative emission reductions (over the same period as for energy savings) of 22 million metric tons (Mt)[c] of carbon dioxide (CO_2), 233 thousand tons of methane (CH_4), 2.1 thousand tons of sulfur dioxide (SO_2), 162 thousand tons of nitrogen oxides (NO_X), 0.1 thousand tons of nitrous oxide (N_2O), and 0.0003 tons of mercury (Hg).[d] The cumulative reduction in CO_2 emissions through 2030 amounts to 2.86 Mt, which is equivalent to the emissions resulting from the annual electricity use of 0.393 million homes.

The value of the CO_2 reductions is calculated using a range of values per metric ton of CO_2 (otherwise known as the Social Cost of Carbon, or SCC) developed by a Federal

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[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 no-new-standards case assumptions are described in chapter 8 of this TSD.

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

[d] DOE calculated emissions reductions relative to the no-new-standards case, which reflects key assumptions in 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.

interagency process.[e] The derivation of the SCC values is discussed in chapter 14. Using discount rates appropriate for each set of SCC values, DOE estimates the present monetary value of the CO_2 emissions reduction is between \$0.14 billion and \$2.0 billion, with a value of \$0.66 billion using the central SCC case represented by \$40.0 per metric ton in 2015.[f] DOE also estimates the present monetary value of the NO_X emissions reduction is \$0.16 billion at a 7-percent discount rate and \$0.45 billion at a 3-percent discount rate.[g]

Table 1.2.1 summarizes the economic benefits and costs expected to result from the proposed standards for commercial packaged boilers.

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[e] *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).

[f] The values only include CO_2 emissions; CO_2 equivalent emissions from other greenhouse gases are not included.

[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.

Table 1.2.1 Summary of Economic Benefits and Costs of Proposed Energy Conservation Standards for Commercial Packaged Boilers (TSL 2[*])

Category	Present Value *million 2014$*	Discount Rate
Benefits		
Operating Cost Savings	925	7%
	2,550	3%
CO_2 Reduction (using mean SCC at 5% discount rate)[**]	136	5%
CO_2 Reduction (using mean SCC at 3% discount rate)[**]	655	3%
CO_2 Reduction (using mean SCC at 2.5% discount rate)[**]	1,054	2.5%
CO_2 Reduction (using 95th percentile SCC at 3% discount rate)[**]	1,998	3%
NO_X Reduction[†]	158	7%
	447	3%
Total Benefits[††]	1,738	7%
	3,653	3%
Costs		
Incremental Installed Costs	512	7%
	863	3%
Total Net Benefits		
Including CO_2 and NO_X Reduction Monetized Value[††]	1,227	7%
	2,789	3%

[*] This table presents the costs and benefits associated with commercial packaged boilers shipped in 2019−2048. These results include benefits to consumers that accrue after 2048 from the equipment purchased in 2019−2048. 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 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 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 section chapter 14 for more details.

[†] The $/ton values used for NO_X are described in chapter 14. 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 3-percent discount rate.

The benefits and costs of this NOPR's proposed energy conservation standards, for covered commercial packaged boilers sold in 2019−2048, 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 commercial packaged boilers shipped in 2019–2048.

The CO_2 reduction is a benefit that 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.

Estimates of annualized benefits and costs of the proposed standards are shown in Table 1.2.2. The results under the primary estimate are as follows. Using a 7-percent discount rate for benefits and costs other than CO_2 reduction, for which DOE used a 3-percent discount rate along with the average SCC series that has a value of $40.0 per metric ton in 2015, the cost of the standards proposed in this rule is $51 million per year in increased equipment costs, while the benefits are $91 million per year in reduced equipment operating costs, $37 million in CO_2 reductions, and $16 million in reduced NO_X emissions. In this case, the net benefit amounts to $93 million per year. Using a 3-percent discount rate for all benefits and costs and the average SCC series that has a value of $40.0 per metric ton in 2015, the estimated cost of the CPB standards proposed in this rule is $48 million per year in increased equipment costs, while the benefits are $142 million per year in reduced operating costs, $37 million in CO_2 reductions, and $25 million in reduced NO_X emissions. In this case, the net benefit amounts to $156 million per year.

Table 1.2.2 Annualized Benefits and Costs of Proposed Energy Conservation Standards for Commercial Packaged Boilers

	Discount Rate	**Primary Estimate***	**Low Net Benefits Estimate***	**High Net Benefits Estimate***
		million 2014$/year		
Benefits				
Consumer Operating Cost Savings*	7%	91	84	101
	3%	142	129	160
CO_2 Reduction Monetized Value (using mean SCC at 5% discount)*,**	5%	10	10	11

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[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 1.2.2. Using the present value, DOE then calculated the fixed annual payment over a 30-year period starting in the compliance year that yields the same present value.

[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,'" J. Geophys. Res. 110. pp. D14105 (2005).

	Discount Rate	**Primary Estimate***	**Low Net Benefits Estimate***	**High Net Benefits Estimate***
		million 2014$/year		
CO2 Reduction Monetized Value (using mean SCC at 3% discount rate)*,**	3%	37	34	39
CO_2 Reduction Monetized Value (using mean SCC at 2.5% discount rate)*,**	2.5%	54	51	58
CO_2 Reduction Monetized Value (using 95th percentile SCC at 3% discount rate)*,**	3%	111	104	119
NO_X Reduction †	7%	16	15	37
	3%	25	23	59
Total Benefits††	7% plus CO_2 range	117 to 218	108 to 203	149 to 258
	7%	143	133	177
	3% plus CO_2 range	177 to 278	162 to 256	230 to 338
	3%	204	186	258
Costs				
Consumer Incremental Equipment Costs	7%	51	54	47
	3%	48	52	45
Net Benefits				
Total††	7% plus CO_2 range	67 to 168	54 to 149	102 to 210
	7%	93	79	130
	3% plus CO_2 range	129 to 230	110 to 205	185 to 293
	3%	156	135	213

	Discount Rate	Primary Estimate*	Low Net Benefits Estimate*	High Net Benefits Estimate*
		million 2014$/year		

* This table presents the annualized costs and benefits associated with commercial packaged boilers shipped in 2019−2048. These results include benefits to consumers that accrue after 2048 from the equipment purchased in 2019−2048. 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 building stock and energy prices from the *AEO2015* Reference case, Low Economic Growth case, and High Economic Growth case, 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.

** 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

† The $/ton values used for NO_X are described in chapter 14. 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.

DOE has tentatively concluded that the proposed standards represent the maximum improvement in energy efficiency that is technologically feasible and economically justified, and would result in the significant conservation of energy. DOE further notes that equipment achieving these standard levels is already commercially available for at least some, if not most, equipment classes covered by this proposal. Based on the analyses described above, DOE has tentatively concluded that the benefits of the proposed standards to the Nation (energy savings, positive NPV of consumer benefits, consumer life-cycle cost (LCC) savings, and emission reductions) would outweigh the burdens (loss of industry net present value (INPV) for manufacturers and LCC increases for some consumers).

DOE also considered more stringent energy efficiency levels as potential standards, and is considering them in this rulemaking. However, DOE has tentatively concluded that the potential burdens of the more stringent energy efficiency levels would outweigh the projected benefits. Based on consideration of the public comments that DOE receives in response to this document and related information collected and analyzed during the course of this rulemaking effort, DOE may adopt energy efficiency levels presented in this document that are either higher or lower than the proposed standards, or some combination of level(s) that incorporate the proposed standards in part.

1.3 OVERVIEW OF STANDARDS FOR COMMERCIAL PACKAGED BOILERS

DOE is initiating this rulemaking to consider amending the energy conservation standards for commercial packaged boilers, as required under the Energy Policy and Conservation Act (EPCA), as amended. EPCA defines the term "packaged boiler" to mean "a boiler that is shipped complete with heating equipment, mechanical draft equipment, and automatic controls; usually shipped in one or more sections." (42 U.S.C. 6311(11)(B)) EPCA prescribed the initial minimum efficiency levels (in terms of combustion efficiency) both for gas-fired packaged boilers and oil-fired packaged boilers with rated maximum fuel input rate[j] of 300,000 Btu or more. (42 U.S.C. 6313(a)(4)(C) and (D)) The minimum efficiency levels generally correspond to the levels set in the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE)/Illuminating Engineering Society (IES) Standard 90.1.[k] Further, EPCA provides that if ASHRAE/IES Standard 90.1 is amended with respect to packaged boilers, then DOE shall consider amending the prescribed minimum efficiency levels. (42 U.S.C. 6313((a)(6)) In other words, when ASHRAE amends the efficiency levels for packaged boilers in Standard 90.1, DOE must adopt the new ASHRAE requirements unless clear and convincing evidence supports a determination that adoption of a more stringent level would produce significant additional energy savings and would be technologically feasible and economically justified. (42 U.S.C. 6313(a)(6))

In 2009, DOE acted in response to an ASHRAE trigger and published a final rule amending the energy conservation standards for commercial packaged boilers to correspond to the efficiency levels in the most recent ASHRAE Standard 90.1, which amended CPB efficiency levels (*i.e.*, ASHRAE Standard 90.1-2007). 74 FR 36312 (July 22, 2009).

In the event that ASHRAE does not act to amend Standard 90.1 (thereby triggering DOE to conduct an amended standards rulemaking), EPCA provides an alternative statutory mechanism for initiating such review. More specifically, EPCA requires that every 6 years, the Secretary of Energy (Secretary) shall consider amending the energy conservation standards for covered commercial equipment and shall publish either a notice of determination that those standards do not need to be amended, or a NOPR for amended energy efficiency standards. (42 U.S.C. 6313(a)(6)(C)) Pursuant to (42 U.S.C. 6313(a)(6)(C)) DOE initiated this rulemaking to evaluate CPB energy conservation standards and to determine whether new or amended standards are warranted.

In addition, EPCA prescribes test procedures for commercial packaged boilers that are generally accepted industry testing procedures or rating procedures developed or recognized by

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[j] In this TSD, DOE uses "fuel input rate" to refer to the maximum rate at which a commercial packaged boiler uses energy, in order to be consistent with the definition and language in the test procedure NOPR for commercial packaged boilers issued on February 22, 2016. The industry also uses terms such as input capacity, input ratings, capacity, and rating, and any such instances should be considered synonymous with fuel input rate. A link to the issued February 2016 test procedure NOPR can be found at http://energy.gov/eere/buildings/downloads/issuance-2016-02-22-energy-conservation-program-certain-commercial-and.

[k] For more information, see www.ashrae.org.

the Air-Conditioning, Heating and Refrigeration Institute[l] (AHRI) or by ASHRAE, as referenced in ASHRAE/IES Standard 90.1. (42 U.S.C. 6314(a)(4)(A)) Furthermore, EPCA directs that if an industry test procedure or rating procedure for commercial packaged boilers is amended, then DOE shall amend the test procedure as necessary for the equipment to be consistent with the amended industry procedure. (42 U.S.C. 6314(a)(4)(B)) In addition to requiring DOE to update its test method each time the relevant industry test procedure is modified, EPCA requires that DOE conduct an evaluation of its test procedure for each covered class of equipment at least once every 7 years. (42 U.S.C. 6314(a)(1)(A)) DOE last reviewed its test procedures for commercial packaged boilers in a final rule published in the *Federal Register* on July 22, 2009 (77 FR 36312), so DOE must evaluate the test procedures for this equipment not later than July 22, 2016. DOE is considering updating the test procedures for commercial packaged boilers in a separate rulemaking that would occur in parallel with the energy conservation standards rulemaking outlined in this TSD.

On February 22, 2016, DOE issued a NOPR which proposed to update the test procedure for determining the efficiency of commercial packaged boilers (February 2016 test procedure NOPR).[m] In this energy conservation standards rulemaking, DOE considered whether the amendments proposed in the test procedure would affect efficiency ratings of commercial packaged boilers. To assess the impact on ratings, DOE tested several commercial packaged boilers in order to observe the variation in efficiency ratings as a result of the proposed amendments to the test procedure. As explained in the February 2016 test procedure NOPR, based on the results of this testing, DOE has tentatively concluded that the proposed changes in the test procedure will have a de minimis impact on the efficiency ratings.

Specifically, the current test procedure allows for a wide range of temperature rises across the commercial packaged boiler due to the allowance of recirculating loops and a measurement location upstream of the recirculation loop, which obscures the actual temperature rise across the commercial packaged boiler, DOE's proposed test procedure amendments would remove ambiguity by standardizing this temperature rise across all commercial packaged boilers where possible. DOE notes that the effect on any individual commercial packaged boiler could be to slightly increase or slightly decrease measured efficiency, depending on how the test was previously performed. Further, based on discussions with manufacturers, DOE believes that testing is already performed using optional testing method (recirculation loop) in order to prevent damaging the equipment and provide the boiler with inlet water temperatures more representative of typical field conditions. Therefore, in combination with the other proposed amendments to the test procedure, DOE has tentatively determined that the proposed amendments, in aggregate, would not result in an overall measurable impact on ratings.

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[l] EPCA refers to the Air-Conditioning, and Refrigeration Institute (ARI), which was renamed the Air-Conditioning, Heating, and Refrigeration Institute (AHRI) after ARI merged with the Gas Appliance Manufacturer's Association (GAMA).

[m] A link to the February 2016 test procedure NOPR issued by DOE can be found at: http://energy.gov/eere/buildings/downloads/issuance-2016-02-22-energy-conservation-program-certain-commercial-and

1.4 PROCESS FOR SETTING ENERGY CONSERVATION STANDARDS

Under EPCA, when DOE is studying new or amended standards, it must consider, to the greatest extent practicable, the following seven factors:

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;
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)(I)-(VII))

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

Before DOE determines whether or not to adopt a proposed energy conservation standard, it must first solicit comments on the proposed standard. (42 U.S.C. 6313(a)(6)(B)(ii)) 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)) 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))

After the publication of the Framework document and the preliminary technical support document, the energy conservation standards rulemaking process typically involves two additional, formal public notices, which DOE publishes in the *Federal Register*. The first notice is the NOPR, which presents a discussion of comments received in response to the preliminary analysis and analytical tools; analyses of the impacts of potential amended energy conservation standards on consumers, manufacturers, and the Nation; DOE's weighting of these impacts of amended energy conservation standards; and the proposed energy conservation standards for each product. The second notice is the final rule, which presents a discussion of the comments received in response to the NOPR; the revised analyses; DOE's weighting of these impacts; the amended energy conservation standards DOE is adopting for each product; and the effective dates of the amended energy conservation standards.

In September 2013, DOE published a notice of public meeting and availability of the Framework document. 78 FR 54197 (September 3, 2013). The Framework document, *Rulemaking Framework Document for Commercial Packaged Boilers*, describes the procedural and analytical approaches DOE anticipated using to evaluate the amendment of existing energy conservation standards for this equipment. This document is available at: http://www.regulations.gov/#!documentDetail;D=EERE-2013-BT-STD-0030-0002.

Subsequently, DOE held a public meeting on October 1, 2013 ("October 2013 public meeting") to discuss procedural and analytical approaches to the rulemaking. In addition, DOE used the public meeting to inform and facilitate involvement of interested parties in the rulemaking process. The analytical framework presented at the public meeting described the different analyses, such as the engineering analysis and the consumer economic analyses (*i.e.*, the LCC and payback period (PBP) analyses), the methods proposed for conducting them, and the relationships among the various analyses. Table 1.4.1 provides an overview of the rulemaking analysis stages.

Table 1.4.1 Rulemaking Analysis Stages

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

During the October 2013 public meeting, interested parties commented about numerous issues relating to each one of the analyses listed in Table 1.4.1. Comments from interested parties submitted during the Framework document comment period elaborated on the issues raised during the public meeting. DOE attempted to address these issues during its preliminary analyses and summarized the comments and DOE's responses in chapter 2 of the preliminary TSD.

As part of the information gathering and sharing process, DOE organized and held interviews with manufacturers of the commercial packaged boilers considered in this rulemaking as part of the engineering analysis. DOE selected companies that represented production of all types of equipment, ranging from small to large manufacturers. DOE had four objectives for these interviews: (1) solicit manufacturer feedback on the draft inputs to the engineering analysis; (2) solicit feedback on topics related to the preliminary manufacturer impact analysis

(MIA); (3) provide an opportunity, early in the rulemaking process, to express manufacturers' concerns to DOE; and (4) foster cooperation between manufacturers and DOE.

DOE incorporated the information gathered during the engineering interviews with manufacturers into its engineering analysis (chapter 5) and the preliminary MIA (chapter 12). Following the publication of the preliminary analyses and the public meeting, DOE held additional meetings with manufacturers as part of the consultative process for the MIA conducted during the NOPR phase of the rulemaking.

DOE developed an LCC spreadsheet that calculates the LCC and PBP at various energy efficiency levels. DOE also developed a national impact analysis (NIA) spreadsheet that calculates the national energy savings (NES) and national NPVs at various energy efficiency levels.[n] All of these spreadsheets are available on the DOE website for commercial packaged boilers: www1.eere.energy.gov/buildings/appliance_standards/rulemaking.aspx/ruleid/79.

In November 2014, DOE published a notice of public meeting and availability of the preliminary TSD. 79 FR 69066 (November 20, 2014). The preliminary TSD, *Preliminary Technical Support Document – Commercial Packaged Boilers*, describes the analytical approaches DOE developed during the preliminary analysis stage to evaluate the amendment of existing energy conservation standards for this equipment. These documents are available at www.regulations.gov/#!documentDetail;D=EERE-2013-BT-STD-0030-0027.

Subsequently, DOE held a public meeting on December 9, 2014 ("December 2014 public meeting") to inform and facilitate involvement of interested parties in the rulemaking process and to solicit feedback on the analytical approaches developed during the preliminary analysis stage. During the public meeting, DOE presented on four major topics: the analytical framework, models (including the updated LCC and NIA models) and tools that DOE is using to evaluate the potential standards for this equipment; the results of preliminary analyses performed by DOE for this equipment; potential energy conservation standard levels derived from these analyses that DOE could consider for this equipment; and other issues relevant to the development of amended energy conservation standards for commercial packaged boilers.

During the December 2014 public meeting, interested parties commented about numerous issues relating to the analyses conducted during the preliminary analysis stage. Comments from interested parties submitted during the preliminary analysis comment period, which was open until January 20, 2015, elaborated on the issues raised during the public meeting. DOE attempted to address these issues during its NOPR analyses and summarized the comments and DOE's responses in its NOPR.

1.5 STRUCTURE OF THE DOCUMENT

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

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[n] The "shipment forecast" and "historical shipments" worksheets of the NIA model present the scope of the shipment analysis and the total shipments in units for the commercial packaged boilers in scope.

Chapter 1	Introduction: Provides an overview of standards for commercial packaged boilers and describes DOE's process for setting energy conservation standards.
Chapter 2	Analytical Framework: Provides an overview of the rulemaking process, methodology, analytical tools, and relationships among the various analyses.
Chapter 3	Market and Technology Assessment (MTA): Characterizes the relevant equipment markets and technology options, including prototype designs.
Chapter 4	Screening Analysis: Reviews each technology option uncovered in the MTA to determine whether it is technologically feasible, practicable to manufacture, install, or service; would adversely affect equipment utility or equipment availability; or would have adverse impacts on health and safety.
Chapter 5	Engineering Analysis: Develops price-efficiency relationships that show the increase in manufacturer selling price for achieving efficiency levels above the current minimum efficiency standards.
Chapter 6	Markups Analysis: Estimates commercial consumer equipment prices based on market structures and the manufacturing costs developed in the engineering analysis.
Chapter 7	Energy Use Analysis: Determines the annual energy consumption of the equipment under consideration.
Chapter 8	Life-Cycle Cost (LCC) and Payback Period (PBP) Analysis: Discusses the effects of standards on individual commercial consumers and users of the equipment and compares the LCC and PBP of equipment with and without higher efficiency standards.
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[o] Regulatory Information Service Center (RISC) & Office of Information and Regulatory Affairs (OIRA)

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CHAPTER 2. ANALYTICAL FRAMEWORK

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2.1 INTRODUCTION

The Energy Policy and Conservation Act (EPCA) requires the U.S. Department of Energy (DOE) to set forth energy conservation standards for commercial packaged boilers (CPB) that are technologically feasible and economically justified and would result in significant additional energy conservation. (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. 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.

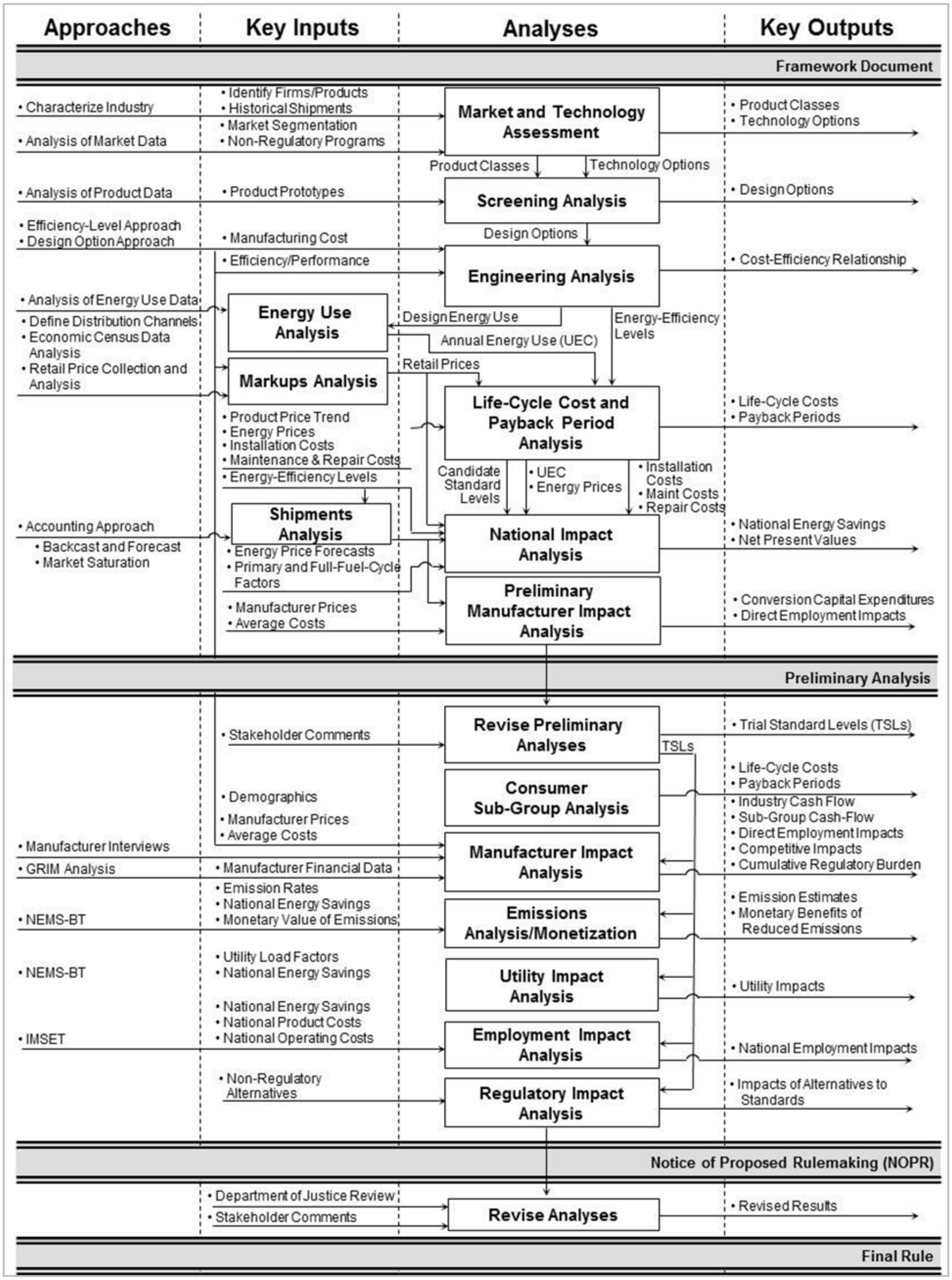

Figure 2.1.1 Flow Diagram of Analyses for the Rulemaking Process

This chapter provides a description of the analytical framework that DOE is using to evaluate potential amended energy conservation standards for CPB equipment 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 December 2014 public meeting. The analyses that were performed as part of the NOPR stage and reported in the technical support document (TSD) are listed below.

- 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 price of achieving increased efficiency.
- A markups analysis to develop distribution channel markups that relate the manufacturer sale price (MSP) to the cost to the commercial consumer.
- An energy use analysis to determine the annual energy use of the considered equipment in a representative set of users.
- A life-cycle cost (LCC) and payback period (PBP) analysis to calculate savings in operating costs at the consumer level throughout the life of covered equipment compared with any increase in installed cost for the equipment likely to result directly from adoption of a standard.
- A shipments analysis to forecast 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 might 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 assess the potential impacts of energy conservation standards on manufacturers' capital conversion expenditures, marketing costs, shipments, research and development costs, 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.

- 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 equipment do not need to be amended or a NOPR including new proposed energy conservation standards.

For initiating this rulemaking, DOE developed a Framework document, *Energy Conservation Standards Rulemaking Framework Document for Commercial Packaged Boilers*, which describes the procedural and analytical approaches DOE anticipated using to evaluate energy conservation standards for commercial packaged boilers. On September 3, 2013, DOE published a notice in the *Federal Register* that announced both the availability of the Framework document and a public meeting. 78 FR 54197. Subsequently, DOE presented the analytical approach to interested parties during a public meeting held on October 1, 2013. The Framework document is available at www1.eere.energy.gov/buildings/appliance_standards/rulemaking.aspx/ruleid/79.

On November 20, 2014, DOE published a second notice, "Energy Conservation Standards for Commercial Packaged Boilers: Public Meeting and Availability for the Preliminary Technical Support Document" in the *Federal Register* to announce the availability of the preliminary analysis TSD. 79 FR 69066. In chapter 2 of the preliminary TSD, DOE addressed all the comments received in response to the September 2013 Framework document. In the preliminary TSD, DOE also provided preliminary results for the different analyses that DOE conducted as part of this rulemaking such as the engineering analysis, the LCC and PBP analyses, and the NIA. Moreover, DOE invited parties to comment on the preliminary analysis, and requested public comments on specific issues related to the TSD. DOE listed these issues in the executive summary of the preliminary TSD. On December 9, 2014, DOE held a public meeting where it presented the results of the analyses and sought comments and feedback from the participants. The preliminary TSD is available at www1.eere.energy.gov/buildings/appliance_standards/rulemaking.aspx/ruleid/79.

In preparing the NOPR, DOE considered the comments and new information received in response to the preliminary TSD. The following sections provide a general description of the different analytical components of the rulemaking analytical framework for the NOPR. 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

When DOE commences an energy conservation standards rulemaking, it develops information that provides an overall snapshot of the market for the equipment considered, including the nature of the equipment, market characteristics, and industry structure. This activity consists of both quantitative and qualitative efforts based primarily on publicly available information. The market assessment examined manufacturers, trade associations, and the quantities and types of equipment offered for sale. The technology assessment evaluated different technology options that are available on the market and that have the potential to raise thermal or combustion efficiency of commercial packaged boilers. Chapter 3 of this NOPR TSD discusses the characterization of the CPB market and provides a list of different technology options.

For chapter 3 of this TSD, DOE reviewed relevant literature and interviewed manufacturers to develop an overall snapshot of the CPB industry in the United States. Industry publications and trade journals, government agencies, and trade associations provided the bulk of the information for the market and technology assessment. DOE also created a database of CPB models that is available on the market. This equipment database consists of CPB models that are manufactured by members of Air-Conditioning Heating and Refrigeration Institute (AHRI) and American Boiler Manufacturers Association (ABMA). For the commercial packaged boilers manufactured by AHRI members DOE used AHRI's Directory of Certified Product Performance.[a] For getting information on CPB models manufactured by ABMA members, DOE accessed the publicly available equipment literature and brochures available on the websites of different member manufacturers.[b]

2.3.1 Scope of Coverage

EPCA authorizes DOE to regulate certain commercial and industrial equipment including packaged boilers. EPCA defines the term "packaged boiler" as "a boiler that is shipped complete with heating equipment, mechanical draft equipment, and automatic controls; usually shipped in one or more sections." (42 U.S.C. 6311(11)(B)) DOE's regulations provide further clarification of this term, as well as others addressing different subsets of boilers. To understand the types of boilers which DOE is authorized to regulate under EPCA and the scope of coverage for the present rulemaking, terms related to commercial packaged boilers are defined below.

In its regulations, DOE clarifies the term "packaged boiler" to exclude a boiler that is "custom designed and field constructed," and it further provides that if the boiler is shipped in more than one section, the sections may be produced by more than one manufacturer, and may be originated or shipped at different times and from more than one location. 10 CFR 431.82

DOE's regulations define the term "commercial packaged boiler" as "a type of packaged low pressure boiler that is industrial equipment with a capacity, (rated maximum input) of

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[a] The AHRI Directory of Certified Product Performance can be accessed at www.ahridirectory.org/ahridirectory/pages/cblr/defaultSearch.aspx. Last accessed in March 2015.
[b] ABMA member manufacturers are listed at www.abma.com/member-listing. Last accessed June 2015.

300,000 Btu per hour (Btu/h) or more which, to any significant extent, is distributed in commerce: (1) For heating or space conditioning applications in buildings; or (2) For service water heating in buildings but does not meet the definition of 'hot water supply boiler' in [10 CFR part 431]." 10 CFR 431.82

In addition, DOE's regulations define the term "packaged low pressure boiler" as "a packaged boiler that is: (1) A steam boiler designed to operate at or below a steam pressure of 15 psig [pounds per square inch gauge]; or (2) A hot water boiler designed to operate at or below a water pressure of 160 psig and a temperature of 250 °F; or (3) A boiler that is designed to be capable of supplying either steam or hot water, and designed to operate under the conditions in paragraphs (1) and (2) of this definition." 10 CFR 431.82

For this rulemaking, DOE has analyzed all commercial packaged boilers that fit the above definitions including all mechanical and natural draft commercial packaged boilers with the exception of electric commercial packaged boilers.[c] Moreover, DOE has tentatively decided not to regulate standby loss and off mode energy consumption of commercial packaged boilers. For more discussion on the scope of the current rulemaking, see chapter 3 of this TSD, Market and Technology Assessment.

2.3.2 Market Assessment

As part of the market and technology assessment, DOE gathered information for an overall picture of the market for CPB 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 commercial boiler 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. As part of this assessment, DOE created an equipment database consisting of 2,625 CPB models manufactured by AHRI and ABMA member manufacturers. 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.

2.3.3 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-

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[c] DOE notes that, because commercial packaged boilers are currently defined as a subset of packaged low pressure boilers, all commercial packaged boilers have to meet the pressure and temperature criteria established in the definition of a "packaged low pressure boiler." Consequently, in the commercial packaged boiler test procedure NOPR, DOE is proposing to modify DOE's definition of "commercial packaged boiler" to explicitly include the pressure and temperature criteria established by the "packaged low pressure boiler" definition.

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.

The current regulations in 10 CFR 431.87 categorize commercial packaged boilers into 10 equipment classes. These classes are based on three performance parameters: (1) Input capacity (small (300 kBtu/h to 2,500 kBtu/h) and large (>2,500 kBtu/h)); (2) fuel used (gas or oil); and (3) heating medium (hot water or steam). The small and large gas-fired steam equipment classes are further divided based on draft type thereby, leading to 10 equipment classes.

In the NOPR, DOE proposes to discontinue the separation of CPB equipment classes based on draft type (natural or mechanical), as draft type is not a performance-related feature that provides unique utility to the consumer. DOE is also proposing to divide the large CPB equipment classes (>2,500 kBtu/h) into separate classes based on fuel input rate (>2,500 kBtu/h and ≤10,000 kBtu/h; >10,000 kBtu/h). Therefore, DOE has proposed to modify and expand its existing 10 CPB equipment classes to 12 equipment classes.

In the NOPR, DOE did not find sufficient information to provide by clear and convincing evidence that more stringent standards would be economically justified for very large CPB equipment with a maximum fuel input rate greater than 10,000 kBtu/h. As a result, DOE proposes to maintain the existing standard levels for very large CPB equipment classes at the current levels.

The Table 2.3.1 shows the equipment classes that DOE has proposed and analyzed in this NOPR TSD.

Table 2.3.1 Proposed Equipment Classes for Commercial Packaged Boilers

Equipment Class	Size	Fuel	Heating Medium	Acronym	Propose Amended Standards
Small Gas-fired Hot Water	≥300kBtu/h to ≤2,500kBtu/h	Gas	Hot Water	SGHW	Yes
Small Gas-fired Steam	≥300kBtu/h to ≤2,500kBtu/h	Gas	Steam	SGST	Yes
Small Oil-fired Hot Water	≥300kBtu/h to ≤2,500kBtu/h	Oil	Hot Water	SOHW	Yes
Small Oil-fired Steam	≥300kBtu/h to ≤2,500kBtu/h	Oil	Steam	SOST	Yes
Large Gas-fired Hot Water	>2,500kBtu/h to ≤10,000kBtu/h	Gas	Hot Water	LGHW	Yes
Large Gas-fired Steam	>2,500kBtu/h to ≤10,000kBtu/h	Gas	Steam	LGST	Yes
Large Oil-fired Hot Water	>2,500kBtu/h to ≤10,000kBtu/h	Oil	Hot Water	LOHW	Yes
Large Oil-fired Steam	>2,500kBtu/h to ≤10,000kBtu/h	Oil	Steam	LOST	Yes
Very Large Gas-fired Hot Water	>10,000kBtu/h	Gas	Hot Water	VLGHW	No
Very Large Gas-fired Steam	>10,000kBtu/h	Gas	Steam	VLGST	No

Equipment Class	Size	Fuel	Heating Medium	Acronym	Propose Amended Standards
Very Large Oil-fired Hot Water	>10,000kBtu/h	Oil	Hot Water	VLOHW	No
Very Large Oil-fired Steam	>10,000kBtu/h	Oil	Steam	VLOST	No

2.3.4 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 believes are technologically feasible.

Based on the information obtained through market analysis, DOE conducted a review of existing boiler technologies and upcoming technologies that can potentially improve boiler 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. An initial list of technologies was presented in the Framework document, upon which DOE sought comment. These technology options broadly include

1) Technology options to improve combustion and/or thermal efficiency
   a) Jacket insulation
   b) Heat exchanger improvements (including condensing heat exchanger, pulse combustion, and external and internal tube surface enhancement)
   c) Burner derating
   d) Improved burner technology
   e) Combustion air preheaters
   f) Economizers
   g) Blowdown waste heat recovery
   h) Oxygen trim systems
   i) Integrated, high-efficiency steam boilers

2) Technology options to reduce seasonal boiler energy consumption
   a) Modulating burners
   b) Electronic ignition
   c) Dampers
   d) Temperature reset controls
   e) Thermal post-purge controls
   f) Delayed-action oil pump solenoid valve
   g) Upgraded fan controls

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. DOE consulted with industry and other interested parties in developing a list of feasible technologies for the technology assessment. DOE then applied screening criteria to determine which technologies are not suitable for further consideration in this rulemaking. Chapter 4 of this NOPR TSD, Screening Analysis, contains details about DOE's screening criteria.

As detailed below, the screening analysis examines whether various technologies (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. DOE notes that the four screening criteria do not directly address the proprietary status of design options. DOE only considers efficiency levels achieved through the use of proprietary designs in the engineering analysis if they are not part of a unique pathway to achieve that efficiency level (*i.e.*, if there are other non-proprietary technologies capable of achieving the same efficiency). DOE reviewed the list of CPB technologies according to these criteria. In the engineering analysis, DOE further considers the efficiency-enhancement technologies that it did not eliminate in the screening analysis.

1) *Technological feasibility.* DOE screens out technologies that are not incorporated in commercially available equipment or working prototypes.

2) *Practicability to manufacture, install, and service.* If DOE determines that mass production of a technology in commercial equipment and reliable installation and servicing of the technology could not be achieved on the scale necessary to serve the relevant market by the time of the compliance date of the standard, it will not further consider that technology.

3) *Adverse impacts on equipment utility or availability.* If DOE determines a technology has a significant adverse impact on the utility of the equipment for significant consumer subgroups or results in the unavailability of any covered equipment type with performance characteristics (including reliability), features, size, capacities, and volumes that are substantially the same as equipment generally available in the United States at the time, it will not further consider that technology.

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 further consider that technology.

Based on these criteria, the technology options that passed the screening analysis are (1) heat exchanger improvements (including condensing heat exchanger), (2) improvement in burner technology, and (3) oxygen trim systems.

2.5 ENGINEERING ANALYSIS

The engineering analysis (chapter 5 of the NOPR TSD) establishes the relationship between MSP and increased efficiency for each CPB 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 commercial packaged boilers at higher efficiency levels, DOE estimated MSPs at various efficiency levels. Contractors and manufacturers provided price lists for different CPB models, which were used along with the distribution of models available on the market to get a weighted average MSP at each efficiency level analyzed. The prices at each efficiency level were then normalized to a representative fuel input rate for each equipment class. The engineering analysis results are used further in the downstream analysis to determine the cost to the consumer.

2.6 MARKUPS ANALYSIS

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

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

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

2.7 ENERGY USE ANALYSIS

The purpose of the energy use analysis is to determine the annual energy consumption of commercial packaged boilers in representative U.S. buildings and to assess the energy savings potential of increased boiler efficiency. DOE estimated the annual energy consumption of commercial packaged boilers at specified energy efficiency levels across a range of climate zones. The annual energy consumption includes the fuel use (oil or natural gas) by the boiler for space heating and water heating (if applicable), as well as the electricity use of auxiliary components, including blower fan, igniter, and pumps. The annual energy consumption of commercial packaged boilers is used in subsequent analyses, including the LCC and PBP analysis and the NIA.

DOE primarily used Commercial Buildings Energy Consumption Survey (CBECS) 2003 energy data and weather data from the National Oceanic and Atmospheric Administration

(NOAA) to estimate weather-normalized energy use of commercial packaged boilers.[d] CBECS is a national sample survey of commercial building units that collects statistical information on the consumption of and expenditures for energy in commercial building units along with data on energy-related characteristics of the commercial building units and occupants (*e.g.*, vintage of the building, square footage, fuels used, heating energy use). For commercial packaged boilers used in residential applications, DOE used the Residential Energy Consumption Survey (RECS) 2009 building sample, which provides similar information as CBECS.

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

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 consumers. The effect of new or amended standards on individual consumers usually includes a reduction in operating cost and an increase in purchase cost. DOE uses the following two metrics to measure consumer impacts:

- LCC 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 MSP, 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 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.

DOE analyzed the net effect of potential amended CPB standards on commercial consumers by calculating the LCC and PBP using the engineering cost and performance data, the energy-use data, and the 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 or other defined period of analysis, and a discount rate. Inputs to the PBP 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 single-point values. Therefore, the Monte Carlo analysis produces a range of LCC and PBP results that allows DOE to identify the fraction of customers achieving LCC savings or incurring net cost at the considered efficiency levels.

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[d] National Oceanic and Atmospheric Administration, NNDC Climate Data Online. Available at: www7.ncdc.noaa.gov/CDO/CDODivisionalSelect.jsp. Last accessed March 15, 2013.

DOE performed a separate 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).

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

2.9 SHIPMENTS ANALYSIS

DOE uses projections 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 CPB shipments by projecting boiler shipments in two market segments: (1) replacements and (2) new construction. For this analysis, the replacement market segment includes building owners switching between different boiler equipment classes, and building owners substituting existing non-boiler heating equipment with boilers.

To project CPB replacement shipments, DOE used building stock forecasts from the U.S. Energy Information Administration (EIA) *Annual Energy Outlook 2015* (*AEO2015*), shipment trends derived from CBECS data, and data found in a U.S. Environmental Protection Agency (EPA) database.

To project shipments to the new construction market, DOE used *AEO2015* for forecasts of new buildings. Boiler saturation rates in new buildings are derived from recently constructed buildings in CBECS 2012, CBECS 2003, and RECS 2009.

Chapter 9 of the TSD presents the mathematical formulation of the shipment analysis model and the methodology used to estimate historical and future shipments of CPB 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 CPB 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.

2.10.1 National Energy Savings Analysis

The inputs for determining the NES for each equipment type 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 a 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).[e] 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 10B 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 forecast

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

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").

2.11 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 higher energy conservation standards on manufacturers of commercial packaged boilers. In conducting this analysis for the NOPR, DOE sought input from manufacturers and other interested parties and considered 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 commercial packaged boilers. DOE sought to identify and discuss these potential impacts in interviews with manufacturers and other interested parties during the NOPR stage of the 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 chapter 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.[f] 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 CPB 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.[g]

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 the NOPR 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

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[f] Available at www.epa.gov/sites/production/files/2015-07/documents/emission-factors_2014.pdf.

[g] 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).

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 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.[h] 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 the NOPR 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

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

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.

Further detail is provided in chapter 15 and appendix 15A of the NOPR 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 the indirect employment impacts in the employment impact analysis using the Pacific Northwest National Laboratory's "Impact of Sector Energy Technologies" (ImSET) model.[i] 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 the NOPR TSD.

2.17 REGULATORY IMPACT ANALYSIS

In the NOPR stage, DOE prepared the RIA pursuant to Executive Order 12866, regulatory Planning and Review, 58 FR 51735, October 4, 1993, which is subject to review by

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[i] 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: Richland, WA. Report No. PNNL-18412.

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 the TSD.

REFERENCES

1. Interagency Working Group on Social Cost of Carbon, United States Government, *Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866*. May 2013; revised July 2015. 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 preliminary analysis for the energy conservation standards rulemaking for commercial packaged boilers.

The goal of the market assessment is to develop a qualitative and quantitative characterization of the commercial packaged boiler (CPB) industry and market structure, based on information that is publicly available and on data submitted by manufacturers and other interested parties. Issues addressed include commercial packaged boiler characteristics, market share and equipment classes; existing regulatory and non-regulatory efficiency improvement initiatives; overview of historical equipment shipments and lifetimes and trends in the equipment markets. The technology assessment is an investigation into technologies that will improve the energy efficiency of commercial packaged boilers, and results in a preliminary list of technologies that can improve the thermal and/or combustion efficiency of commercial packaged boilers. In addition, technology options which can improve seasonal efficiency are also discussed as part of this assessment.

A commercial packaged boiler, which is defined later in this chapter (see section 3.1.1), is a boiler designed to provide space heating or hot water to commercial institutions. These boilers are differentiated from residential boilers by their fuel input rate[a]. Residential boilers have a fuel input rate up to (but not equal to) 300,000 British thermal units per hour (kBtu/h), whereas commercial packaged boilers have capacities of 300 kBtu/h or more. This chapter further describes the scope of the assessment and divides commercial packaged boilers into various equipment classes. These equipment classes are directly analyzed by DOE to understand various aspects of the CPB market such as number of models under each equipment class, types of boilers (*e.g.*, modulating or condensing), heat exchanger materials, and potential technology options for enhancing efficiency, *etc.* The equipment classes created by DOE to analyze boilers are based on general characteristics of boilers and are discussed in detail in later sections.

3.1.1 Equipment Definitions, Scope of Coverage and Background

The Energy Policy and Conservation Act, as amended, (EPCA) defines a "packaged boiler" as "a boiler that is shipped complete with heating equipment, mechanical draft equipment, and automatic controls; usually shipped in one or more sections." (42 U.S.C. 6311(11)(B)) In its regulations as set forth in subpart E of title 10 of the Code of Federal Regulations (CFR) part 431 (10 CFR 431.82), DOE further refined the "packaged boiler"

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[a] In this NOPR TSD, DOE uses "fuel input rate," to refer to the maximum rate at which a commercial packaged boiler uses energy, in order to be consistent with Test Procedure definition and language. The industry also uses terms such as input capacity, input ratings, capacity, and rating, and any such instances should be considered synonymous with fuel input rate.

definition to exclude a boiler that is custom designed and field constructed. Additionally, 10 CFR 431.82 provides that if the boiler is shipped in more than one section, the sections may be produced by more than one manufacturer, and may be originated or shipped at different times and from more than one location.

In its regulations as set forth in 10 CFR 431.82, DOE defines a "commercial packaged boiler" as "a type of packaged low pressure boiler that is industrial equipment with a capacity, (rated maximum input) of 300,000 Btu/h or more, which to any significant extent, is distributed in commerce: (1) For heating or space conditioning applications in buildings; or (2) For service water heating in buildings but does not meet the definition of a 'hot water supply boiler' in this part" [Part 431].

A "packaged low pressure boiler" is defined as "a packaged boiler that is (1) A steam boiler designed to operate at or below a steam pressure of 15 psig [pounds per square inch gauge]; or (2) A hot water boiler designed to operate at or below a water pressure of 160 psig and a temperature of 250 °F; or (3) A boiler that is designed to be capable of supplying either steam or hot water, and designed to operate under the conditions in paragraphs (1) and (2) of this definition." 10 CFR 431.82

In initiating this rulemaking, DOE released the Rulemaking Framework Document for Commercial Packaged Boilers (Framework document) on August 28, 2013. On that same day DOE also issued the Notice of Public Meeting and Availability of the Framework Document for commercial packaged boilers, which was published in the *Federal Register* on September 3, 2013. 78 FR 54197.

On November 20, 2014, DOE published a notice of public meeting in the *Federal Register* to announce the availability of the preliminary analysis technical support document (TSD). 79 FR 69066. In the preliminary TSD, DOE provided preliminary results of the various analyses that were conducted for this rulemaking, such as engineering analysis, life-cycle cost analysis (LCC), payback period analyses (PBP), and the national impact analysis (NIA).

In the preliminary TSD, DOE defined the scope of the current rulemaking to cover all equipment that meets the definition of commercial packaged boilers (as defined at the start of this section) with the exception of electric commercial packaged boilers. In this rulemaking, DOE has tentatively decided not to propose energy conservation standards for electric commercial packaged boilers. Based on DOE's review of the market, electric commercial packaged boilers account for a relatively small number of annual shipments (approximately 1,500–2,100 units), and the thermal efficiency of such equipment already approaches 100 percent. Thus, DOE believes that there is little to no room for improvement in efficiency. DOE notes that although Federal energy conservation standards for electric commercial packaged boilers are not proposed to be established, the definitions set forth in this section do not preclude DOE from adopting standards for such equipment in the future, if justified.

In the notice of proposed rulemaking (NOPR), DOE has proposed separate equipment classes for commercial packaged boilers with fuel input rates greater than 10,000 kBtu/h. As explained in the NOPR, DOE does not propose to amend standards for this type of equipment in the current rulemaking. Additional discussion on the separate equipment classes for commercial packaged boilers with fuel input rates greater than 10,000 kBtu/h is provided in the section 3.1.2.1 of this chapter.

On August 13, 2013, DOE published in the *Federal Register* a notice of proposed determination (August 2013 NOPD) of coverage to explicitly clarify its statutory authority to regulate natural draft commercial packaged boilers, since the existing definition of "packaged boiler" leaves room for interpretation as to whether natural draft commercial packaged boilers are covered equipment. 78 FR 49202. As explained in the August 2013 NOPD, under DOE's interpretation of the relevant statutory provisions, natural draft commercial packaged boilers are covered equipment with standards set forth in 10 CFR part 431, subpart E. DOE undertook a coverage determination to explicitly clarify its statutory authority under EPCA to cover natural draft commercial packaged boilers.

After considering comments received on the August 2013 NOPD, DOE decided to withdraw the August 2013 NOPD, and published a notice in the *Federal Register* on August 25, 2015, withdrawing the proposed coverage determination of natural draft commercial packaged boilers. 80 FR 51487. In the August 2015 withdrawal notice, DOE determined that comments received support DOE's understanding as currently defined under EPCA that natural draft commercial packaged boilers are covered equipment under the definition for "packaged boiler." Therefore, DOE has included natural draft commercial packaged boilers in the scope of this rulemaking.

3.1.2 Equipment Classes

3.1.2.1 Existing Equipment Classes

EPCA, as amended, established mandatory Federal energy conservation standards for certain commercial equipment, including commercial packaged boilers, based on the American Society of Heating, Refrigerating and Air-Conditioning Engineers/ Illuminating Engineering Society (ASHRAE/IES) Standard 90.1, "Energy Standard for Buildings Except Low-Rise Residential Buildings." Section 42 U.S.C 6313(a)(6) of EPCA provides that, if ASHRAE/IES Standard 90.1 is amended with respect to packaged boilers, DOE shall publish in the *Federal Register* for public comment an analysis of the energy savings potential of amended energy efficiency standards. Further, EPCA requires DOE to establish an amended uniform national standard for commercial packaged boilers at the minimum level specified in the amended ASHRAE/IES Standard 90.1, unless DOE determines by rule and supported by clear and convincing evidence that adoption of a more stringent standard is technologically feasible and economically justified. In 2007, ASHRAE amended the efficiency levels of commercial packaged boilers. Subsequently, in July 2009, DOE published in the *Federal Register* a final rule (July 2009 final rule) amending the energy conservation standards for commercial packaged boilers to correspond to levels in ASHRAE 90.1-2007. 74 FR 36312.

ASHRAE/IES Standard 90.1-2007 divides commercial packaged boilers into 10 equipment classes on the basis of fuel type (oil or gas (natural or propane)), size (small (≥300 and ≤2,500 kBtu/h) or large (>2,500 kBtu/h)) and heating media (steam or hot water). The gas-fired steam commercial packaged boilers are further divided based on the draft type (natural draft or mechanical draft). In the July 2009 final rule, DOE followed the approach taken by ASHRAE

Standard 90.1-2007 and adopted efficiency levels and equipment classes that are specified for commercial packaged boilers with compliance required beginning March 2, 2012. Table 3.1.1 shows the division of equipment classes based on ASHRAE/IES Standard 90.1-2007.

Table 3.1.1 Existing Equipment Classes for Commercial Packaged Boilers

CPB Equipment Class	Description of Characteristics
Small Gas-Fired Hot Water	Fuel input of 300–2,500 kBtu/h; fueled by propane or natural gas; hot water output
Small Gas-Fired Steam All Except Natural Draft	Fuel input of 300–2,500 kBtu/h; fueled by propane or natural gas; steam output; draft mechanism other than natural draft (*e.g.*, forced or induced draft mechanism)
Small Gas-Fired Steam Natural Draft	Fuel input of 300–2,500 kBtu/h; fueled by propane or natural gas; steam output; natural draft mechanism
Small Oil-Fired Hot Water	Fuel input of 300–2,500 kBtu/h; fueled by oil; hot water output
Small Oil-Fired Steam	Fuel input of 300–2,500 kBtu/h; fueled by oil; steam output
Large Gas-Fired Hot Water	Fuel input of >2,500 kBtu/h; fueled by propane or natural gas; hot water output
Large Gas-Fired Steam All Except Natural Draft	Fuel input of >2,500 kBtu/h; fueled by propane or natural gas; steam output; draft mechanism other than natural draft (*e.g.*, forced or induced draft mechanism)
Large Gas-Fired Steam Natural Draft	Fuel input of >2,500 kBtu/h; fueled by propane or natural gas; steam output; natural draft mechanism
Large Oil-Fired Hot Water	Fuel input of >2,500 kBtu/h; fueled by oil; hot water output
Large Oil-Fired Steam	Fuel input of >2,500 kBtu/h; fueled by oil; steam output

3.1.2.2 Proposed Equipment Classes

In the preliminary TSD, DOE considered separate equipment classes for natural draft commercial packaged boilers presuming a positive outcome of the August 2013 NOPD, which would have established natural draft commercial package boilers as a separate type of covered equipment. As a result, in the preliminary analysis DOE separated commercial packaged boilers into 16 equipment classes based on fuel type (oil or gas (natural or propane)), size (small (≥300 and ≤2,500 kBtu/h) or large (>2,500 kBtu/h)), heating media (steam or hot water) and draft type (mechanical or natural draft).

In the NOPR stage of the rulemaking, DOE reviewed the current equipment classes in light of the August 2015 withdrawal notice. Based on this review, DOE has tentatively determined that natural draft commercial packaged boilers do not have any performance-related features or unique utility that is distinct from mechanical draft commercial packaged boilers. Further, both mechanical and natural draft commercial packaged boilers are often used for similar commercial space heating applications. Therefore, in the NOPR, DOE proposes to discontinue the use of draft type as a parameter for defining equipment classes.

In addition, as mentioned in section 3.1.1 of this chapter, DOE has proposed in the NOPR to create separate equipment classes for commercial packaged boilers with fuel input rates greater than 10,000 kBtu/h. In choosing the appropriate fuel input rate upper limit, DOE examined the prices that it received for the engineering analysis from manufacturers, distributors and contractors. The data included prices of commercial packaged boilers with fuel input rates ranging from 300 kBtu/h to 9,500 kBtu/h. Further, DOE also conducted an analysis for estimating the energy savings potential for several fuel input rate upper limits. Based on the range of trial standard levels that are considered in the NOPR TSD, DOE estimated the energy savings potential for commercial packaged boilers with fuel input rates greater than 10,000 kBtu/h to be between 0.014 and 0.025 quads. Considering that DOE did not have sufficient price data available to analyze commercial packaged boilers with fuel input rates greater than 10,000 kBtu/h, DOE has tentatively decided to create separate equipment classes for commercial packaged boilers with input capacities greater than 10,000 kBtu/h. In this NOPR TSD, DOE addresses commercial packaged boilers with fuel input rates greater than 10,000 kBtu/h as "very large" commercial packaged boilers.

In conclusion, DOE has proposed to (1) discontinue the use of draft as a parameter for defining equipment classes; and (2) establish new equipment classes for commercial packaged boilers with fuel input rates greater than 10,000 kBtu/h. The equipment classes proposed in the NOPR are shown in the Table 3.1.2.

Table 3.1.2 Proposed Commercial Packaged Boiler Equipment Classes

Equipment Class	**Fuel Input Rate**	**Equipment Class Acronym**
Small Gas Hot Water	≥ 300 kBtu/h and ≤ 2,500 kBtu/h	SGHW
Large Gas Hot Water	>2,500 kBtu/h and ≤ 10,000 kBtu/h	LGHW
Very Large Gas Hot Water	>10,000 kBtu/h	VLGHW
Small Oil Hot Water	≥ 300 kBtu/h and ≤ 2,500 kBtu/h	SOHW
Large Oil Hot Water	>2,500 kBtu/h and ≤ 10,000 kBtu/h	LOHW
Very Large Oil Hot Water	>10,000 kBtu/h	VLOHW
Small Gas Steam	≥ 300 kBtu/h and ≤ 2,500 kBtu/h	SGST
Large Gas Steam	>2,500 kBtu/h and ≤ 10,000 kBtu/h	LGST
Very Large Gas Steam	>10,000 kBtu/h	VLGST
Small Oil Steam	≥ 300 kBtu/h and ≤ 2,500 kBtu/h	SOST
Large Oil Steam	>2,500 kBtu/h and ≤ 10,000 kBtu/h	LOST
Very Large Oil Steam	>10,000 kBtu/h	VLOST

3.2 MARKET ASSESSMENT

The following market assessment identifies the manufacturer trade associations and domestic and international manufacturers of commercial packaged boilers. The market assessment also identifies existing regulatory and non-regulatory programs for commercial boilers, and summarizes relevant characteristics and market performance data for each equipment class.

3.2.1 Trade Association

To gain insight into the CPB industries, DOE researched various associations available to manufacturers, suppliers, and users of such equipment. DOE identified the Air-Conditioning, Heating, and Refrigeration Institute (AHRI) and the American Boiler Manufacturers Association (ABMA) as the only trade groups that support, or have an interest in, the CPB industry.

3.2.1.1 Air-Conditioning, Heating, and Refrigeration Institute

AHRI is a national trade association for manufacturers of heating, ventilation, air-conditioning, and refrigeration (HVACR) which includes CPB manufacturers. AHRI was established in January of 2008 when the Air-Conditioning and Refrigeration Institute (ARI) merged with the Gas Appliance Manufacturers Association (GAMA). 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 product performance. AHRI maintains the Directory of Certified Product Performance, which is a database of ratings for all manufacturers who elect to participate in the program. Table 3.2.1 shows the manufacturers of AHRI's Directory of Certified Product Performance as of March 2015. The directory consists of 2,254 boiler models.[1]

DOE used the data in this directory in its market assessment. DOE also examined other data sources such as manufacturer literature, technical reports, and any other relevant information to provide a broad insight into the commercial packaged boilers market.

Table 3.2.1 Commercial Packaged Boiler Manufacturers Represented in the Air-Conditioning, Heating, and Refrigeration Institute Ratings Directory1

Manufacturers Listed	
• A.O. Smith Water Products Co. • Advanced Thermal Hydronics • Aerco International, Inc. • Bosch Thermotechnology Corp • Bradford White Corp. • Burnham Commercial • Camus Hydronics Ltd. • Cleaver-Brooks • Crown Boiler Co. • DDR Americas, Inc. • ECR International	• National Combustion Co., Inc. • New Yorker Boiler Co., Subsidiary Of Burnham Holdings Inc. • Ny Thermal Inc. • Parker Boiler Company • PB Heat, LLC • Raypak, Inc. • RBI Water Heaters Division of Mestek, Inc. • Slant/Fin Corporation • Smith Cast Iron Boilers • Sterling HVAC Products

Manufacturers Listed	
• Fulton Heating Solutions • Hamilton Engineering, Inc. • Harsco Industrial, Patterson-Kelley • HTP, Inc. • Laars Heating Systems Company • Lochinvar, LLC	• Thermal Hydronic Supply Ltd. • Thermal Solutions Products LLC. • Triangle Tube Phase Iii Inc. • U.S. Boiler Company, Inc. • Viessmann Manufacturing Company, Inc. • Weil-Mclain

3.2.1.2 American Boiler Manufacturers Association

ABMA is a national, nonprofit trade association of commercial, institutional, industrial, and electricity-generating boiler system manufacturing companies (>400,000 Btu/h heat input), dedicated to the advancement and growth of the boiler and combustion equipment industry.[b]

DOE identified the several ABMA manufacturers that produce commercial boilers that meet EPCA's definition of packaged boilers. Some of the major manufacturers include: Aerco International, Aesys Technologies, LLC, Burnham Commercial; Clayton Industries, Cleaver-Brooks, Group Simoneau, Johnston Boiler Company, Sellers Manufacturing Company, Powermaster Boiler, Vapor Power International, LLC.[c] DOE also found several ABMA manufacturers that did not manufacture boilers that meet EPCA's definitions of packaged boilers such as high pressure boilers that are used in process and power generation industries. DOE did not consider such boilers while conducting the market assessment.

3.2.2 Manufacturers

As per the definition set forth in 10 CFR 431.82, a manufacturer of a commercial packaged boiler is any person who: (1) manufactures, produces, assembles or imports a commercial packaged boiler in its entirety; (2) manufactures, produces, assembles or imports a commercial packaged boiler in part, and specifies or approves the boiler's components, including burners or other components produced by others, as for example by specifying such components in a catalogue by make and model number or parts number; or (3) is any vendor or installer who sells a commercial packaged boiler that consists of a combination of components that is not specified or approved by a person described in the two previous definitions.

Based on this definition DOE identified 45 CPB manufacturers. Sections 3.2.7.1 through 3.2.7.12 provide additional details on the types of CPB models that are manufactured by these companies.

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[b] See www.abma.com/.

[c] For more information, visit www.abma.com/member-listing.

3.2.3 Regulatory Programs

The following section details current regulatory programs requiring energy conservation standards for commercial packaged boilers. Section 3.2.2.1 addresses Federal energy conservation standards, and section 3.2.2.2 provides an overview of existing state standards. Section 3.2.2.3 reviews Canadian standards programs that may affect the companies servicing the North American market.

3.2.3.1 Current Federal Energy Conservation Standards

The existing Federal energy conservation standards as set forth in 10 CFR 431.87 cover 10 equipment classes. Apart from gas-fired steam boilers, no other equipment class is currently divided based on draft type. As a result, both natural draft and mechanical draft boilers have the same energy conservation standard (except for gas steam boiler equipment classes). Further, the energy efficiency descriptor for large hot water CPB equipment classes is combustion efficiency, while for all other equipment classes the descriptor is thermal efficiency. Table 3.2.2 shows the current energy efficiency standards for commercial packaged boilers.

Table 3.2.2. Current Federal Energy Conservation Standards for Commercial Packaged Boilers

Equipment Type	Subcategory	Size Category (input)	Efficiency level—Effective date: March 2, 2012*
Hot Water Commercial Packaged Boilers	Gas-fired	≥300,000 Btu/h and ≤2,500,000 Btu/h	80% E_T
Hot Water Commercial Packaged Boilers	Gas-fired	>2,500,000 Btu/h	82% E_C
Hot Water Commercial Packaged Boilers	Oil-fired	≥300,000 Btu/h and ≤2,500,000 Btu/h	82% E_T
Hot Water Commercial Packaged Boilers	Oil-fired	>2,500,000 Btu/h	84% E_C
Steam Commercial Packaged Boilers	Gas-fired—all, except natural draft	≥300,000 Btu/h and ≤2,500,000 Btu/h	79% E_T
Steam Commercial Packaged Boilers	Gas-fired—all, except natural draft	>2,500,000 Btu/h	79% E_T
Steam Commercial Packaged Boilers	Gas-fired—natural draft	≥300,000 Btu/h and ≤2,500,000 Btu/h	77% E_T**
Steam Commercial Packaged Boilers	Gas-fired—natural draft	>2,500,000 Btu/h	77% E_T**
Steam Commercial Packaged Boilers	Oil-fired	≥300,000 Btu/h and ≤2,500,000 Btu/h	81% E_T
Steam Commercial Packaged Boilers	Oil-fired	>2,500,000 Btu/h	81% E_T

* E_T means "thermal efficiency." E_C means "combustion efficiency."10 CFR part 431.82.

**On March 2, 2022 the minimum efficiency standard for small and large gas-fired natural draft steam commercial packaged boilers will be 79% E_T.

3.2.3.2 State Energy Conservation Standards

Under EPCA, states may petition to have more-stringent energy conservation standards than those codified under subpart E of 10 CFR part 431. (42 U.S.C. 6316(b)(2); 6297(d)). At this time, no states have been granted a petition from DOE to establish more-stringent energy conservation standards than the levels EPCA established for commercial packaged boilers.

3.2.3.3 Canadian Energy Conservation Standards

In May 2010, the Natural Resources Canada (NRCan) Office of Energy Efficiency, proposed energy conservation standards for gas- and oil-fired commercial packaged boilers according to the standards set forth in ASHRAE 90.1–2007. After release of the proposed standards, additional updates were published in August 2010 and November 2011. As part of the August 2010 update, NRCan made three changes to its original proposal. NRCan changed its proposed near-condensing efficiency level for small gas-fired boilers from 85 percent to 84 percent (thermal efficiency) and for large gas-fired boilers from 87 percent to 86 percent (combustion efficiency). NRCan also decided to allow boilers with near-condensing efficiency levels only for replacement markets and to require boilers to achieve efficiencies requiring condensation only for new construction beginning in 2015.

In the November 2011 update, NRCan amended efficiency levels and changed effective dates for certain equipment classes of boilers. The latest version of the proposed energy conservation standards for Canada is shown in the Table 3.2.3.

Table 3.2.3 Canadian Energy Conservation Standards Proposed by NRCan – Updated on November 2011[2]

Boiler Type	Prescriptive Requirements	Minimum Efficiency*	Date of Manufacture
Small Gas Hot Water	No standing pilot	80% E_T	March 2, 2012
Small Gas Hot Water	No standing pilot	84% E_T	March 2, 2015
Small Gas Steam	No standing pilot	77% E_T	March 2, 2012
Small Gas Steam	No standing pilot	79% E_T	March 2, 2015
Small Oil Hot Water	Nil	82% E_T	March 2, 2012
Small Oil Steam	Nil	81% E_T	March 2, 2012
Large Gas Hot Water	No standing pilot	82% E_C	March 2, 2012
Large Gas Hot Water	No standing pilot	85% E_C	March 2, 2015
Large Oil Hot Water	Nil	84% E_C	March 2, 2012
Large Gas Steam	No standing pilot	77% E_T	March 2, 2012
Large Gas Steam	No standing pilot	79% E_T	March 2, 2015
Large Oil Steam	Nil	81% E_T	March 2, 2012

* E_T refers to Thermal Efficiency; E_C refers to Combustion Efficiency

3.2.4 Non-Regulatory Programs

3.2.4.1 ENERGY STAR Program

ENERGY STAR®, a voluntary labeling program backed by the U.S. Environmental Protection Agency (EPA) and DOE, identifies energy efficient products through a qualification process.[d] To qualify, a product must exceed Federal minimum standards by a specified amount, or if no Federal standard exists, then exhibit selected energy-saving features. The ENERGY STAR program works to recognize the top quartile of products on the market, meaning that approximately 25 percent of products on the market meet or exceed the ENERGY STAR levels. The ENERGY STAR Version 1.0 specification for commercial boilers is currently in development. On August 28, 2015, the EPA published the ENERGY STAR Program Requirements, Product Specification for Commercial Boilers Eligibility Criteria Version 1.0: Draft 1 for public review.

3.2.4.2 Federal Energy Management Program

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

FEMP designates standards for commercial packaged boilers purchased by the Federal government. FEMP specifies different efficiency levels for commercial packaged boilers based on fuel type, size, and output. FEMP levels are specified using the thermal efficiency metric. Table 3.2.4 presents the FEMP designated efficiency requirements for commercial packaged boilers ranging from 300,000 to 10,000,000 Btu/h rated capacity.

Table 3.2.4 FEMP Designated Thermal Efficiency Levels for Commercial Packaged Boilers[3]

Equipment Class	Recommended Thermal Efficiency [%]
Small Gas-Fired Hot Water	80
Large Gas-Fired Hot Water	80
Small Gas-Fired Steam	79
Large Gas-Fired Steam	80
Small Oil-Fired Hot Water	83
Large Oil-Fired Hot Water	83
Small Oil-Fired Steam	83
Large Oil-Fired Steam	83

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[d] For more information, visit www.energystar.gov.

[e] For more information, visit www.energy.gov/eere/femp.

3.2.4.3 Rebate Programs

DOE has identified and reviewed various local utility rebate programs. Some of the local utilities reviewed by DOE include Minnesota Energy Resources, Pacific Gas and Electric Company (PG&E), San Diego Gas and Electric (SDG&E), and the Southern California Gas Company (SoCalGas).

Minnesota Energy Resources

The Minnesota Energy Resources Commercial Custom Rebate program offers businesses cash rebates as an incentive to install energy efficient commercial equipment, including boilers and boiler retrofits. Minnesota Energy Resources does not have a standard rebate amount; rather it individually reviews each application it receives. Rebate amounts are awarded based on the type and efficiency of boiler. Rebate amounts for hot water boilers having efficiency greater than 90 percent are higher than those for efficiency greater than 85 percent and less than 90 percent. For steam boilers rebate is available for boilers having thermal efficiency greater than 83 percent.[4]

Pacific Gas and Electric Company

PG&E offers energy efficiency rebates to commercial customers who use energy efficient space heating boilers in their businesses or commercial facilities. PG&E offers different rebates amounts depending on the characteristics of the space heating boiler. Table 3.2.5 describes the rebates offered by PG&E for space heating boilers.[5]

Table 3.2.5 Rebate Offered by PG&E for Commercial Space Heating Boilers

Description of Boiler	Rebate Amount
Space heating atmospheric water boiler thermal efficiency of ≥ 85% and input rating 300 kBtu/h and ≤ 2500 kBtu/h	$1 per kBtu/h
Space heating forced draft water boiler thermal efficiency of ≥ 85% and input rating 300 kBtu/h and ≤ 2500 kBtu/h	$1 per kBtu/h
Space heating condensing water boiler thermal efficiency of ≥ 94% and input rating 300 kBtu/h and ≤ 2500 kBtu/h	$1 per kBtu/h
Space heating atmospheric water boiler combustion efficiency of ≥ 85% and input rating > 2500 kBtu/h	$1 per kBtu/h
Space heating forced draft water boiler combustion efficiency of ≥ 85% or thermal efficiency of ≥83% and input rating > 2500 kBtu/h	$1 per kBtu/h
Space heating condensing water boiler thermal efficiency of ≥ 94% and input rating > 2500 kBtu/h	$1 per kBtu/h
Space heating atmospheric steam boiler thermal efficiency of ≥ 85% and input rating 300 kBtu/h and ≤ 2500 kBtu/h	$1 per kBtu/h
Space heating forced draft steam boiler thermal efficiency of ≥ 85% and input rating 300 kBtu/h and ≤ 2500 kBtu/h	$1 per kBtu/h
Space heating atmospheric steam boiler combustion efficiency of ≥ 80% or 81% thermal efficiency and input rating > 2500 kBtu/h	$1 per kBtu/h
Space heating forced draft steam boiler combustion efficiency of ≥ 80% or 81% thermal efficiency and input rating > 2500 kBtu/h	$1 per kBtu/h

San Diego Gas and Electric Company

SDG&E offers rebates and incentives to commercial customers through two programs. The first program is its Energy Efficiency Business Incentive program. This program provides cash incentives to businesses that improve boiler performance through replacement of boiler parts resulting in natural gas savings. The incentive amounts to $1 per therm (~100 cu.ft of natural gas) of natural gas saved with the gas being supplied by SDG&E, PG&E or SoCalGas. This program is not offered to space heating commercial boilers with input ratings ≤ 5,000 kBtu/h and process (non-space-heating) boilers with fuel input rates < 10,000 kBtu/h for industrial end-use customers.[6]

The second program offered is the Energy Efficiency Business Rebates program. This is available for a wide range of products and equipment from the agricultural, commercial, and industrial sectors. For commercial boilers, SDG&E provides a rebate of $0.5 per kBtu/h for any commercial space heating boiler having a fuel input rate of 300 kBtu/h to 2,500 kBtu/h with a combustion efficiency greater than or equal 85 percent. For process boilers (non-space-heating) having a fuel input rate more than 75,000 Btu/h and a thermal efficiency greater than or equal to 84 percent, SDG&E offers a rebate of $0.5 per kBtu/h.[7]

Southern California Gas Company

SoCalGas offers Energy Efficiency Rebates for Business (EERB) for replacing inefficient gas-fired equipment with more-efficient models. Rebates are offered for commercial, industrial or agricultural customer with an active, valid, and non-delinquent account. Eligible customers can receive rebates for space heating hot water and process heating boilers. For a space heating boiler, which is installed by a licensed contractor and has a fuel input rate greater than or equal to 300 kBtu/h, SoCalGas offers the following rebates shown in Table 3.2.6.

Table 3.2.6 Rebates Offered by SoCalGas for Space Heating Boilers[8]

Type of Boiler	Required Efficiency	Rebate Amount
Medium/Large – steam	≥83% Combustion Efficiency	$0.50/(kBtu/h)
Medium/Large hot water (Tier I)	≥85% Combustion Efficiency	$0.50/(kBtu/h)
Medium/Large hot water (Tier II)	≥90% Combustion Efficiency	$4.00/(kBtu/h)

For process heating boilers having a capacity of less than or equal to 10,000 kBtu/h, SoCalGas offers the following rebates shown in Table 3.2.7.

Table 3.2.7 Rebates Offered by SoCalGas for Process Heating Boiler[8]

Type of Boiler	Required Efficiency	Rebate Amount
Steam	≥83% Combustion Efficiency	$0.75/(kBtu/h)
Hot water (Tier I)	≥85% Combustion Efficiency	$0.75/(kBtu/h)
Hot water (Tier II)	≥90% Combustion Efficiency	$1.50/(kBtu/h)

3.2.5 Shipments

Information about annual equipment shipment trends allows DOE to estimate the impacts of energy conservation standards on the CPB industry. For commercial packaged boilers, very little information about historical shipments is publicly available. DOE estimated historical shipments in its NOPR analysis using stock to shipment correlations from stock estimates based on the Commercial Buildings Energy Consumption Survey (CBECS) data series from 1979 to 2012. From 1960 to 1978, DOE estimated historical shipments of commercial package boilers that shadowed the trends in the historical shipments of residential boilers for the same period. Additional details about commercial boiler shipments are discussed in chapter 9 of this TSD (Shipments Analysis).

3.2.6 Equipment Lifetime

For its analysis of lifetime, DOE used national survey data, published studies, and projections based on manufacturer shipment data to calculate the distribution of CPB lifetimes. More information about CPB equipment lifetime can be found in the life-cycle cost and payback period analyses section in chapter 8 (Life-Cycle Cost and Payback Period Analysis) and appendix 8F of this TSD.

3.2.7 Market Performance Data

For gathering information on the types of commercial packaged boilers available on the market, DOE reviewed CPB equipment literature available from manufacturers, including those listed as ABMA and AHRI members. For the analysis, DOE used a combined database of CPB models produced by both AHRI and ABMA member manufacturers. For AHRI certified CPB models, DOE used AHRI's certified directory of product performance as the primary source of data. For models manufactured by ABMA members, DOE explored the websites of each member manufacturer and listed the models that meet EPCA's definition of packaged boilers. DOE was able to create a database of 2,625 boiler models which serves as the basis of its analysis of the CPB market. While listing the different boiler models, DOE also gathered critical information about the performance and specification of the models, such as fuel used, fuel input rate, draft type, and heating medium for each boiler model. After creating this database, DOE categorized the entire list into the 12 equipment classes proposed by the NOPR.

While conducting a review of the market, DOE noticed that many CPB models have the capability to deliver both hot water and steam and often have only one efficiency rating listed in the equipment database. In such instances, DOE classified these models under steam equipment classes because as per the current Federal test procedure, commercial packaged boilers capable of producing either hot water or steam need to be tested either only in steam mode or in both hot water and steam modes. (See 10 CFR 431.86.) Where the manufacturers provided separate performance ratings for both hot water and steam, DOE considered such models under both hot water and steam equipment classes with their respective efficiencies. In view of existing energy conservation standards, steam equipment classes have lower efficiency standards compared to corresponding hot water equipment classes and, thus, it is likely that the rating in steam mode is more conservative.

After sorting the CPB models, DOE verified listed efficiency levels of the models with equipment literature. During its review of the CPB performance data, DOE noticed that some boiler models did not have their efficiency listed in the database. These models were not included in the analysis of efficiency distributions. DOE also found several models with efficiency ratings less than the minimum efficiency standards, and did not include those units in its analysis. There were approximately 149 models that were missing the relevant efficiency information and 157 models that did not meet the efficiency standard. Table 3.2.8 shows the proposed 12 equipment classes along with their corresponding energy conservation standards and the models considered in the analysis.

In order to examine how the performance and characteristics of commercial packaged boilers vary with capacity, models within each equipment class were further categorized by fuel input rate. Small-size boiler models were divided into bins with fuel input rate categories of 100 kBtu/h step sizes (*e.g.*, 300 kBtu/h – 400 kBtu/h, 400 kBtu/h – 500 kBtu/h). The lower limit of each fuel input rate category was included within category range while the upper limit was excluded (*e.g.*, 300 kBtu/h – 400 kBtu/h has a range of ≥ 300 kBtu/h to 400 kBtu/h). For the last fuel input rate category for small boilers, however, DOE made an exception to include the upper limit within the range of the category (*i.e.*, 2,400 kBtu/h – 2,500 kBtu/h had a range of ≥ 2,400 kBtu/h to ≤ 2,500 kBtu/h). This exception allowed boilers having a 2,500 kBtu/h fuel input rate to be included as part of the last fuel input rate category for small boilers rather than having a separate fuel input rate category altogether.

Similarly, DOE classified large CPB equipment classes by fuel input rates. Fuel input rate categories for large boilers had a step size of 1,500 kBtu/h. Furthermore, unlike the fuel input rate categories of small boilers, these fuel input rate categories exclude the lower limit of the category and include the upper limit (*e.g.*, 2,500 kBtu/h – 4,000 kBtu/h has a range defined by >2,500 kBtu/h to ≤4,000 kBtu/h). As such, DOE created 22 fuel input rate categories for small CPB equipment classes and 6 fuel input rate categories for large CPB equipment classes.

DOE also grouped and examined commercial packaged boilers based on efficiency. The efficiency groupings were created by rounding off the relevant efficiency rating for every boiler of each equipment class to the nearest integer. For example, all efficiency values between 79.5 and 79.9 percent were rounded to 80 percent, while all efficiency values equal to or less than 79.4 percent were rounded to 79 percent. Examining models by efficiency levels helped DOE analyze the influence of boiler characteristics (condensing, modulating, material used, *etc.*) on efficiency.

Table 3.2.8 Number of Boiler Models in Each Equipment Class

Equipment Class Full Name	**Abbreviation**	**Number of Models**	**Models Used for Analysis**	**Current Efficiency[†] Standard**
Small (≥300,000 Btu/h and ≤2,500,000 Btu/h) Gas-fired Hot Water CPB	SGHW	1,150	1,103	80% E_T
Large (>2,500,000 Btu/h and ≤10,000 kBtu/h) Gas-fired Hot Water CPB	LGHW	373	224	82% E_C

Equipment Class Full Name	**Abbreviation**	**Number of Models**	**Models Used for Analysis**	**Current Efficiency† Standard**
Very Large (>10,000 kBtu/h) Gas-fired Hot Water CPB	VLGHW	45	31	82% E_C
Small (≥300,000 Btu/h and ≤2,500,000 Btu/h) Oil-fired Hot Water CPB	SOHW	124	122	82% E_T
Large (>2,500,000 Btu/h and ≤10,000 kBtu/h) Oil-fired Hot Water CPB	LOHW	83	74	84% E_C
Very Large (>10,000 kBtu/h) Oil-fired Hot Water CPB	VLOHW	35	2	8% E_C
Small (≥300,000 Btu/h and ≤2,500,000 Btu/h) Gas-fired Steam CPB	SGST	252	251	77% E_T^*
Large (>2,500,000 Btu/h and ≤10,000 kBtu/h) Gas-fired Steam CPB	LGST	186	178	77% E_T^*
Very Large (>10,000 kBtu/h) Gas-fired Steam CPB	VLGST	77	77	77% E_T^*
Small (≥300,000 Btu/h and ≤2,500,000 Btu/h) Oil-fired Steam CPB	SOST	127	125	81% E_T
Large (>2,500,000 Btu/h and ≤10,000 kBtu/h) Oil-fired Steam CPB	LOST	109	95	81% E_T
Very Large (>10,000 kBtu/h) Oil-fired Steam CPB	VLOST	64	42	81% E_T
Total		2,625	2324	

* For all CPB models other than natural draft, minimum efficiency standard is 79%.

† E_T refers to Thermal Efficiency and E_C refers to Combustion Efficiency.

Using the aforementioned equipment classes, baselines, fuel input rate categories, and efficiency groupings, DOE conducted its market analysis for each equipment class based on fuel input rate, distribution of boilers based on efficiency levels, equipment offering by each company, and variation of efficiency with respect to fuel input rate. DOE also gave due consideration to important characteristics of boilers, such as condensing, modulating and material type, and assessed how these factors influence fuel input rate and efficiency. The following sections describe equipment classes and the results of the market assessment for each class.

3.2.7.1 Small (≥300 kBtu/h and ≤2,500 kBtu/h) Gas-Fired Hot Water Commercial Packaged Boilers

The small gas-fired hot water equipment class includes both mechanical and natural draft commercial packaged boilers. There are 206 natural draft boilers in this equipment class. Small gas-fired hot water boilers constitute about 44 percent of the models in the equipment database. Compared to all other equipment classes, the small gas-fired hot water equipment class contains the highest number of models available on the market. All small gas-fired hot water commercial packaged boilers are required to have a minimum thermal efficiency of 80 percent. The heat exchangers of boilers in this equipment class are made from aluminum, cast iron, copper, stainless steel, or steel. Figure 3.2.1 shows a pie chart which depicts the constitution of boilers in this equipment class based on materials used to make the primary heat exchanger. Figure 3.2.2 depicts classification of condensing boilers based on the type of material used for making the primary heat exchanger.

In condensing boilers, the condensate that is removed from exhaust gases turns acidic in nature, due to the presence of carbon dioxide in flue gases. As a result, materials used to make the heat exchangers of condensing boilers have anti-corrosion properties that resist acidic corrosion. A condensing boiler, can have either one primary heat exchanger that is made from corrosion-resistant material or one primary and one secondary heat exchanger with the latter being made from corrosion-resistant material. The classification of materials used to make the heat exchangers shown in Figure 3.2.1 and Figure 3.2.2 is based on primary heat exchangers.

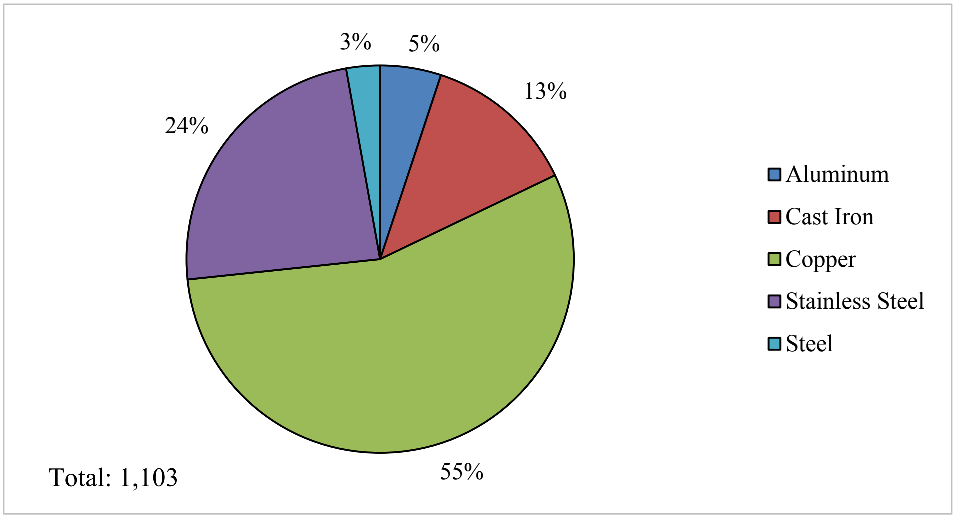

Figure 3.2.1 Distribution of Small Gas-Fired Hot Water Commercial Packaged Boilers Based on Material Used in the Primary Heat Exchanger

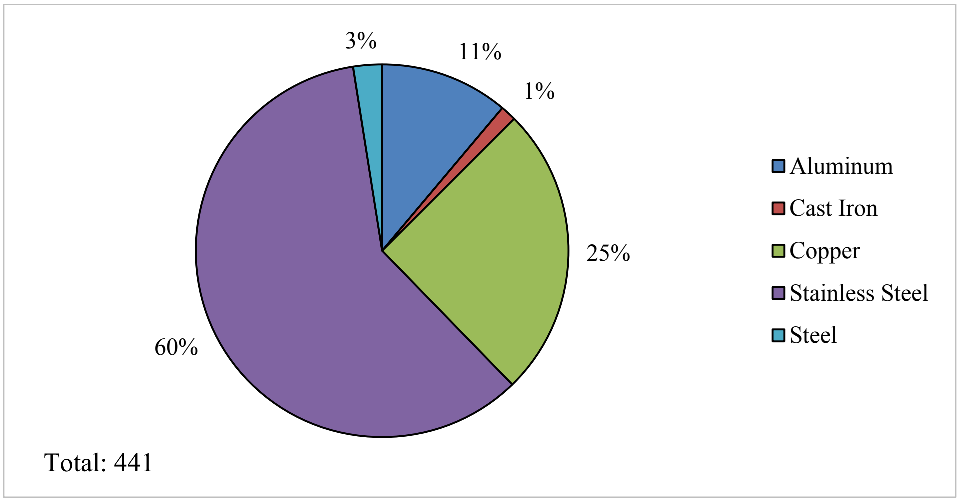

Figure 3.2.2 Distribution of Small Gas-Fired Hot Water Commercial Packaged Condensing Boilers Based on Material Used in the Primary Heat Exchanger

In this equipment class, out of 1,103 boiler models, 441 models are condensing boilers and 854 models are modulating. Figure 3.2.3 shows the distribution of models based on fuel input rate. The figure also shows the number of condensing and modulating boilers in each fuel input rate category.

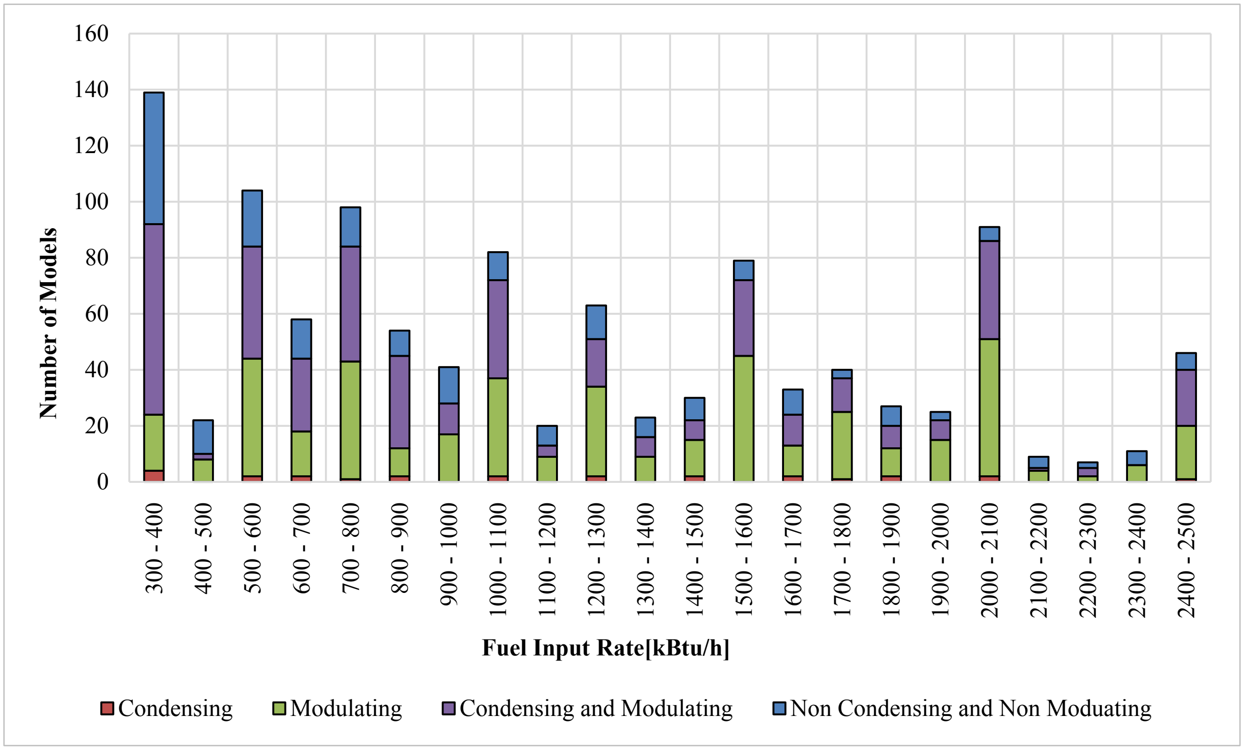

Figure 3.2.3 Distribution of Small Gas-Fired Hot Water Commercial Packaged Boilers Based on Fuel Input Rate

Manufacturers

Based on the equipment database, 31 manufacturers produce small gas-fired hot water commercial packaged boilers. Raypak, Lochinvar, Thermal Solutions and Camus Hydronics offer the highest number of models in this equipment class. Table 3.2.9 shows the list of manufacturers and the size of boiler which they produce.

Table 3.2.9 List of Companies that Manufacture Small Gas-Fired Hot Water Commercial Packaged Boilers

Name of Manufacturer	**Fuel Input Rate Category [kBtu/h]**										
	300 – 500	500 – 700	700 – 900	900–1100	1100 – 1300	1300–1500	1500 – 1700	1700 – 1900	1900 – 2100	2100 – 2300	2300 – 2500
A.O. Smith Water Products Co.	X	X		X		X		X	X		
Advanced Thermal Hydronics	X	X		X			X		X	X	X
Aerco International, Inc.	X	X	X	X	X		X	X	X	X	X
Bosch Thermotechnology Corp	X	X	X	X	X	X	X	X	X	X	X
Bradford White Corp	X	X	X	X	X		X	X	X		X
Burnham Commercial	X	X	X	X	X	X	X	X	X	X	X
Camus Hydronics Ltd.	X	X	X	X	X	X	X	X	X		X
Cleaver-Brooks		X	X	X			X	X			X
Crown Boiler Co, - Subsidiary Of Burnham Holdings Inc.	X	X	X	X	X						
DDR Americas, Inc.	X	X	X	X	X	X	X	X	X	X	
Fulton Heating Solutions	X	X	X	X			X		X		X
Hamilton Engineering Inc.	X	X	X	X	X	X	X	X	X	X	X
Heat Transfer Products Inc.	X	X	X	X				X			
Laars Heating Systems Company	X	X	X	X	X		X	X	X		X
Lochinvar Corporation	X	X	X	X	X	X	X	X	X		X
National Combustion Co., Inc.		X	X	X	X		X	X	X		
NY Thermal, Inc.	X	X	X								
P B Heat, LLC	X	X	X	X			X				X
Parker Boiler Company		X	X	X		X	X		X		
Raypak, Inc.	X	X	X	X	X	X	X	X	X	X	X
RBI Water Heaters Division of Mestek, Inc.	X	X	X	X	X	X	X	X	X	X	X
Slant/Fin Corporation	X	X	X	X	X	X	X	X	X	X	X
Sterling HVAC Products			X		X						
Thermal Hydronic Supply Limited	X										
Thermal Solutions Products LLC, Subsidiary Of Burnham Holdings Inc.	X	X	X	X	X		X		X		X
Triangle Tube	X	X	X								
U.S. Boiler Co., Subsidiary of	X	X	X	X							

Name of Manufacturer	Fuel Input Rate Category [kBtu/h]										
	300 – 500	500 – 700	700 – 900	900– 1100	1100 – 1300	1300–1500	1500 – 1700	1700 – 1900	1900 – 2100	2100 – 2300	2300 – 2500
Burnham Holdings Inc.											
Viessmann Manufacturing Company, Inc.	X	X	X	X	X	X	X	X	X	X	
Weil-McLain	X	X	X	X	X	X	X	X	X	X	
Miura							X				

Characterization of Boilers Based on Efficiency

Figure 3.2.4 shows the distribution of boiler in this equipment class by thermal efficiency. The distribution of these boilers is broadly divided based on condensing and non-condensing boilers and generally concentrated around two peaks: most of the non-condensing boilers have a thermal efficiency of 85 percent and most condensing boilers have a thermal efficiency of 94 to 95 percent.

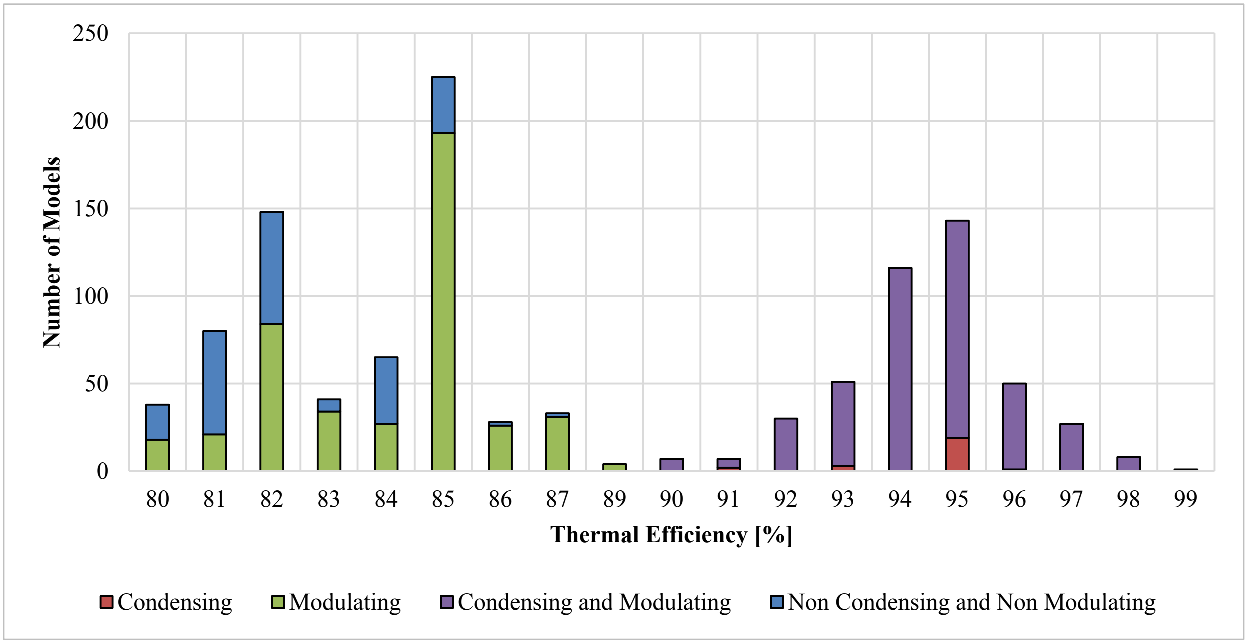

Figure 3.2.4 Distribution of Small Gas-Fired Hot Water Commercial Packaged Boilers Based On Thermal Efficiency

Variation of Average Efficiency with Fuel Input Rate

The presence of condensing boilers across the entire range of fuel input rates increases the average efficiency of boilers in this category substantially. Figure 3.2.5 shows the variation of average thermal efficiency with fuel input rate category.

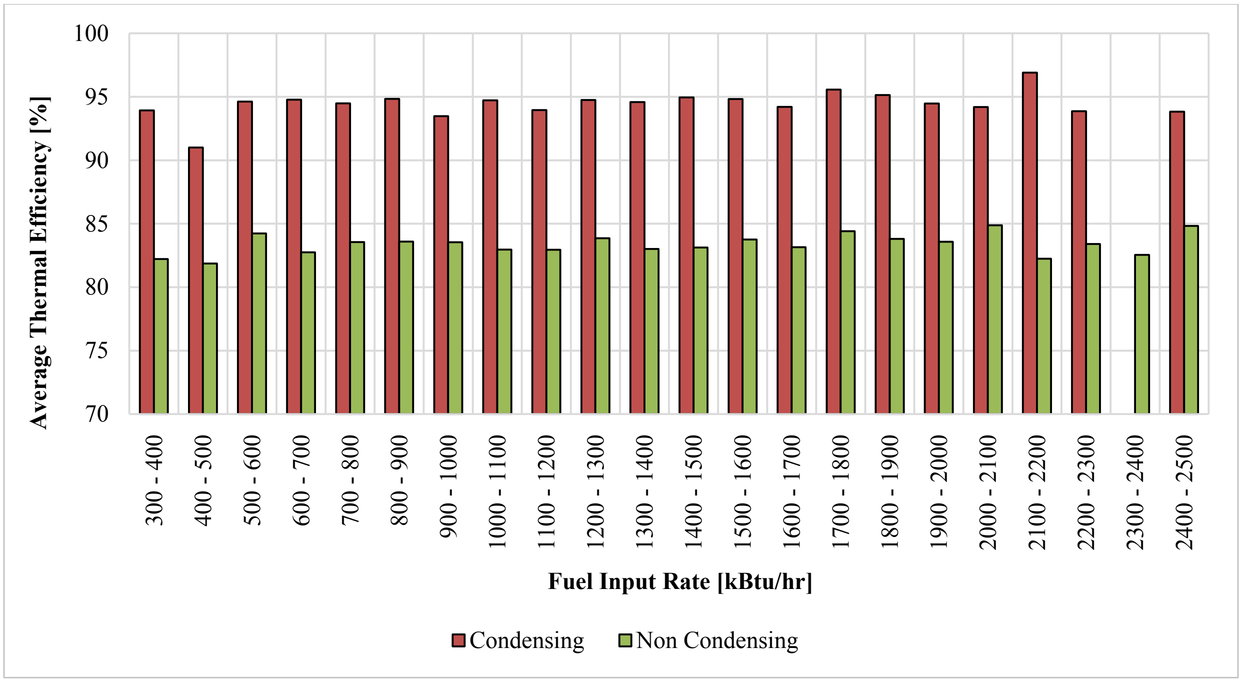

Figure 3.2.5 Comparison of Average Thermal Efficiency of Small Gas-Fired Hot Water Commercial Packaged Boilers Subcategory Based on Fuel Input Rate

3.2.7.2 Large (>2,500 kBtu/h and ≤10,000 kBtu/h) Gas-Fired Hot Water Commercial Packaged Boilers

Large gas-fired hot water commercial packaged boilers are required to have a minimum combustion efficiency of 82 percent. There are 46 natural draft boilers in this equipment class. Similar to the small gas-fired mechanical draft hot water equipment class, boiler models in this equipment class are made from cast iron, stainless steel, steel, aluminum and copper. DOE analyzed the number of boilers of each heat exchanger material type. Figure 3.2.6 is a pie chart that depicts the distribution of boiler models based on the material used in the primary heat exchanger. Figure 3.2.7 is a pie chart that shows classifications of condensing boilers based on material used to make the primary heat exchanger.

Similar to the observations in the small gas-fired mechanical draft hot water equipment class, DOE notes, that the classifications of boilers shown in Figure 3.2.6 and Figure 3.2.7 are based on primary heat exchangers that do not come in contact with the acidic condensate. The secondary or condensing heat exchanger that does come in contact with the acidic condensate is made from a different material that is typically corrosion resistant. This observation was subsequently validated by DOE through literature review of condensing boiler models.

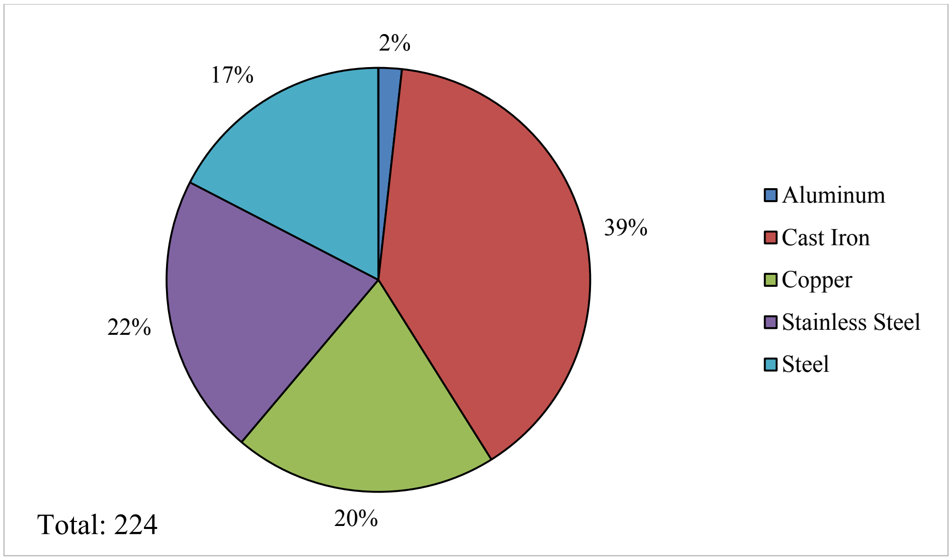

Figure 3.2.6 Classification of Large Gas-Fired Hot Water Commercial Packaged Boilers Based on Material Used in the Primary Heat Exchanger

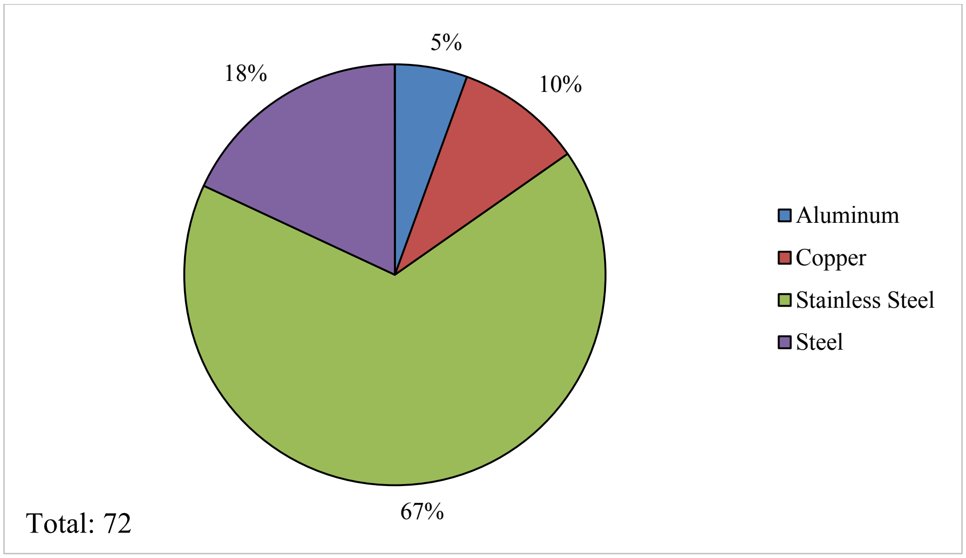

Figure 3.2.7 Classification of Large Gas-Fired Hot Water Commercial Packaged Condensing Boilers Based on Material Used in the Primary Heat Exchanger

DOE also analyzed the distribution of models with respect to fuel input rate. Figure 3.2.8 shows this analysis and highlights the type of boiler included in this equipment class (*e.g.*, condensing and/or modulating). All condensing boilers in this equipment class are modulating.

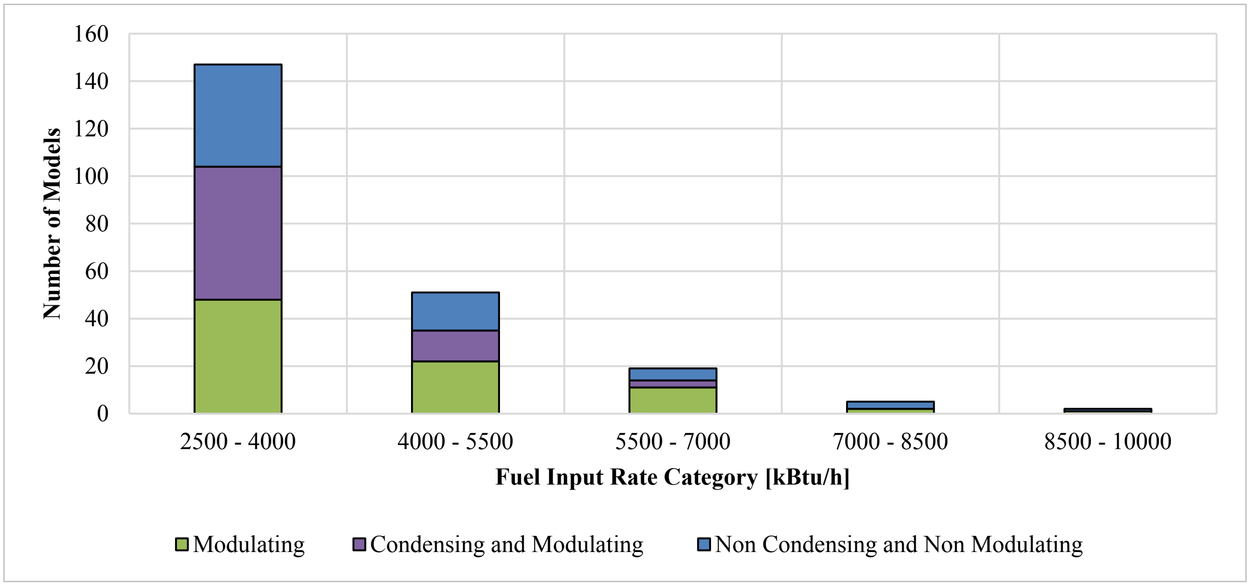

Figure 3.2.8 Distribution of Large Gas-Fired Hot Water Commercial Packaged Boilers Based on Fuel Input Rate

Manufacturers

A total of 22 manufacturers listed in the combined database produced boilers in this equipment class. Bosch Thermotechnology Corp., Cleaver-Brooks, and Weil-McLain produce the majority of the models. Table 3.2.10 shows the list of manufacturers and the size of equipment they produce.

Table 3.2.10 List of Companies that Manufacture Large Gas-Fired Hot Water Commercial Packaged Boilers

Name of Manufacturer	Fuel Input Rate Category [kBtu/h]				
	2500 – 4000	4000 – 5500	5500 – 7000	7000 – 8500	8500 –10000
A.O. Smith Water Products Co.	X				
Advanced Thermal Hydronics	X				
Aerco International, Inc.	X		X		
Bosch Thermotechnology Corp	X	X			
Burnham Commercial	X	X	X		
Camus Hydronics Ltd.	X	X			
Cleaver-Brooks	X	X	X	X	
DDR Americas, Inc.	X	X	X		
Fulton Heating Solutions	X	X	X		
Hamilton Engineering, Inc.	X				
Harsco Industrial, Patterson-Kelley	X				
Laars Heating Systems Company	X	X			
Lochinvar, LLC	X	X			
Parker Boiler Company	X	X			
Raypak, Inc.	X				
RBI Water Heaters Division Of Mestek, Inc.	X	X			
Slant/Fin Corporation	X				
Thermal Solutions Products LLC.	X				
Viessmann Manufacturing Company, Inc.	X	X			
Weil-Mclain	X	X	X	X	X
Miura	X	X	X		
Group Simoneau, Inc.	X	X	X		X

Characterization of Boilers Based on Efficiency

Similar to most equipment classes which have condensing boilers, the distribution of boiler combustion efficiency shows a concentration of equipment in two ranges—the non-condensing range (generally less than 86 percent) and the condensing range (generally over 90 percent). This is because condensing boilers typically achieve efficiencies that are substantially higher than non-condensing boilers. There are only eleven boilers in the range between condensing and non-condensing (roughly 87 percent). A large number of non-condensing boilers were found to have a combustion efficiency of 82 percent, while the condensing boilers typically have combustion efficiencies around 94 to 95 percent. Figure 3.2.9 shows the distribution of boilers over different combustion efficiency levels.

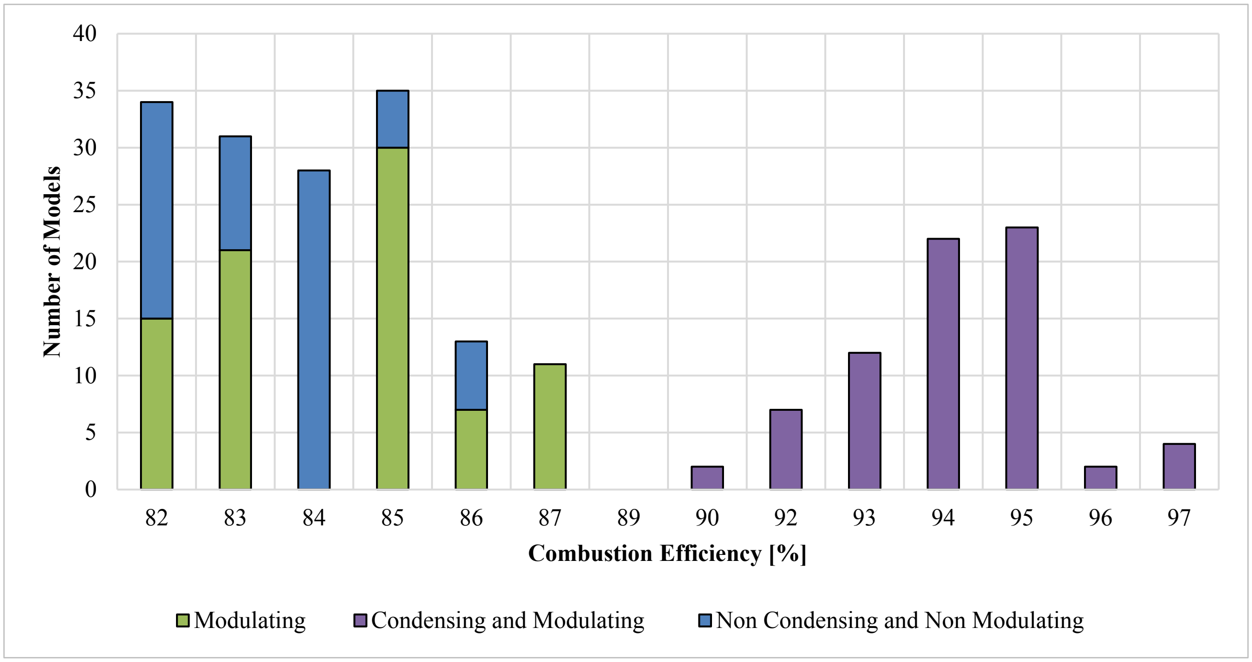

Figure 3.2.9 Distribution of Large Gas-Fired Hot Water Commercial Packaged Boilers Based On Combustion Efficiency

Variation of Average Efficiency with Fuel Input Rate

Average combustion efficiencies for this equipment class are between 89 and 90 percent. These efficiency levels in each input category are raised significantly due to presence of high-efficiency condensing boilers. Figure 3.2.10 shows average combustion efficiency levels of boilers in each fuel input rate category.

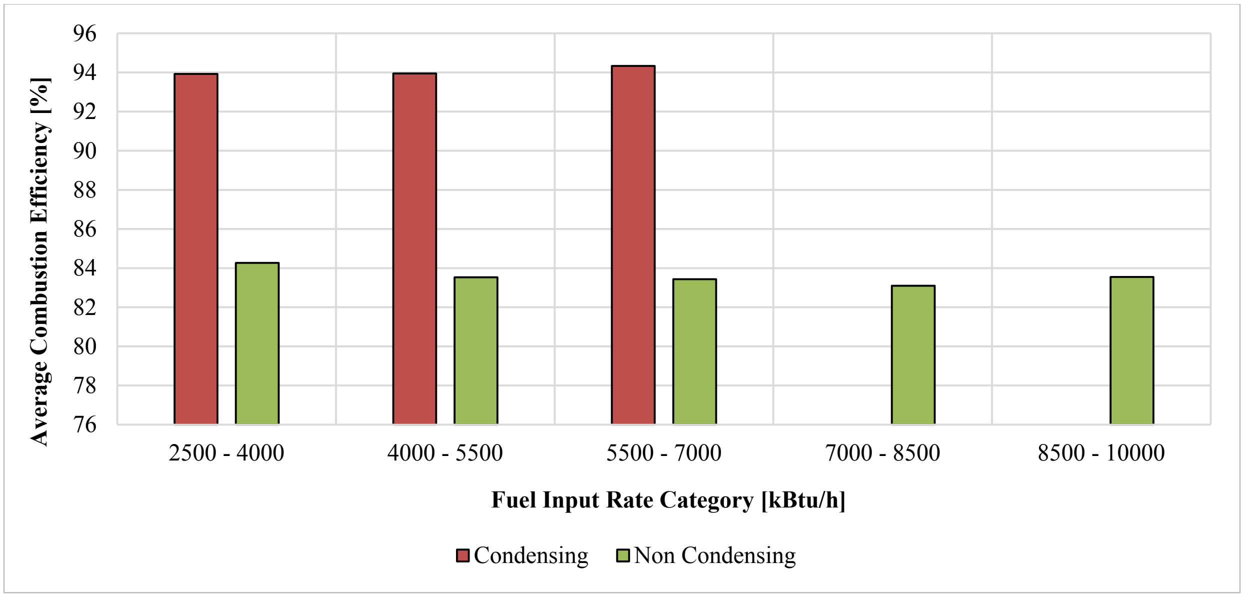

Figure 3.2.10 Comparison of Average Combustion Efficiency of Large Gas-Fired Hot Water Commercial Packaged Boilers Subcategory Based on Fuel Input Rate

3.2.7.3 Very Large (>10,000 kBtu/h) Gas-Fired Hot Water Commercial Packaged Boilers

There are 31 models listed in the database out of which one boiler is reported as natural draft. Major manufacturers based on model availability include: Miura, Group Simoneau Inc., Cleaver-Brooks Inc., and Power Master.

In this equipment class, CPB fuel input rates ranged from 10,000 kBtu/h to 63,000 kBtu/h. All the models in this class are modulating type. The maximum rated combustion efficiency within this equipment class is reported to be 83 percent combustion efficiency.

3.2.7.4 Small (≥300 kBtu/h and ≤2,500 kBtu/h) Oil-Fired Hot Water Commercial Packaged Boilers

Small oil-fired mechanical draft hot water commercial packaged boilers are required to have a minimum thermal efficiency of 82 percent. There are 122 CPB models in this equipment class, 58 of which are natural draft boilers. Of the 122 boilers, only 1 boiler is condensing. Figure 3.2.11 illustrates the distribution of the primary heat exchangers of the models in this equipment class.

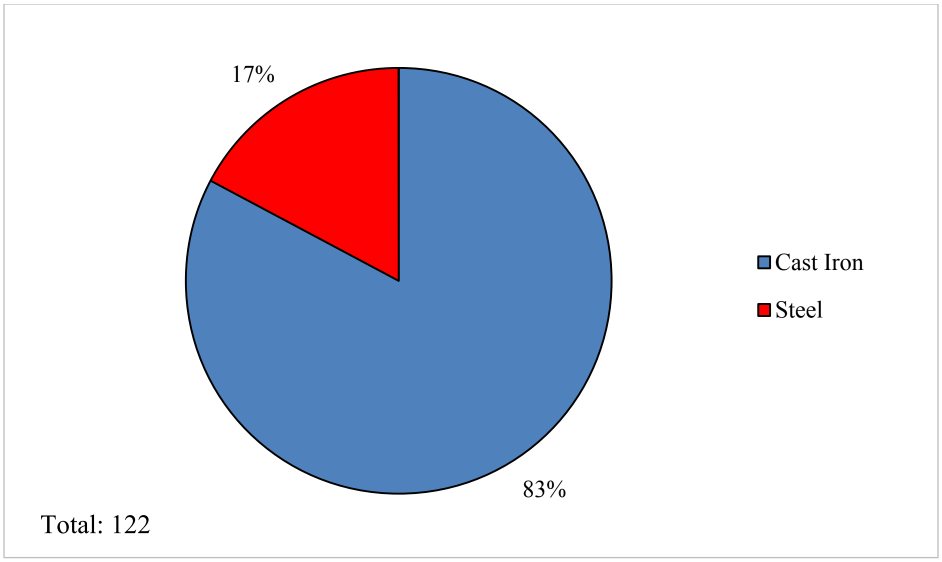

Figure 3.2.11 Distribution of Small Oil-Fired Hot Water Commercial Packaged Boilers Based on Material Used in the Primary Heat Exchanger

Figure 3.2.12 shows the distribution of boiler models for each boiler input category.

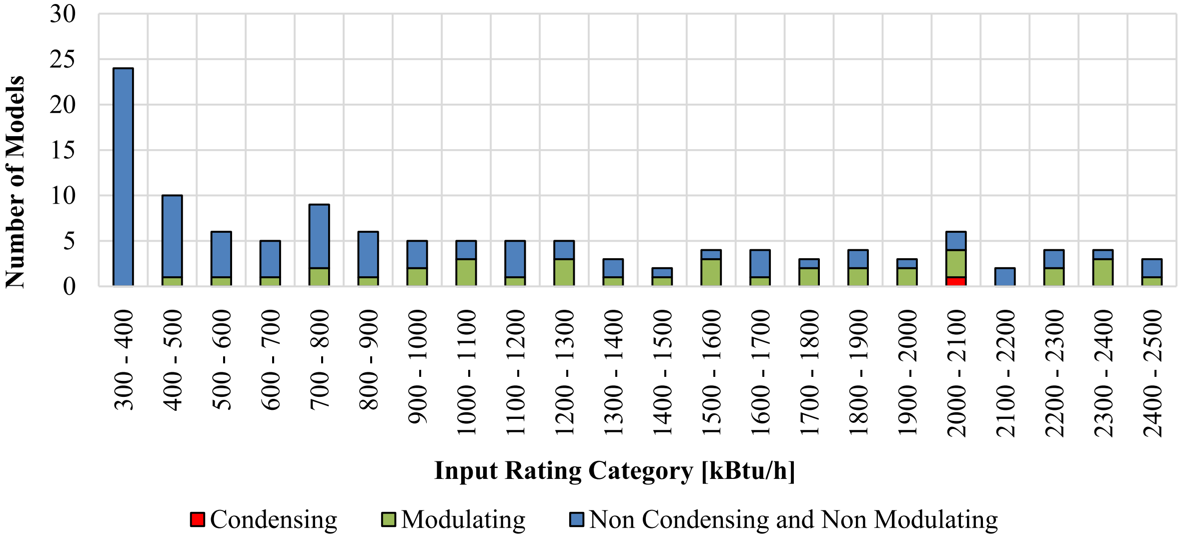

Figure 3.2.12 Distribution of Small Oil-Fired Hot Water Commercial Packaged Boilers Based on Fuel Input Rate

Manufacturers

There are eleven companies listed in the equipment database that manufacture boilers of this equipment class. Table 3.2.11 shows the names of the companies and the size of boilers they manufacture.

Table 3.2.11 List of Companies that Manufacture Small Oil-Fired Hot Water Commercial Packaged Boilers

Name of Manufacturer	Fuel Input Rate Category [kBtu/h]										
	300 – 500	500 – 700	700 – 900	900 – 1100	1100 – 1300	1300 – 1500	1500 – 1700	1700 – 1900	1900 – 2100	2100 – 2300	2300 – 2500
Bosch Thermotechnology Corp	X	X	X	X	X	X	X	X	X	X	
Burnham Commercial	X	X	X	X	X	X	X	X	X	X	X
Crown Boiler Co. Subsidiary Of Burnham Holdings Inc.	X	X	X	X	X						
New Yorker Boiler	X	X									
Fulton Heating Solutions									X		
PB Heat, LLC		X									X
Slant/Fin Corporation	X	X	X	X	X		X			X	
Smith Cast Iron Boilers	X	X	X	X	X	X	X	X	X	X	
U.S. Boiler Company	X										
Viessmann Manufacturing Company, Inc.	X	X	X	X	X	X		X	X	X	X
Weil-McLain	X										X

Characterization of Boilers Based on Efficiency

Figure 3.2.13 shows distribution of boilers based on thermal efficiency. The modulating and other boilers (non-condensing and non-modulating) have a fairly even distribution over all efficiencies. There is only one condensing boiler in this equipment class, with an efficiency of 97 percent.

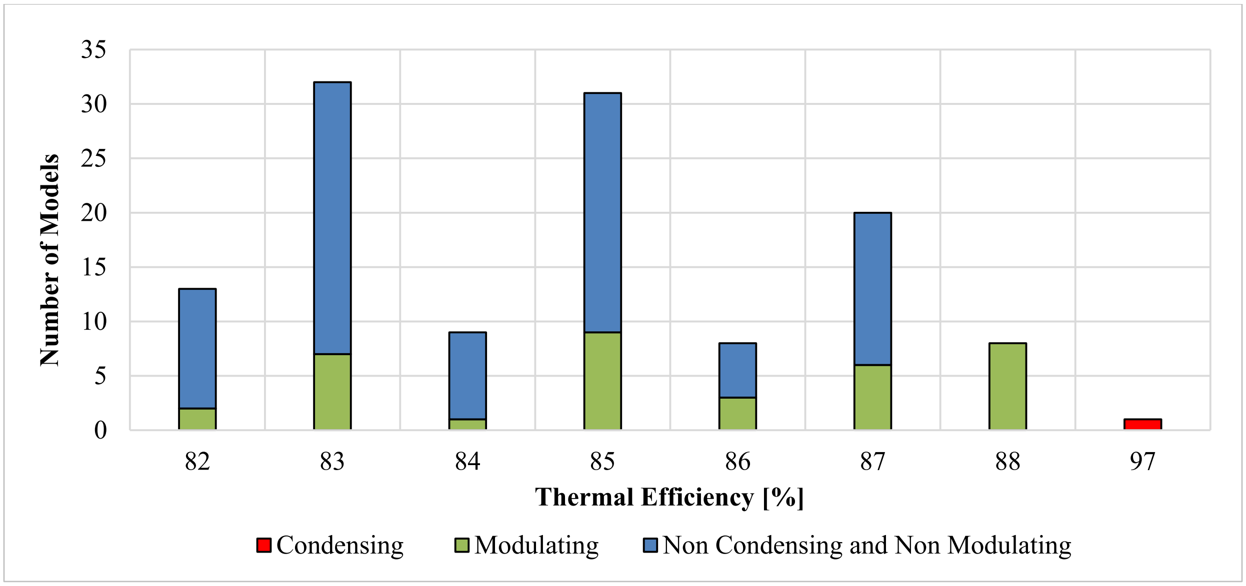

Figure 3.2.13 Distribution of Small Oil-Fired Mechanical Draft Hot Water Commercial Packaged Boilers Based on Thermal Efficiency

Variation of Average Efficiency with Fuel Input Rate

The average thermal efficiency of models as a function of fuel input rate was analyzed for this equipment class. The analysis shows an even distribution of thermal efficiency irrespective of fuel input rate. Figure 3.2.14 shows the variation of average thermal efficiency with fuel input rate.

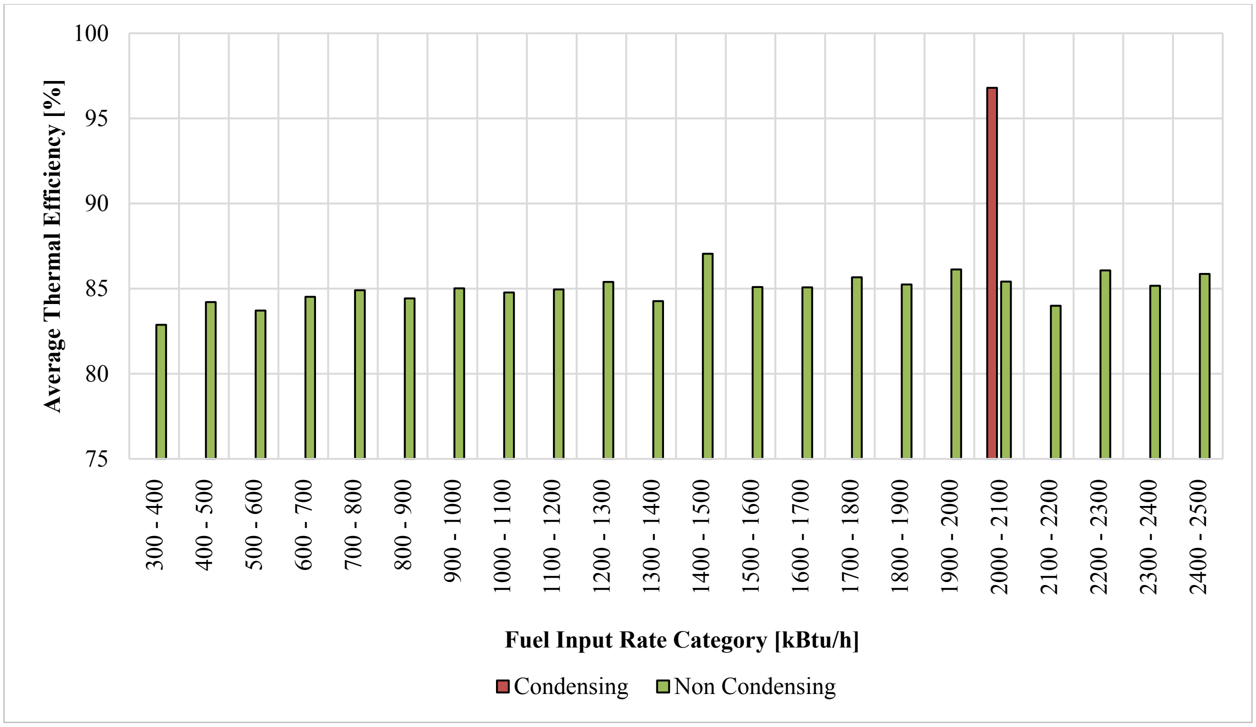

Figure 3.2.14 Comparison of Average Thermal Efficiency of Small Oil-Fired Hot Water Commercial Packaged Boilers Subcategory Based on Fuel Input Rate

3.2.7.5 Large (>2,500 kBtu/h and ≤10,000 kBtu/h) Oil-Fired Hot Water Commercial Packaged Boilers

Large oil-fired mechanical draft commercial packaged boilers are required to have a minimum combustion efficiency of 84 percent. Of the 74 boilers in this segment, only 3 are condensing. Each of the 3 condensing models have a heat exchanger made from steel. See Figure 3.2.15 for the distribution of the boilers based on the material of the primary heat exchanger.

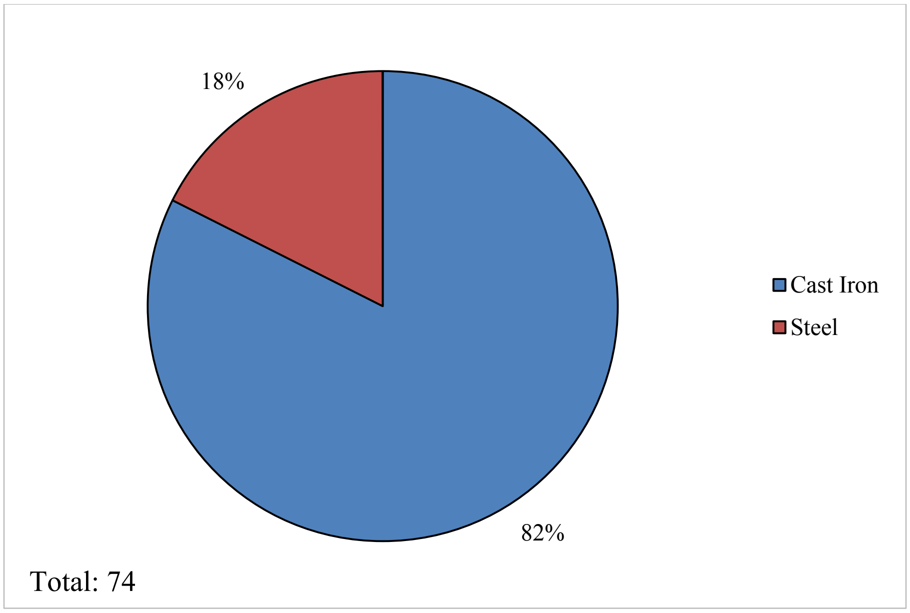

Figure 3.2.15 Distribution of Large Oil-Fired Hot Water Commercial Packaged Boilers Based on Material Used in the Primary Heat Exchanger

Figure 3.2.16 shows the distribution of boilers in this equipment class. All condensing boilers in this class are also modulating in this equipment class.

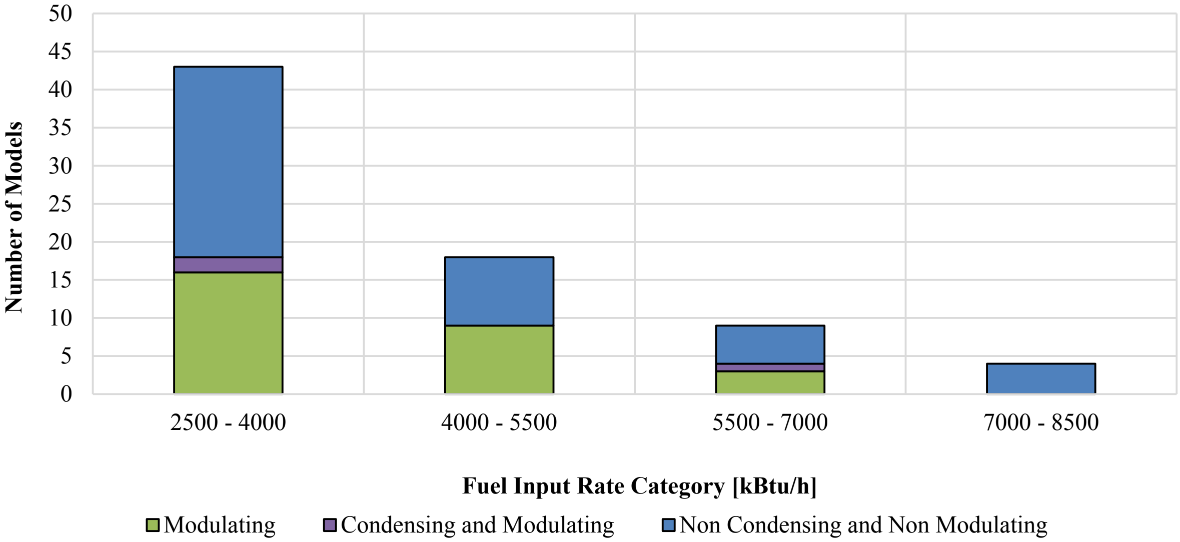

Figure 3.2.16 Distribution of Large Oil-Fired Hot Water Commercial Packaged Boilers Based On Fuel Input Rate

Manufacturers

There are eight companies in the equipment database that manufacture boilers belonging to this equipment class. Table 3.2.12 shows the different boilers manufactured by different companies for each fuel input rate.

Table 3.2.12 List of Companies that Manufacture Large Oil-Fired Hot Water Commercial Packaged Boilers

Name of Manufacturer	Fuel Input Rate Category [kBtu/h]			
	2500 - 4000	4000 -5500	5500 -7000	7000 - 8500
Bosch Thermotechnology Corp	X	X		
Burnham Commercial	X	X	X	
Fulton Heating Solutions	X		X	
PB Heat, LLC	X	X		
Slant/Fin Corporation	X			
Viessmann Manufacturing Company, Inc.	X	X		
Weil-McLain	X	X	X	X
Johnston Boiler Company	X	X	X	

Characterization of Boilers Based on Efficiency

As mentioned previously, there are three condensing boilers listed as part of this equipment class. The majority of non-condensing and non-modulating boilers have efficiencies of about 84 percent. Figure 3.2.17 shows distribution of equipment for different combustion efficiencies.

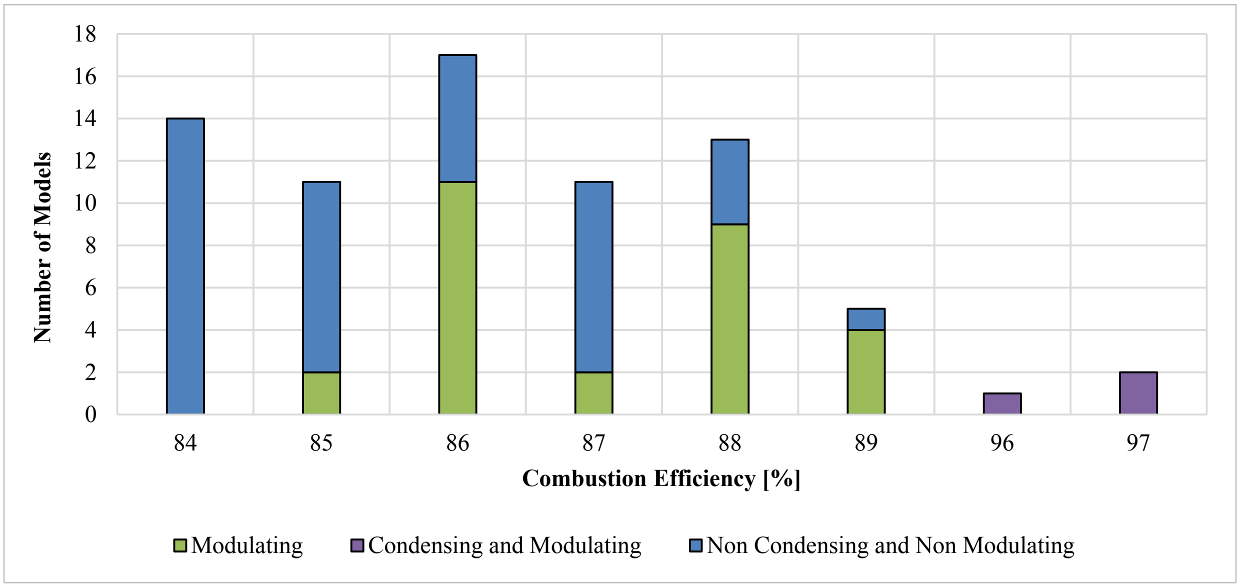

Figure 3.2.17 Distribution of Large Oil-Fired Hot Water Commercial Packaged Boilers Based On Combustion Efficiency

Variation of Average Efficiency with Fuel Input Rate

The variation of combustion efficiency with fuel input rate is shown in Figure 3.2.18. The two spikes in the 2,500–4,000 kBtu/h and 5,500–7,000 kBtu/h are due to condensing boilers.

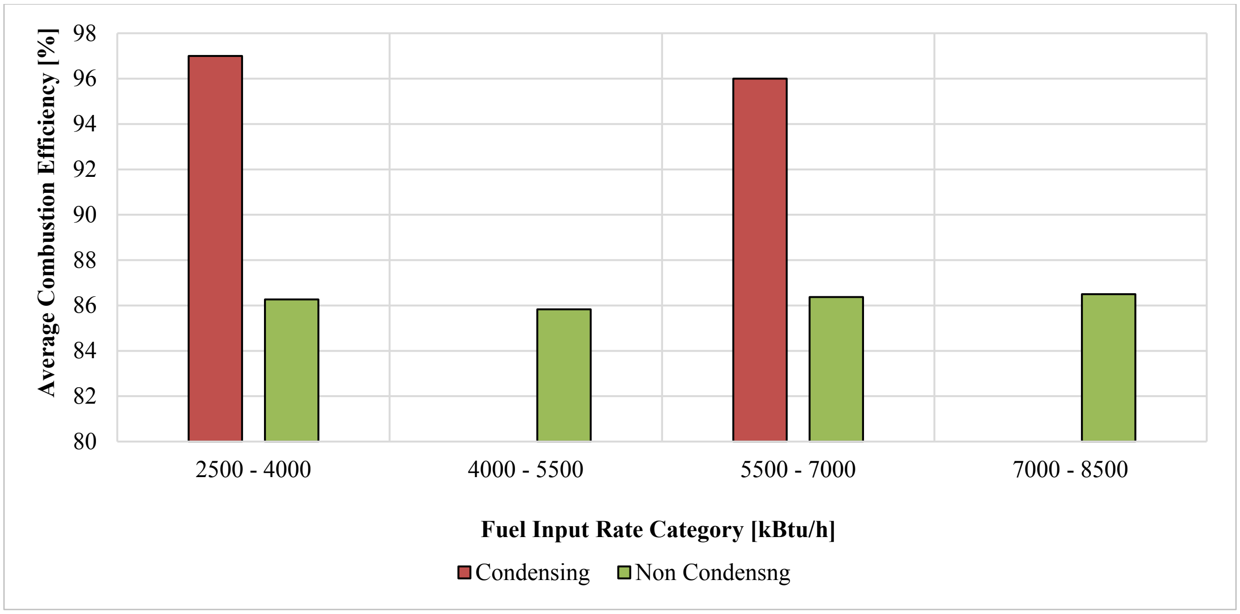

Figure 3.2.18 Comparison of Average Combustion Efficiency of Large Oil-Fired Hot Water Commercial Packaged Boilers Subcategory Based on Fuel Input Rate

3.2.7.6 Very Large (>10,000 kBtu/h) Oil-Fired Hot Water Commercial Packaged Boilers

This equipment class consists of only two commercial packaged boilers models that report and meet the current energy conservation. For the remaining 33 CPB models, DOE was unable to determine whether the equipment complies with the current energy conservation standards. Although DOE searched the equipment literature on the manufacturers' websites, DOE was only able to obtain values for thermal efficiency of the equipment.

Because DOE could not determine whether the models listed comply with DOE's regulations, DOE has tentatively removed the boilers from further consideration. Manufacturers of such equipment (including the models that were not considered) include: Miura, Cleaver-Brooks, Johnston Boiler Company, and Power Master. The maximum fuel input rates within the models of this equipment class is about 75,000 kBtu/h.

3.2.7.7 Small (≥300 kBtu/h and ≤2,500 kBtu/h) Gas-Fired Steam Commercial Packaged Boilers

Small gas-fired mechanical and natural draft steam equipment classes are currently divided into two separate equipment classes. In the NOPR, DOE has proposed to consolidate the two equipment classes into one small gas-fired steam equipment class. The mechanical draft boilers are required to comply with a minimum thermal efficiency of 79 percent, while natural draft boilers are required to comply with a minimum thermal efficiency of 77 percent. There are 251 boilers in this equipment class listed in the combined database that DOE created. There are no condensing boilers in this product class. The primary heat exchangers of the boilers in this equipment class are predominantly made of cast iron (see Figure 3.2.19).

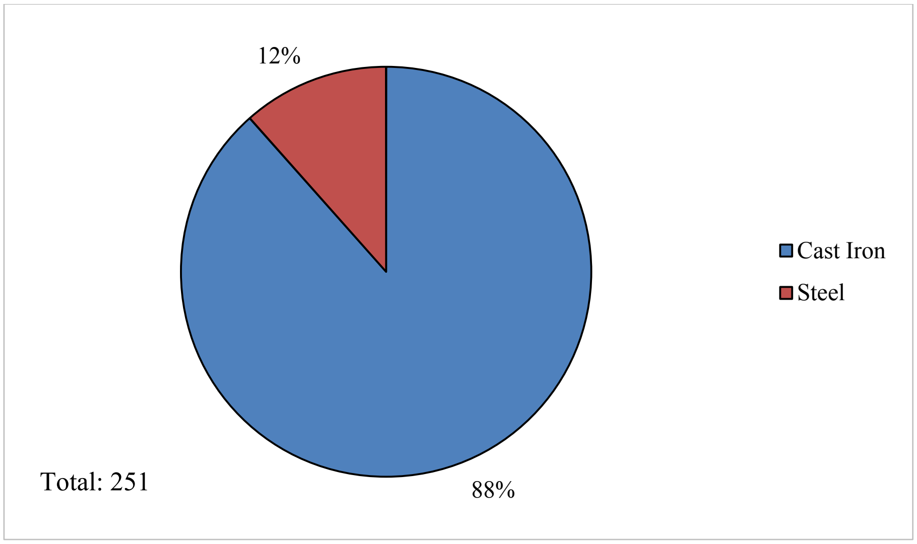

Figure 3.2.19 Distribution of Small Gas-Fired Steam Commercial Packaged Condensing Boilers Based on Material Used in the Primary Heat Exchanger

Figure 3.2.20 shows distribution of equipment based on boiler fuel input rate. Modulating boilers are represented in almost every input range.

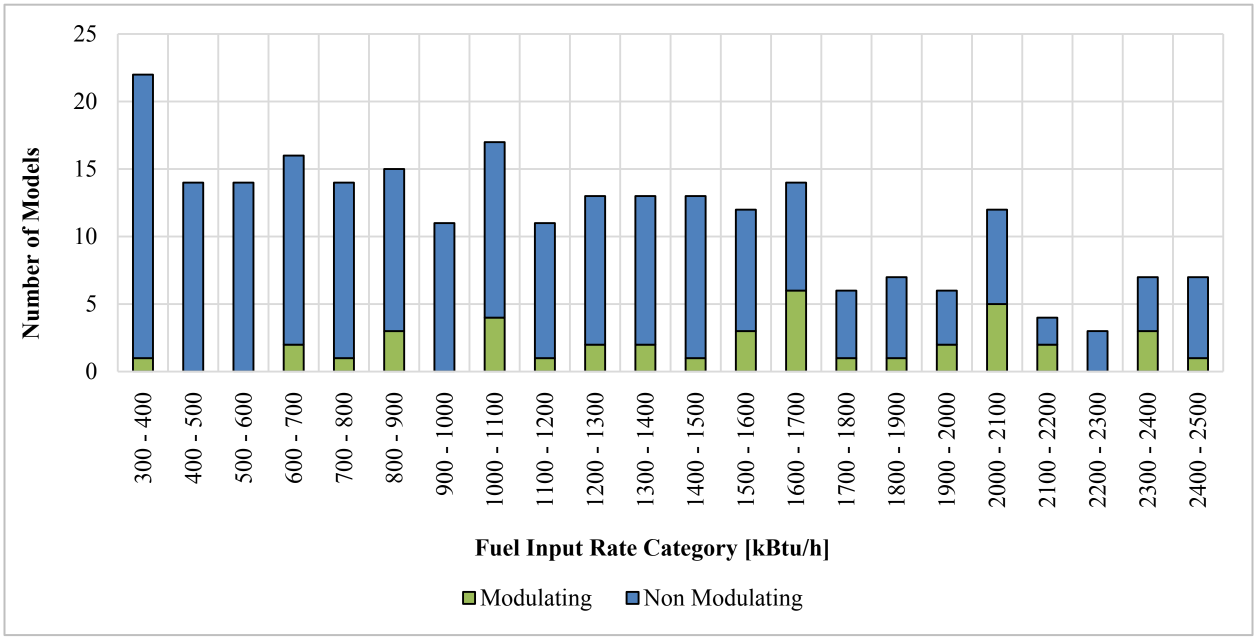

Figure 3.2.20 Distribution of Small Gas-Fired Steam Commercial Packaged Boilers Based on Fuel Input Rate

Manufacturers

There are 12 manufacturers listed in the combined database that manufacture boilers of this equipment class. Table 3.2.13 shows the list of companies and the fuel input rates manufactured by each company.

Table 3.2.13 List of Companies that Manufacture Small Gas-Fired Steam Commercial Packaged Boilers

Name of Manufacturer	Fuel Input Rate Category [kBtu/h]										
	300 – 500	500 – 700	700 – 900	900 – 1100	1100 – 1300	1300 – 1500	1500 –1700	1700 – 1900	1900 – 2100	2100 – 2300	2300 – 2500
Burnham Commercial	X	X	X	X	X	X	X	X	X	X	X
Crown Boiler Co. Subsidiary Of Burnham Holdings Inc.	X	X	X	X	X	X	X	X	X		X
ECR International	X	X	X	X	X	X	X				
P B Heat, LLC	X	X	X	X	X	X	X	X	X	X	X
Slant/Fin Corporation	X	X		X	X		X				
Smith Cast Iron Boilers	X	X	X	X	X	X	X	X	X	X	X
U.S. Boiler Company	X										
Weil-McLain	X	X	X	X	X	X	X	X	X		X
Miura							X				
Clayton Industries				X		X			X		
Sellers Manufacturing Company	X	X	X		X		X		X		
Vapor Power International, LLC			X				X				

Characterization of Boilers Based on Efficiency

The distribution of boilers over different efficiency levels is shown in Figure 3.2.21. Most of the boilers in this equipment class have thermal efficiencies between 77 and 81 percent.

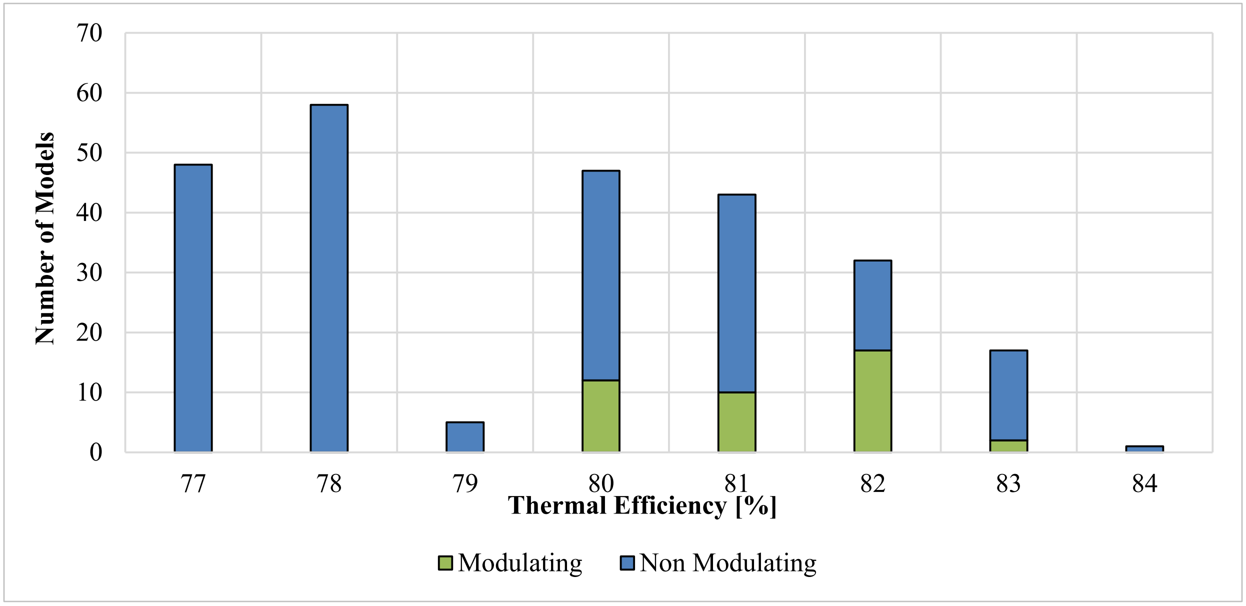

Figure 3.2.21 Distribution of Small Gas-Fired Steam Commercial Packaged Boilers Based on Thermal Efficiency

Variation of Average Efficiency with Fuel Input Rate

The average thermal efficiencies for each boiler fuel input rate varies from 78 to 82 percent. Figure 3.2.22 shows average thermal efficiency levels for each fuel input rate category.

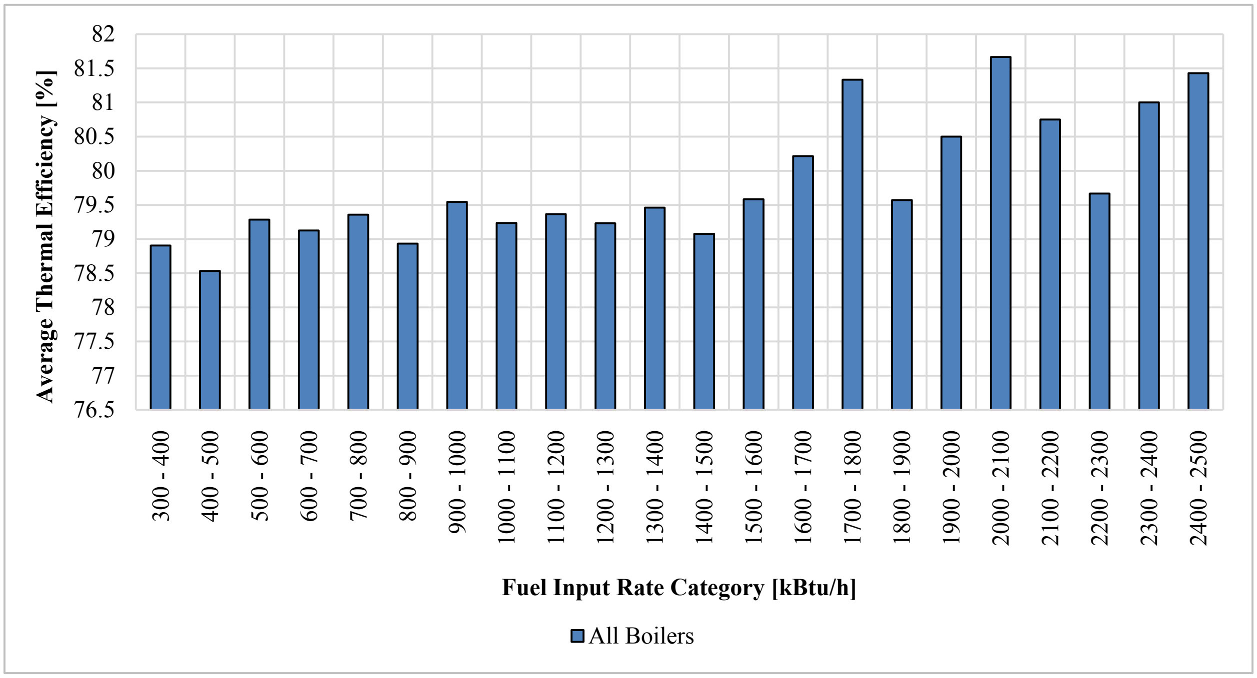

Figure 3.2.22 Comparison of Average Thermal Efficiency of Small Gas-Fired Steam Commercial Packaged Boilers Subcategory Based on Fuel Input Rate

3.2.7.8 Large (>2,500 kBtu/h and ≤10,000 kBtu/h) Gas-Fired Steam Commercial Packaged Boilers

Large gas-fired steam mechanical draft commercial packaged boilers are required to comply with a minimum thermal efficiency of 79 percent, while large gas-fired steam natural draft commercial packaged boilers are required to comply with a minimum efficiency of 77 percent. These two draft types are proposed to be combined into one equipment class. According to DOE’s equipment database, there are 186 models in this equipment class out of which 178 are considered in this assessment. Figure 3.2.23 shows the percentage breakdown of the material of the primary heat exchangers of the models in this equipment class.

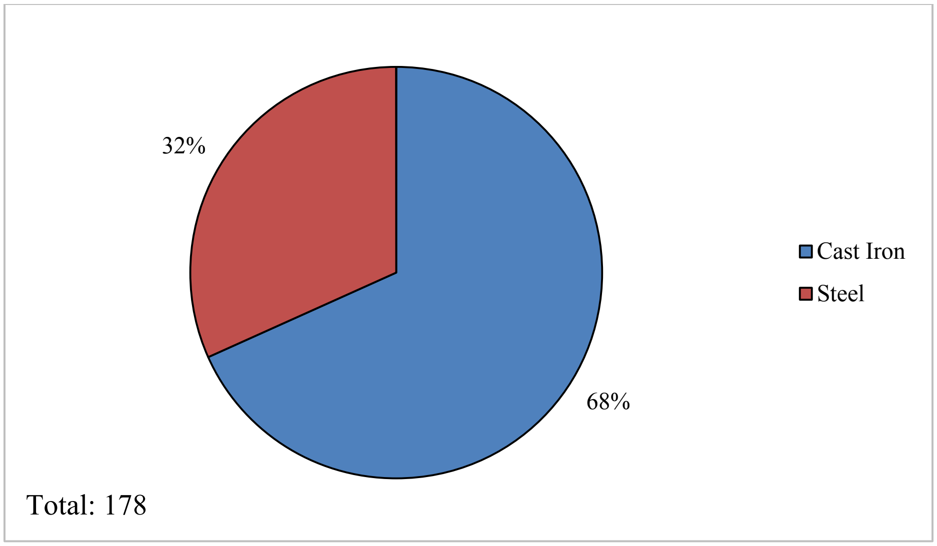

Figure 3.2.23 Distribution of Large Gas-Fired Steam Commercial Packaged Condensing Boilers Based on Material Used in the Primary Heat Exchanger

Figure Figure 3.2.24 shows the distribution of boiler models based on capacity.

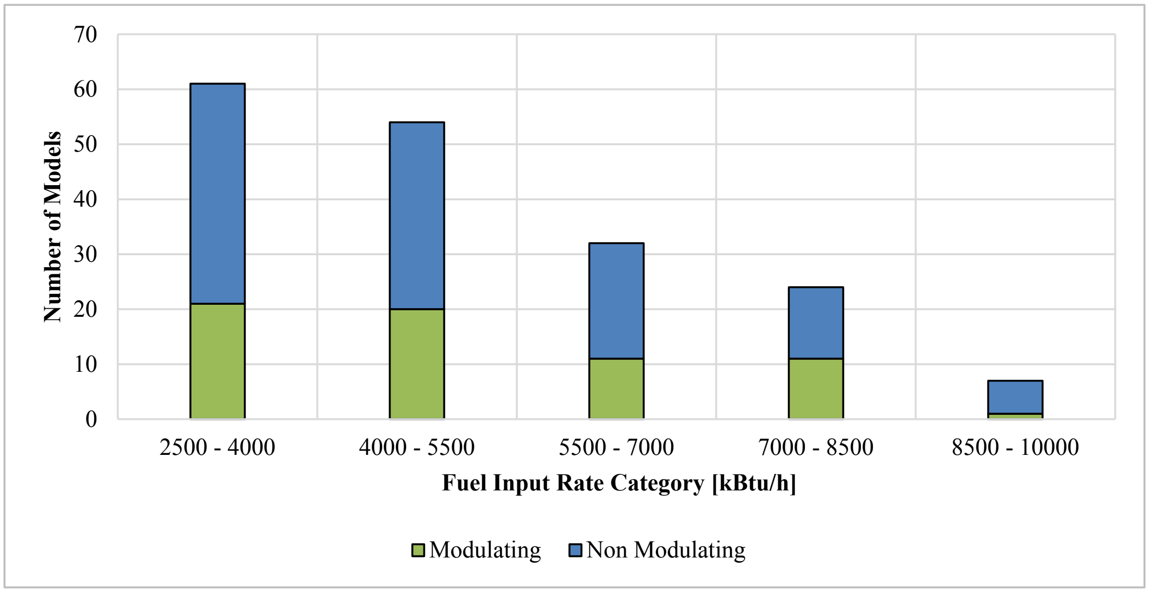

Figure 3.2.24 Distribution of Large Gas-Fired Steam Commercial Packaged Boilers Based on Fuel Input Rate

Manufacturers

There are nine companies that manufacture boilers of this equipment class. Table 3.2.14 shows the size of boiler (fuel input rate) manufactured by all eleven companies.

Table 3.2.14 List of Companies that Manufacture Large Gas-Fired Steam Commercial Packaged Boilers

Name of Manufacturer	Fuel Input Rate Category [kBtu/h]				
	2500–4000	4000–5500	5500–7000	7000–8500	8500–10000
Burnham Commercial	X	X	X		
PB Heat, LLC	X	X	X	X	X
Smith Cast Iron Boilers	X	X	X		
Weil-Mclain	X	X	X	X	X
Miura	X				
Clayton Innovative Team Solutions	X	X	X	X	
Cleaver-Brooks		X	X	X	
Sellers Manufacturing Company	X	X	X	X	
Powermaster Boiler	X	X	X	X	
Vapor Power International, LLC	X	X	X	X	X

Characterization of Boilers Based on Efficiency

The thermal efficiency of boiler models in this equipment class varies from 78 percent to 84 percent. Figure 3.2.25 shows distribution of boiler models for different efficiency levels.

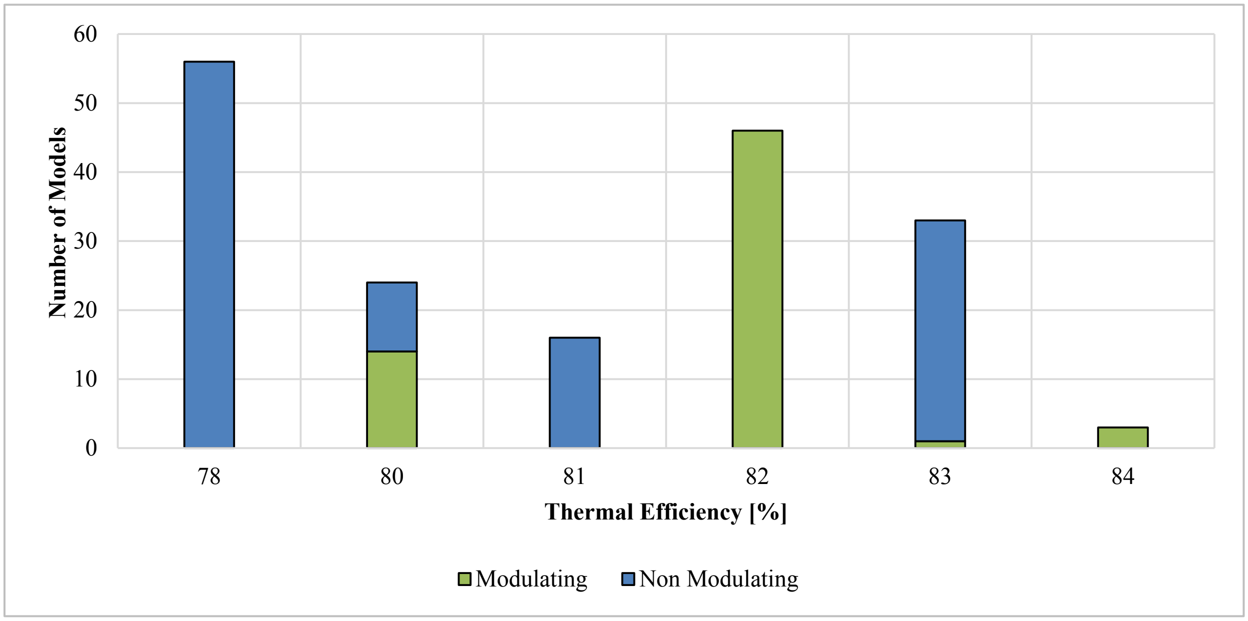

Figure 3.2.25 Distribution of Large Gas-Fired Steam Commercial Packaged Boilers Based on Thermal Efficiency

Variation of Average Efficiency with Fuel Input Rate

DOE also calculated average thermal efficiency at different fuel input rates. Results indicate that the average thermal efficiency of boilers decreased with increased boiler size for this equipment class. Figure 3.2.26 shows the variation of average thermal efficiency with fuel input rate.

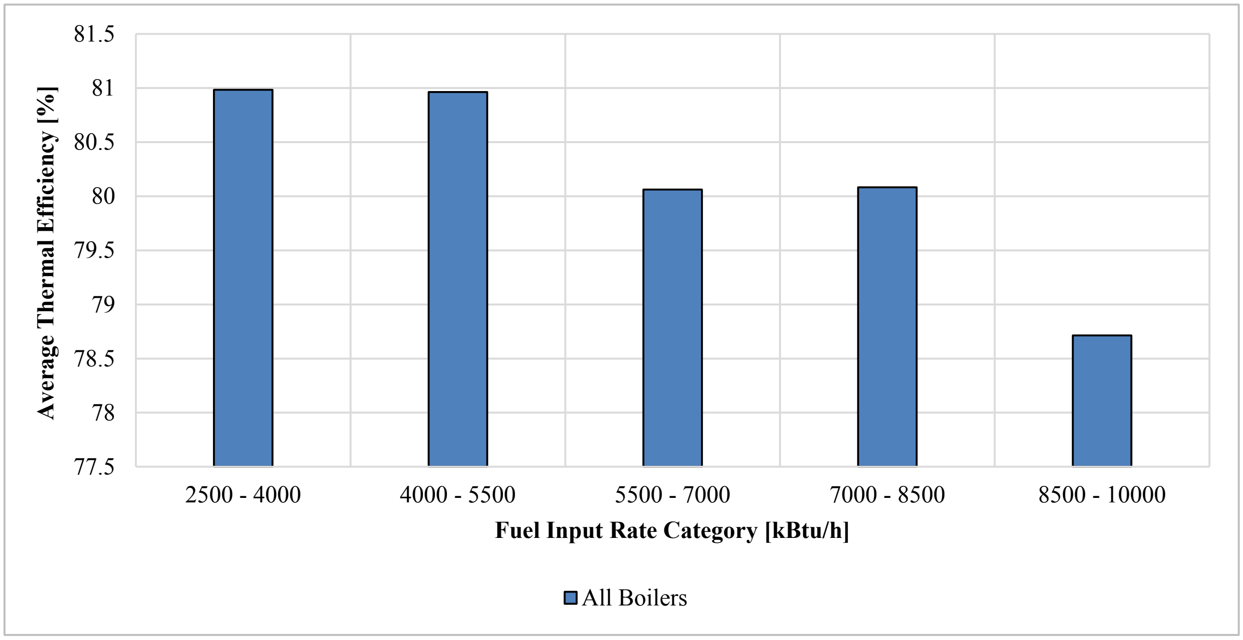

Figure 3.2.26 Comparison of Average Thermal Efficiency of Large Gas-Fired Steam Commercial Packaged Boilers Subcategory Based on Fuel Input Rate

3.2.7.9 Very Large (>10,000 kBtu/h) Gas-Fired Steam Commercial Packaged Boilers

There are 77 models listed in the database out of which one boiler is reported as natural draft. Major manufacturers based on model availability include: Miura, Group Simoneau Inc., Cleaver-Brooks Inc., Clayton Industries, Sellers Manufacturing, Power Master, and Vapor Power International.

In this equipment class, CPB fuel input rates ranged from 10,000 kBtu/h to 63,000 kBtu/h. All the models in this class are modulating type. The maximum rated thermal efficiency within this equipment class is reported to be 89 percent.

3.2.7.10 Small (≥300 kBtu/h and ≤2,500 kBtu/h) Oil-Fired Steam Commercial Packaged Boilers

Small oil-fired steam commercial packaged boilers are required to have a minimum thermal efficiency of 81 percent. Boiler models listed in this equipment class are made from cast iron and steel (see Figure 3.2.27).

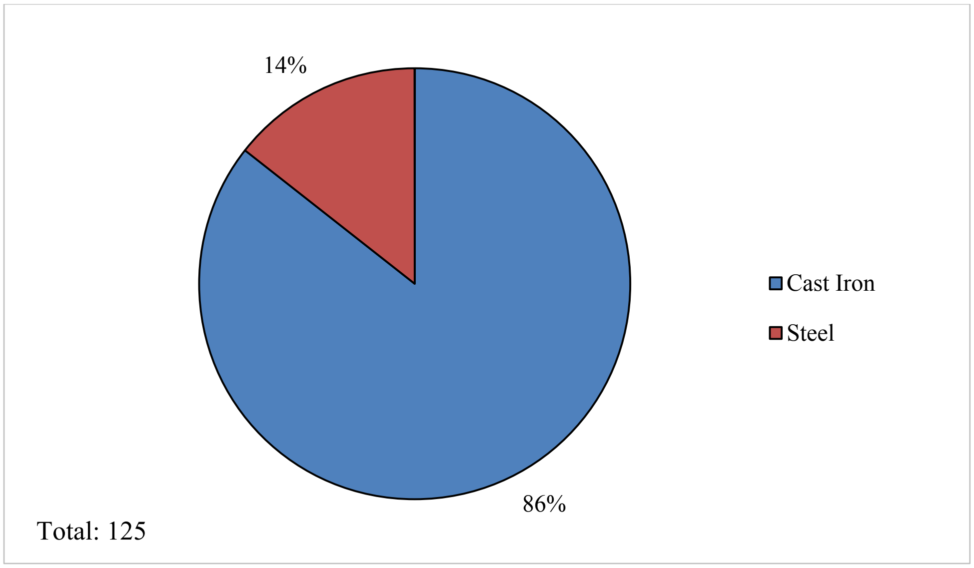

Figure 3.2.27 Classification of Small Oil-Fired Steam Commercial Packaged Boilers Based on Material Used in the Primary Heat Exchanger

Figure 3.2.28 shows the distribution all qualified boiler models based on their size.

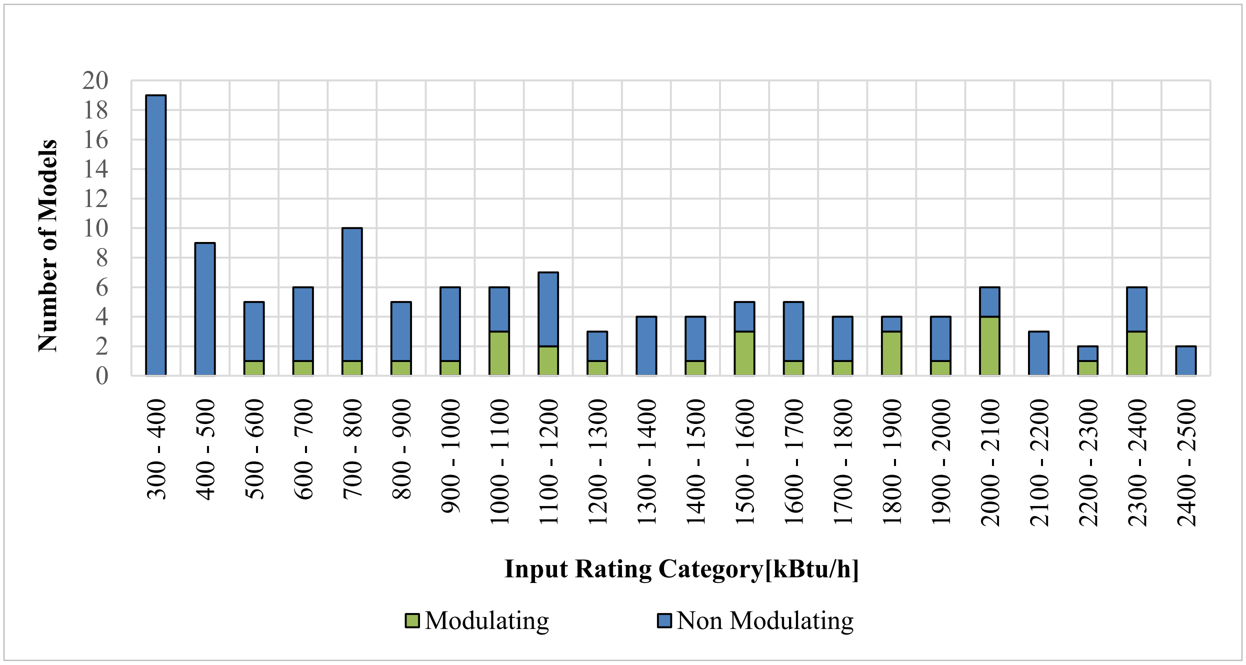

Figure 3.2.28 Distribution of Small Oil-Fired Steam Commercial Packaged Boilers Based On Fuel Input Rate

Manufacturers

Table 3.2.15 shows the list of eight companies that manufacture boilers of this equipment class.

Table 3.2.15 List of Companies that Manufacture Small Oil-Fired Steam Commercial Packaged Boilers

Name of Manufacturer	Fuel Input Rate Category [kBtu/h]										
	300 – 500	500 – 700	700 – 900	900 – 1100	1100 – 1300	1300 – 1500	1500 – 1700	1700 – 1900	1900 – 2100	2100 – 2300	2300 – 2500
Burnham Commercial		X	X	X	X	X	X	X	X	X	X
Crown Boiler Co. Subsidiary Of Burnham Holdings Inc.		X	X	X	X	X	X	X	X	X	
P B Heat, LLC	X	X	X	X	X	X	X	X	X	X	X
Slant/Fin Corporation	X	X	X	X	X		X			X	
Smith Cast Iron Boilers	X	X	X	X	X	X	X	X	X	X	X
U.S. Boiler Company, Inc.	X										
Weil-McLain	X	X	X	X	X	X	X		X		X
Clayton Industries				X		X			X		

Characterization of Boilers Based on Efficiency

Figure 3.2.29 shows the number of models at the various thermal efficiency levels. The majority (almost 80 percent) of models are within the 83 to 84 percent efficiency range.

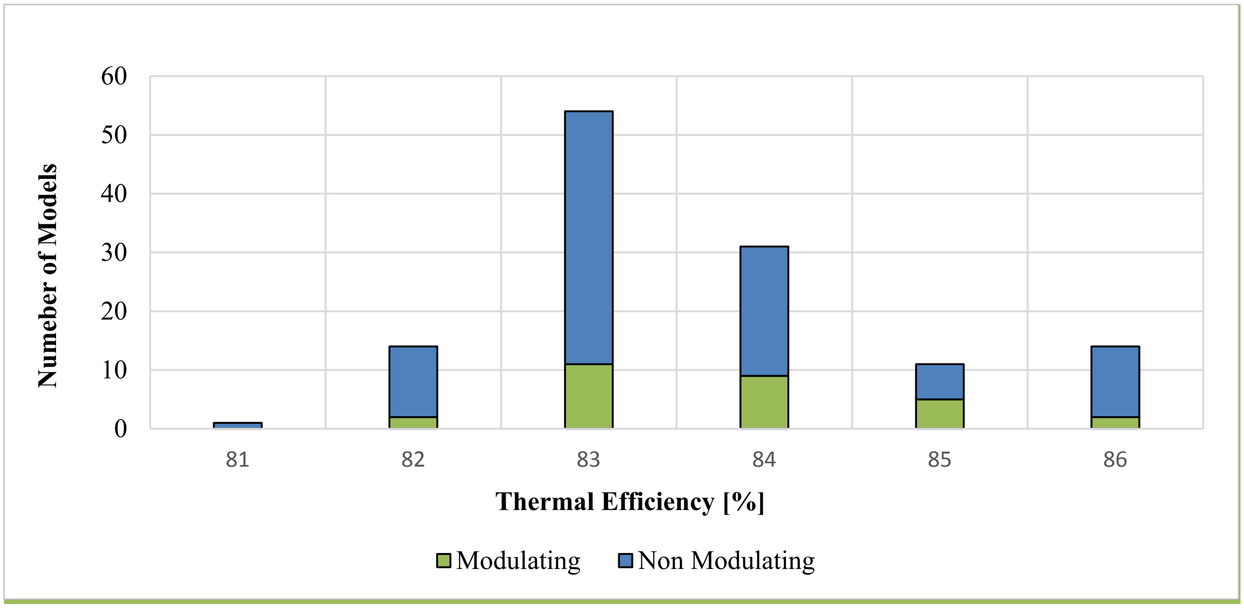

Figure 3.2.29 Distribution of Small Oil-Fired Steam Commercial Packaged Boilers Based on Thermal Efficiency

Variation of Average Efficiency with Fuel Input Rate

The average thermal efficiency for each fuel input rate category was calculated and the result is shown in Figure 3.2.30. The chart shows a reasonably even distribution of average thermal efficiencies with the minimum average thermal efficiency across the entire input range at 82 percent and the maximum at 86 percent.

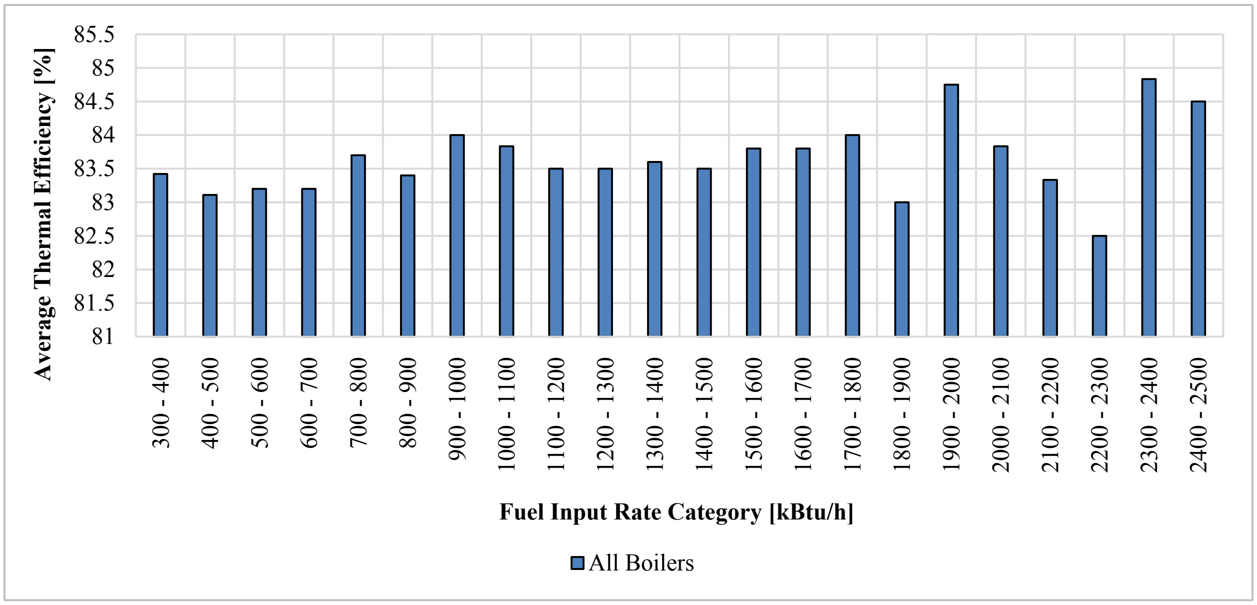

Figure 3.2.30 Comparison of Average Thermal Efficiency of Small Oil-Fired Steam Commercial Packaged Boiler Subcategory Based on Fuel Input Rate

3.2.7.11 Large (>2,500 kBtu/h and ≤10,000 kBtu/h) Oil-Fired Steam Commercial Packaged Boilers

Large oil-fired steam commercial packaged boilers are required to comply with a thermal efficiency of 81 percent. All boilers listed in this equipment class are non-condensing. The primary heat exchangers of large oil-fired steam are made from cast iron and steel. Figure 3.2.31 illustrates the breakdown of the material used for the primary heat exchanger.

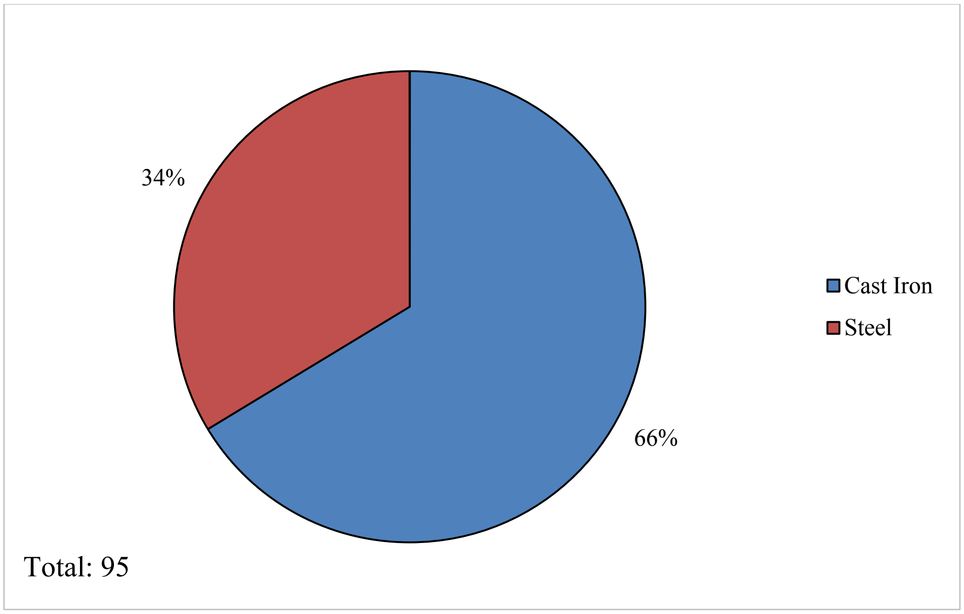

Figure 3.2.31 Classification of Large Oil-Fired Steam Commercial Packaged Boilers Based on Material Used in the Primary Heat Exchanger

Figure 3.2.32 shows that the majority of single-stage commercial packaged boilers in this equipment class have fuel input rates from 2,500 kBtu/h to 5,500 kBtu/h.

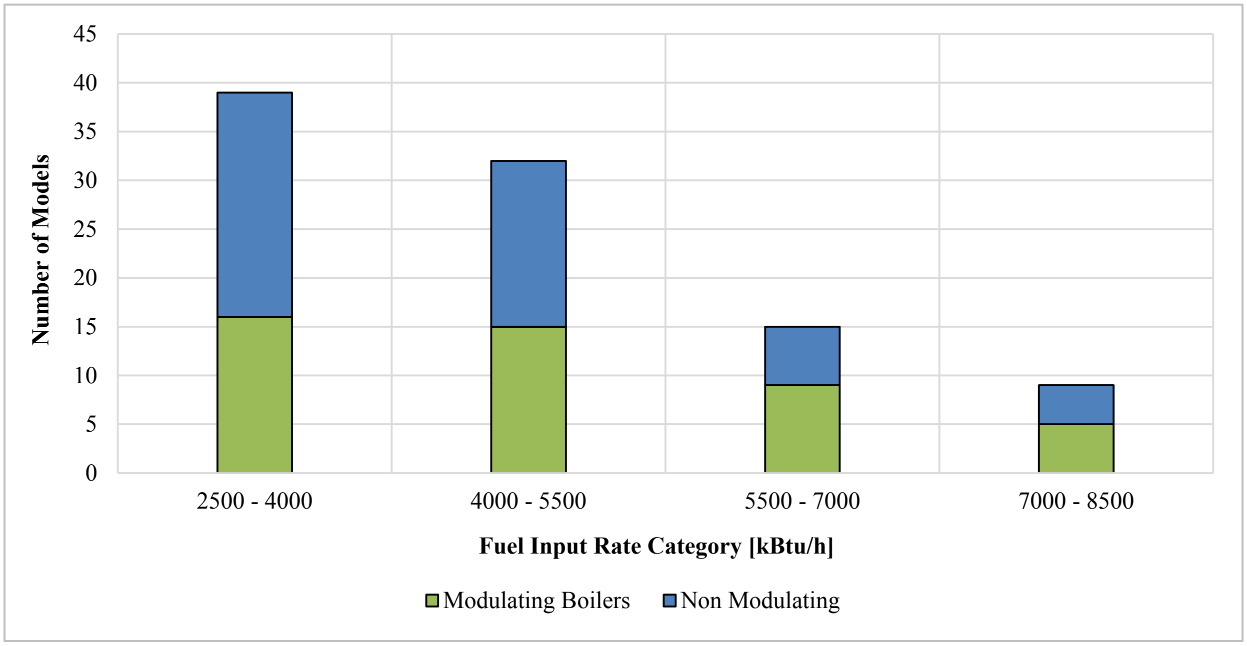

Figure 3.2.32 Distribution of Large Oil-Fired Steam Commercial Packaged Boilers Based on Fuel Input Rate

Manufacturers

There are eight manufacturers listed in the combined database that produce boilers in this equipment class. Burnham Commercial, Weil-McLain, Cleaver-Brooks, and Group Simoneau are the major manufacturers in this class. Table 3.2.16 shows the manufacturers and the boiler size (fuel input rate) that each company is currently producing.

Table 3.2.16 List of Companies that Manufacture Large Oil-Fired Mechanical Draft Steam Commercial Packaged Boilers

Manufacturer Name	Fuel Input Rate Category [kBtu/h]			
	2500 – 4000	4000 – 5500	5500 – 7000	7000 – 8500
Burnham Commercial	X	X	X	
P B Heat, LLC	X	X		
Smith Cast Iron Boilers	X	X		
Weil-McLain	X	X	X	X
Group Simoneau, Inc.	X	X	X	X
Clayton Industries	X	X	X	X
Cleaver-Brooks		X	X	X
Johnston Boiler Company	X	X	X	

Characterization of Boilers Based on Efficiency

The efficiency of boilers in this equipment class varies from 82 percent to 87 percent. Figure 3.2.33 shows the distribution of thermal efficiency ratings for this equipment class.

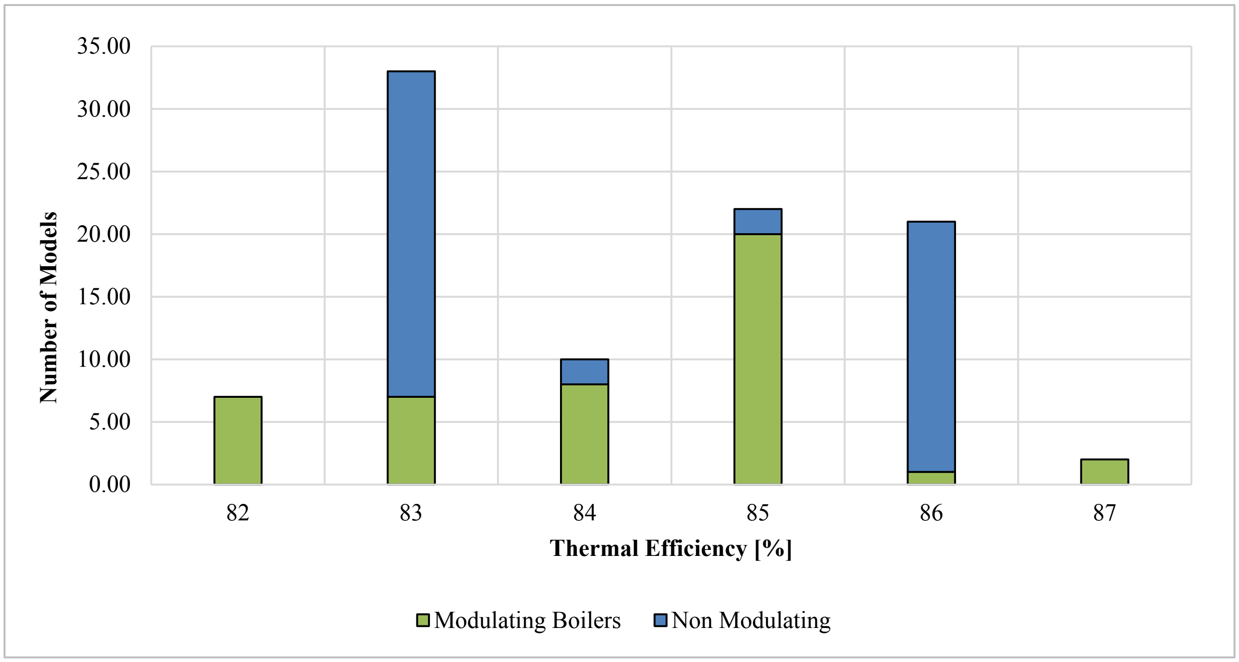

Figure 3.2.33 Distribution of Large Oil-Fired Steam Commercial Packaged Boilers Based On Thermal Efficiency

Variation of Average Efficiency with Fuel Input Rate

Figure 3.2.34 shows the variation of average thermal efficiency with fuel input rate.

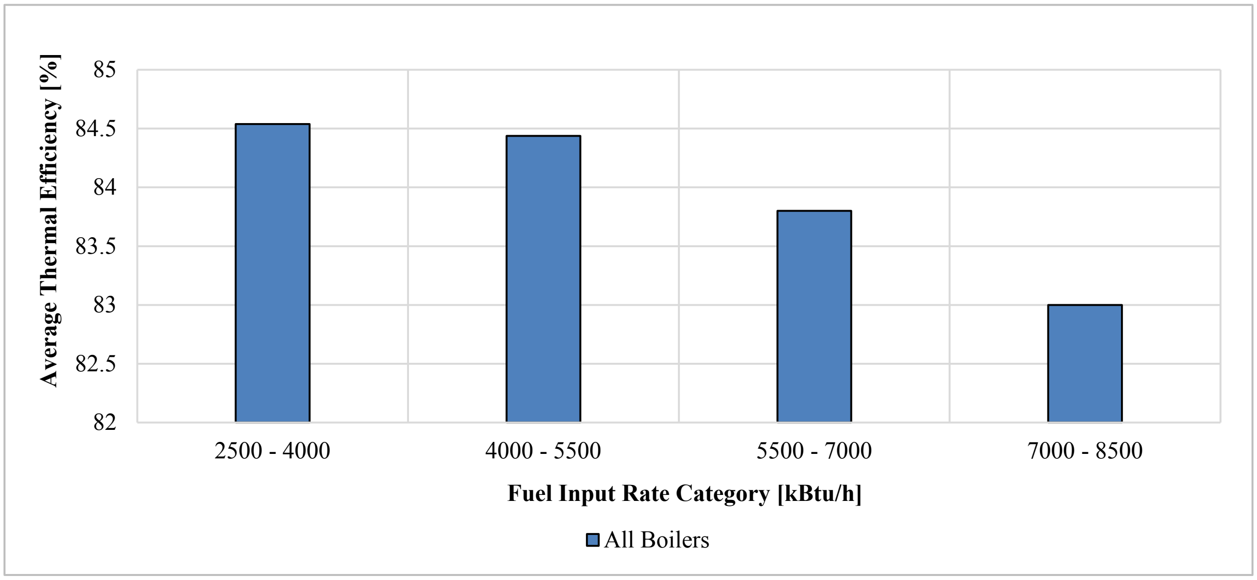

Figure 3.2.34 Comparison of Average Thermal Efficiency of Large Oil-Fired Steam Commercial Packaged Boilers Subcategory Based on Fuel Input Rate

3.2.7.12 Very Large (>10,000 kBtu/h) Oil-Fired Steam Commercial Packaged Boilers

There are 42 models listed in the database that are all mechanical draft systems. Major manufacturers based on model availability include: Group Simoneau Inc., Cleaver-Brooks Inc., Clayton Industries, Johnston Boiler Company, Power Master, and Vapor Power International.

The maximum fuel input rate observed in this equipment class is about 97,000 kBtu/h. All the models in this class are modulating type. The maximum rated thermal efficiency within this equipment class is reported to be 86 percent.

3.3 TECHNOLOGY ASSESSMENT

The technology assessment focuses on understanding how commercial packaged boilers use energy and on identifying potential technology changes that would improve the efficiency of this equipment. Measures that improve the rated equipment efficiency are called technology options, and they are based on existing designs, as well as working prototypes. In consultation with interested parties, DOE created a list of technology options for consideration in this rulemaking. After researching this list of technology options, DOE assessed each option based on the four screening criteria discussed in chapter 4. The technology options that pass the screening criteria were considered suitable options for improving the efficiency of the equipment in the engineering analysis, and assisted DOE in determining the efficiency levels from the baseline through the max-tech design.

3.3.1 Boiler Equipment

Commercial packaged boilers are pressure vessels designed to transfer heat via combustion to water or steam, used for space heating, and in some applications domestic hot water as well. Commercial packaged boilers can be condensing or non-condensing in design. Condensing boilers recover additional heat by condensing part of the water vapor produced by the burning fuel.[f] A boiler consists of (1) a tank/shell (or other forms of pressure vessel to hold the water or steam); (2) a burner; (3) a combustion chamber (also sometimes referred to as a firebox); (4) a heat exchanger; (5) automatic controls; and (6) mechanical draft equipment (*e.g.*, forced or induced draft blower) if applicable (*i.e.,* if the boiler is not a natural draft unit). The following provides further details regarding the components used in commercial packaged boilers.

Construction Materials

Non-condensing boilers are often made of cast iron, steel, copper, or copper-clad steel, and are usually designed to prevent corrosion and thermal shock. Condensing boilers are usually made of stainless steel or aluminum construction, because the acidic condensate would corrode copper, cast iron, or carbon steel. Condensing boilers may include secondary heat exchangers, which, due to exposure to corrosive condensate formation in the heat exchanger, must also be constructed of corrosion-resistant materials.

Tank/Pressure Vessel

Boiler tanks (also called the pressure vessel or boiler shell) are frequently cylindrical in shape but can also be of rectangular or other construction styles. The inside walls of the tank opposite combustion regions are sometimes lined with insulating materials to maintain sufficient flame temperature for clean combustion. The outside surfaces of the tank are usually covered with insulation to reduce heat losses through the boiler jacket.

Burner

Burners combine the fuel and air and then ignite the mixture to start the combustion process. The boiler fuel type dictates the type of burner that is used.

- Atmospheric burners typically use natural gas or propane in natural draft applications. An atmospheric burner uses the pressure-induced velocity of gas exiting an orifice to mix such gas with primary combustion air. An atmospheric burner then uses natural draft to mix secondary air into the flame during combustion.

- A gas-power burner is a type of burner that uses a blower to supply combustion air into the combustion zone. This may be an externally mounted gun-type burner similar

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[f] This requires that the water returning to the boiler system be cold enough to sufficiently carry out the condensation process of the water vapor in the exhaust.

to an oil-pressure atomizing burner, or an incorporated fan and gas delivery system within the boiler.

- An oil-power burner may be a pressure atomizing burner or an air atomizing burner. A pressure atomization oil burner uses oil pumped through a nozzle to create a fine mist that is then mixed with the combustion air and ignited at the front of the burner. An air atomizing burner uses compressed air to atomize the oil into a fine mist before being delivered and ignited in the combustion chamber.

Heat Exchangers

A heat exchanger is a device used to transfer heat from one medium to another. All boilers come equipped with air-to-water heat exchangers. The primary boiler heat exchanger designs include (1) water tube; (2) fire tube; (3) cast iron; and (4) tubeless.[g]

For water tube boilers, combustion gases circulate around water or steam-filled tubes. Heat transfer is achieved by radiation from the flames as well as by convection from the hot combustion gases. There may be up to several thousand water tubes in a boiler, depending on the size of the unit.[h] The water tubes are often welded together to form the walls of the combustion chamber, called a "waterwall." Water tube designs are often used in steam boilers. Finned copper water tube boilers are designed with rows of horizontal finned tubes located above the combustion chamber. Finned copper water tube boilers are generally hot water boilers. The water tube design can enable more rapid start-up due to lower thermal mass and can enhance thermal shock resistance due to greater structural flexibility relating to thermal expansion and contraction.

For fire tube boilers, the boiler tank is filled with water and heat is transferred as hot combustion gases pass through one to several metal tubes or other passageways in the heat exchanger. Fire tube boilers are often characterized by their number of passes (*i.e.*, number of times combustion gases flow the length of the boiler). The combustion gas flows through the length of a bundle of tubes and then is turned around and passes back through an additional bundle of tubes.[i] Fire tube boiler combustion chambers may be dry-base, wet-base, or wet-leg. Dry-base chambers are refractory-lined chambers that direct the combustion gases from the firebox to the heat transfer tubes; the chamber is usually located beneath the fluid-backed sections. Wet-base chambers often utilize a water-cooled turn-around chamber to direct the flue gases from the combustion chamber to the tube banks, although dry-backed turn-around chambers are also sometimes used. A wet-backed turn-around chamber is fully surrounded by

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[g] *ASHRAE Handbook—HVAC Systems and Equipment*. 2008. Available at https://www.ashrae.org/resources--publications/handbook.

[h] *Characterization of the U.S. Industrial/Commercial Boiler Population*. 2005. https://www1.eere.energy.gov/manufacturing/distributedenergy/pdfs/characterization_industrial_commerical_boiler_population.pdf).

[i] DOE's *Improving Steam System Performance: A Sourcebook for Industry. 2012.* http://www1.eere.energy.gov/manufacturing/tech_assistance/pdfs/steamsourcebook.pdf.

fluid-backed sections except for the necessary openings—thereby eliminating the need for the refractory lining. Wet-leg combustion chambers have fluid-backed sections on the top and sides of the chamber.

Cast iron boilers are made up of cast pressure sections bolted together or connected by push nipples to form a block assembly.[j] The water is contained inside cast iron sections, and combustion gases flow through designated passages outside the sections.[k] Cast iron boilers may be of dry-base, wet-leg, or wet-base design.

Tubeless boilers use the outside of its shell as part of the heat exchanger surface. There is a central flue surrounded by water which serves the first pass of the combustion gases.[l] The combustion gases then exit the central flue through a nozzle that connects it to the hollow shell wall which has internal steel fins that run the length of the boiler tank. Then the combustion gases make several passes through the shell wall before exiting the stack.

Controls

A boiler must be capable of providing immediate response to load demand variations while maintaining its efficiency and safety features. Thus, boilers come equipped with a variety of controls.

- The main operating control (pressure-actuated for steam boilers and temperature-actuated for hot water boilers) controls the firing rate of the fuel by monitoring hot water temperature or steam pressure. Operating controls could provide on/off, high/low/off, and modulating functions.[m]

- The low-water cutoff switch stops fuel flow to the burner if minimum water levels are not detected.[n]

- The pressure gauge/regulator monitors boiler pressure and shuts off the fuel supply to the boiler if allowable boiler pressure is exceeded. Additionally, the temperature/pressure relief valve releases steam if the pressure gauge/regulator fails and pressure builds dangerously high.[o]

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[j] See Heselton, Kenneth E. Marcel Dekker. *Boiler Operator's Handbook*. 2005. http://www.waterandfire.ir/Down_En/Boiler_Operators_Handbook.pdf

[k] See BetterBricks. "How Boilers Work" in *Boilers*. www.betterbricks.com/sites/default/files/operations/om_of_boilers_final.pdf.

[l] See www.spthermal.com/hurst.html.

[m] For more information, please see, *ASHRAE Handbook—HVAC Systems and Equipment*. 2008. Available at https://www.ashrae.org/resources--publications/handbook).

[n] For more information, please see, *ASHRAE Handbook—HVAC Systems and Equipment*. 2008. Available at https://www.ashrae.org/resources--publications/handbook).

[o] See http://homerepair.about.com/od/heatingcoolingrepair/ss/Residential-Steam-Boiler-Controls.htm.

- The flame safeguard control monitors the burner for proper operation and shuts off the fuel supply if a flame is not detected in the burner.[p]

Draft

Draft types include natural and mechanical draft, as well as a unique type periodic or intermittent forced draft achieved by pulse combustion. A natural draft boiler is designed to work with a negative pressure in the firebox and flue connection, where the pressure difference is developed by the buoyancy of hot gases in the chimney. A mechanical draft boiler has either a forced draft or induced draft blower. A forced draft boiler uses a blower upstream of the combustion chamber, and the fan is located at the inlet of the burner and pushes air through the burner, thereby ensuring that adequate air is delivered to the combustion process.[q] The blower pulls air from the boiler room or may be connected to a duct system which pulls in outside air, then delivers air to the combustion chamber at a positive pressure above atmospheric pressure. An induced draft boiler uses a blower located at the outlet side of the boiler heat exchanger to pull flue gases out of the boiler due to a negative pressure in the combustion chamber, thereby causing air flow into the inlet of the boiler.

3.3.2 Technology Options that Improve Combustion Efficiency and/or Thermal Efficiency

DOE identified technology options by reviewing CPB manufacturer specification sheets and equipment literature, recent trade publications, technical journals, and patent filings. DOE also consulted with manufacturers during interviews about these technology options. At this time, DOE is aware of a set of technology options (discussed in further detail below) that could be used to improve CPB thermal efficiency and/or combustion efficiency. Technology options that are applicable only to equipment subject to a thermal efficiency standard are noted. The following list includes technologies that would improve the rated efficiency:

1) Jacket Insulation
2) Heat Exchanger Improvements (Including Condensing Heat Exchanger)
3) Burner Derating
4) Improved Burner Technology
5) Combustion Air Preheaters
6) Economizers
7) Blowdown waste heat recovery
8) Oxygen Trim Systems
9) Integrated, High-Efficiency Steam Boilers

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[p] See www.osha.gov/dte/grant.../fy07/sh.../mod_7_boiler_safety2.pptx.

[q] DOE's *Improving Steam System Performance: A Sourcebook for Industry. 2012*. Available at http://www1.eere.energy.gov/manufacturing/tech_assistance/pdfs/steamsourcebook.pdf.

Jacket Insulation

Outside surfaces of boiler tank/pressure vessel are usually covered with insulation to reduce heat losses through the boiler jacket. At many times however, thermal insulation may either be under applied or over applied. Both cases lead to increased thermal losses in form of convection and radiation. To mitigate this problem, thermal insulation optimization techniques can be utilized to improve insulation performance.

Unnecessarily thick insulation leads to increase in surface area, which would subsequently lead to increased losses. Too thin an insulation reduces overall thermal resistance which also leads to significant radiation and convection losses. The optimum insulation thickness for a simple cylinder depends on the outside heat transfer coefficient and the thermal conductivity of the insulation material. The outside heat transfer coefficient for natural convection can be calculated using empirical equations available in literature. Using such simple techniques, overall performance of boilers may be improved significantly.

Heat Exchanger Improvements (Including Condensing Heat Exchanger)

At most operating temperatures, condensing commercial packaged boilers operate at higher efficiencies than non-condensing commercial packaged boilers by capturing latent heat resulting from the phase change of water vapor in combustion gases. The level of efficiency gain by condensing boilers, compared to non-condensing designs, is usually greater at low distribution system operating temperatures, when non-condensing boilers sometimes use supply/return water mixing valves to maintain boiler temperatures that are high enough to prevent condensation and possible related corrosion.

Improvements to the heat exchanger can be achieved by modifying baseline designs of standard boilers. A number of design modifications can be implemented which may increase thermal and/or combustion efficiencies. Some of these are listed below:

1) Increase heat exchanger surface area.
2) Modify or add heat exchanger surface features.
3) Modify or add heat exchanger baffles and turbulators.
4) Increase the corrosion resistance of the primary heat exchanger or use a corrosion-resistant secondary heat exchanger to withstand flue gas condensation.
5) Use pulse combustion for condensing boiler systems.

DOE notes that increasing the heat exchanger surface area may bring about insignificant improvements in thermal efficiency. Through manufacturer interviews, DOE estimates that a 10-percent increase in surface area would result in a 1- to 2-percent increase in thermal efficiency.

An alternative way to increase heat transfer surface area is to add surface features, such as fins. Many commercial boilers made from copper, use compact fin-tube heat exchangers. Cast Iron boilers also have pin fins on the water and/or air side of the heat exchanger. Though these features considerably improve performance, there may still be a possibility for improvement with regard to fin geometry and design.

Many studies have been carried out for different fin designs for fin-tube heat exchangers. One such study compared the air side performance of plate (straight), wavy and louvered fins on a fin-tube heat exchanger. Results indicate that for a fixed fan power and capacity, 40 percent lower surface area would be required while using a louvered fin heat exchanger as compared to a plate fin-tube heat exchanger.[9] The study also compared heat transfer coefficient for heat exchangers having same fin density for all three types of fins and results show superior performance of louvered fin over wavy and plate fins.[9] Similar studies prove that there exists an opportunity to improve conventional heat exchanger design by using wavy fins and louvered fins over straight fins.[10] Figure 3.3.1 shows a type of louvered fin used in cross-flow heat exchangers.

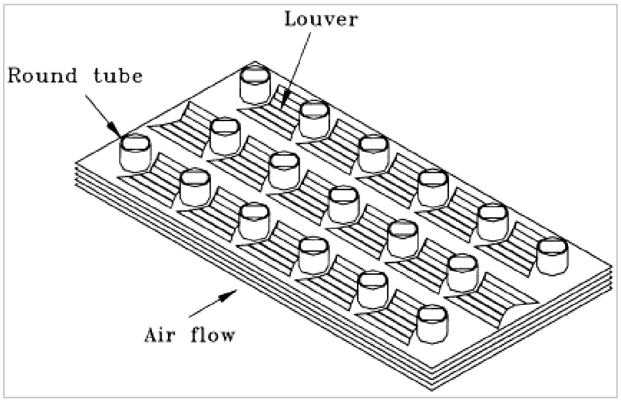

Figure 3.3.1 Fin-Tube Heat Exchanger with Louvered Fins10

Another method to improve heat exchanger performance is the use of turbulators to increase convective heat transfer. Turbulators are used to impart turbulence in the flow of flue gases or water. Turbulent heat transfer generally delivers higher thermal transport as compared to laminar flow heat transfer. This is because turbulent flow causes shearing of thermal boundary layers which are formed when a fluid transfers heat with a surface. In these boundary layers, viscous forces dominate leading to conductive heat transfer and high thermal resistance. With introduction of turbulence, these layers get disturbed and heat transfer becomes dominated by convective forces. This allows greater amount of heat to be transferred.

This effect also occurs when hot flue gases flow through a fire tube boiler. By introducing turbulators, flue gases can easily be converted into turbulent regime. Interviews with manufacturers suggest that almost 1- to 2-percent incremental efficiency can be obtained by adding turbulators inside fire tubes. Some typical turbulators that can be used include twisted tape, conical rings, wire coils, swirl flow generators, *etc.*[11] Internal ribs may also provide improvement in heat transfer by allowing the gases to remain in turbulent flow throughout the tube.[12]

For water tube boilers alternative tube designs, such as corrugated tubes with or without internal rifling, show considerable promise. One extensive study suggests considerable heat transfer enhancement for different geometries of spirally corrugated tubes as compared to smooth circular tubes.[13] In addition, considerable advancement in tube design has occurred over the past few years. A new addition which has come about with advancement of manufacturing techniques is the evolution of microfin surface tubes for boiling and condensation.[14] Depending on wetting capabilities, microfin tubes allow formation of a thin film on the surface of the tubes and therefore provide a substantial increase in heat transfer coefficient.

Internal rifling of water tubes corrugation is another approach that can be used to improve convective heat transfer.[13,14] Similar to turbulators, rifling allows the fluid to approach turbulent regime by providing a circumferential velocity component to the flow. Viscous layers near the surface also get disturbed due to this centrifugal motion, and this increases heat transfer near the surface.

In addition to all of the aforementioned options, switching from natural draft systems to mechanical draft systems can also be implemented. In natural draft systems, movement of air through the boiler is driven by buoyancy of flue gases. Mechanical draft systems allow forced convection dominated heat transfer where a pressure differential is maintained across the boiler (by a blower or fan) in order to allow flow of flue gases. The velocity of flue gases passing through fire tubes or over the heat exchanging surface determines the heat transfer coefficient.

Improving the heat exchanger for a boiler can improve the effectiveness of heat transfer from the hot combustion gases to the water that is distributed to the heated space. The improved effectiveness of the heat exchanger can increase combustion and thermal efficiency. High pressure-drop heat exchangers can also serve to reduce off-cycle draft losses by restricting the flow of air through the heat exchanger, and subsequent loss of heat, when the burner is not operating.

DOE also considered pulse combustion as an approach to develop a condensing boiler. Pulse combustion burners operate on self-sustaining, resonating pressure waves that alternately depressurize the combustion chamber (drawing a fresh fuel-air mixture into the chamber) and pressurize it (through heating and expansion of the fuel/air mixture during combustion). Pulse combustion systems feature high heat transfer rates, and can achieve higher efficiency levels than conventional boiler designs.

Burner Derating

Burner derating is the operation of a boiler at a reduced firing rate. Reducing burner firing rate for gas and oil boilers while keeping heat exchanger geometry, the surface area, and the fuel-to-air ratio the same, will increase the ratio of heat transfer surface area to energy input, thereby increasing the efficiency of the boiler. However, depending on the degree of reduction, a lower energy input means that less heat will be produced, and, thus, lower utility may be provided than with conventional burner firing rates.

Improved Burner Technology

Premix Burners

Premixing fuel gas and combustion air prior to arrival at the flame results in more complete combustion using lower levels of excess air. The lower levels of excess air not only reduce the amount of fuel required to heat the combustion air but also raise the temperature of the gases entering the heat exchanger, which enhances heat exchange and improves efficiency. Lower levels of excess air also raise the water vapor dew point, which facilitates condensation and the recovery of latent heat and improves efficiency when the unit is operating in condensing mode.

Low-Pressure, Air-Atomized Oil Burner

Fuel input rate is controlled by the size of the nozzle orifice. Pressure-atomizing nozzles that are designed for low firing rates suffer rapid fouling of the small internal passages, leading to inadequate spray patterns and poor combustion performance. To overcome the low input limitations of conventional oil burners, Brookhaven National Laboratory developed a low-pressure, air-atomized oil burner.[r] In addition, it can operate with low levels of excess combustion air for lean-burning, ultra-clean combustion. A lower level of excess air generally improves combustion efficiency.

Combustion Air Preheaters

Combustion air preheaters (also known as recuperators) are air-to-air heat exchangers that transfer energy from the flue gases back into the system. However, instead of transferring the energy into the feed water as is done with an economizer, the energy is transferred to increase the temperature of the incoming combustion air, thereby potentially resulting in improved efficiency.

The gas-gas heat transfer for such systems can be achieved using a fin-tube – cross-flow heat exchanger. Modifications such as improved fin-tube designs and fin configuration would provide additional benefit.

Economizers

Economizers may allow for an increase in boiler thermal efficiency[s] by transferring excess flue gas heat into incoming feed water.[t] Economizers are usually air-to-water heat exchangers. There are non-condensing and condensing economizers available on the market. Condensing economizers are designed to allow condensation of the exhaust gas.

Blowdown Waste Heat Recovery

In large steam commercial boilers, salt and sediment residue gets left out in the water stored in the boiler. These dissolved solids also known as TDS (total dissolved solids) are removed from the boiler in a process known as blowdown. Depending on size of boiler, blowdown can be a continuous, periodic, or maintenance time process. In either case, stored heat energy in blowdown water, which would otherwise be wasted away in a drain, can be utilized to preheat incoming water. This blowdown process may require a separator (available on the

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[r] See www.osti.gov/bridge/servlets/purl/248539-wWbYod/webviewable/248539.pdf.

[s] Note that economizers would only show an increase in thermal efficiency if they are an integral component of the boiler.

[t] See https://www1.eere.energy.gov/manufacturing/tech_deployment/pdfs/steamsourcebook.pdf.

market) which separates water from steam. By integrating this technology, there is potential to reduce fuel requirement to achieve desired water temperature. This technique may also marginally increase efficiency levels as the stored heat derived from combustion gases is utilized to a greater extent.

Oxygen Trim Systems

An oxygen "trim" system provides feedback to the burner controls to automatically minimize excess combustion and optimize the air-to-fuel ratio. Such a system is useful when fuel consumption or steam flows are highly variable, thus an on-line oxygen analyzer should be considered. The oxygen trim system increases energy efficiency by 1 to 2%. Furthermore, for very large boilers, efficiency gains of even 0.1% can result in significant annual savings. Basically, every 1% decrease in excess O_2 from the stack, results in 0.5% increase in thermal efficiency.[u]

Integrated, High-Efficiency Steam Boilers

Certain manufacturers have developed integrated, high-efficiency steam boilers that combine multiple design features to increase fuel-to-steam efficiency. Such features can include enhanced heat transfer surfaces (*e.g.*, spiral fire tubes), as well as feed water economizers and high-turndown modulating burners capable of maintaining low levels of excess combustion air. Cleaver-Brooks, in partnership with DOE and the Gas Technology Institute (GTI), developed the first integrated, high-efficiency steam boilers called a "Super Boiler."[v]

DOE notes that the integrated high-efficiency steam boiler concept is essentially a combination of several different technology options integrated into a commercial boiler equipment. It does not refer to any particular technology option that can be applied to commercial packaged boilers to improve efficiency. As a result, DOE has decided not to consider the concept as a potential technology option. DOE has presented the concept here purely for information purposes.

3.3.3 Technology Options to Reduce Seasonal Boiler Energy Consumption

DOE is aware of a number of boiler technologies exist that reduce overall fuel consumption by improving the average seasonal efficiency, including the following technologies:

1) Modulating Burners
2) Electronic Ignition
3) Dampers

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[u] More information is available online at http://www1.eere.energy.gov/manufacturing/tech_assistance/pdfs/steam4_boiler_efficiency.pdf.

[v] See http://www1.eere.energy.gov/manufacturing/tech_assistance/pdfs/how_superboiler_works.pdf for further information.

4) Temperature Reset Controls
5) Thermal Post-Purge Controls
6) Delayed-Action Oil Pump Solenoid Valve
7) Upgraded Fan Controls

Modulating Burners

Two-stage and modulating burners can decrease losses caused by burner cycling at partial loads. However, modulating burners may not accomplish net energy efficiency gains if excess combustion air levels must be increased at low firing rates (in order to maintain combustion performance) or if electrical power requirements for the burner do not decrease in linear proportion to the firing rate. In condensing boiler applications, an increase in excess combustion air ratio can result in reduced latent heat recovery due to decreased flue gas dew point temperatures. This can result in an energy loss that outweighs the benefit of reduced burner cycling.

Electronic Ignition

Boilers can be equipped with electronic ignition systems, which ignite burners on demand using electrical components.

There are different types of electronic ignition systems, including the following:

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

2) Direct Spark Ignition (DSI): DSI ignites the main burner directly by generating a spark.

3) Interrupted Duty Ignition Systems: All modern oil burners have a type of electronic ignition called an interrupted duty ignition. A step-up transformer supplies power to two electrodes, which causes a spark to jump. The interrupted duty ignition system for an oil burner activates the spark until either a steady flame is established or the end of the trial-for-ignition (TFI) period.[w]

4) Hot Surface Ignition: The igniter in this system is an electrically heated resistance element that thermally ignites the main burner directly without the use of a pilot light.

Unlike standing pilot ignition systems that consume fuel continuously, electronic devices and their control modules operate only during the active mode, which improves efficiency. Solid-state electronic ignition components can also achieve electricity savings compared to older, iron-core transformer technologies.

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[w] "Trial for ignition" is the period during which the burner is attempting to ignite the fuel it is delivering to the nozzle.

Dampers

Off-cycle (which refers to the burner off-cycle) dampers restrict the intake and exhaust air flow through the venting system during standby mode by closing when the burner is not operating, thereby trapping residual heat in the heat exchanger. During the burner off-cycle, the boiler loses heat by natural convection and conduction through the combustion air inlet and flue. Installing a damper at these points improves efficiency by preventing heat from escaping and minimizing off-cycle heat losses.

Temperature Reset Controls

Temperature reset controls monitor outside air temperature or burner operating hours (BOH) to estimate the required heating load, which can vary as a function of outdoor temperature, solar and wind conditions, internal heat gain, or thermostat setback/recovery. The hydronic water supply temperature is then modulated up or down to enable the thermal distribution capacity to match the actual heating demand.[x]

Thermal Post-Purge Controls

Thermal post-purge controls allow the hydronic circulating pump to continue operation after the termination of a thermostat demand for heat. The circulation pump continues to operate after the shutdown of the burner until the boiler temperature drops down to a programmed level that depends on type of boiler and fuel. The thermal post-purge concept functions most effectively when the control anticipates the end of the heating demand and shuts off the burner early enough so that the residual heat transferred during the post-purge cycle just satisfies the temperature requirement of the building. Substantial benefits are achieved by reduced boiler temperature during standby mode/off mode through reduced jacket and draft heat losses.

Delayed-Action Oil Pump Solenoid Valve

A delayed-action oil pump solenoid valve is installed between the oil pump and the burner nozzle to supplement the fuel pump regulator. It does so by delaying the fuel release by 3 to 6 seconds after the igniter and burner blower start until the oil pressure reaches the level required to fully discharge the oil into the combustion chamber without dripping. This ensures that the oil burns more completely, which improves efficiency since heat exchangers will suffer less fouling.

Upgraded Fan Controls

In response to boiler load, Variable-Frequency Drives (VFDs) adjust and control fan speed. As a result, upgrading to VFD fan controls can help improve boiler efficiency. The standard constant-speed fan airflow is matched to the boiler load by opening and closing of a

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[x] *ASHRAE Handbook – HVAC Systems and Equipment*. 2008. Available at https://www.ashrae.org/resources--publications/handbook.

damper so horsepower stays relatively constant, regardless of the load. For instance, with VFDs, if a fan operates at 75% of maximum operating speed, the required horsepower would only be 40% of full load compared to a constant-speed fan. Additionally, VFDs can increase the service life of the fan motor, decrease maintenance costs and significantly reduce noise levels.[y]

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[y] More information available at www.metroservicesinc.com/Press%20Releases%20and%20Application%20Histories/Improve%20Gas%20Fired%20Boiler%20Efficiency.pdf.

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CHAPTER 4. SCREENING ANALYSIS

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4.1 INTRODUCTION

This chapter discusses the screening analysis conducted by the U.S. Department of Energy (DOE) of the technology options identified in the market and technology assessment for commercial packaged boilers (CPBs). In chapter 3, the market and technology assessment, DOE presented an initial list of technology options that can be used to improve the energy efficiency of commercial packaged boilers. The goal of the screening analysis is to identify any technology options that will be eliminated from further consideration in the rulemaking analyses.

The candidate technology options are assessed based on DOE's analysis, as well as inputs from interested parties including manufacturers, trade associations, and energy efficiency advocates. Technology options that are judged to be viable approaches for improving energy efficiency are retained as inputs to the subsequent engineering analysis. Technology options that are not yet incorporated in commercial equipment or working prototypes are removed from consideration in chapter 3 of this TSD. Some of the technologies identified during the technology assessment can improve the efficiency of a commercial packaged boiler operating under different operating conditions but may not improve the thermal and/or combustion efficiency of a commercial packaged boiler as measured by the current test procedure prescribed under 10 CFR 431.86. Such technologies are not passed on to the engineering analysis for consideration because they would not be implemented as a result of more stringent energy conservation standards.

The technologies identified in the market and technology assessment were evaluated pursuant to the criteria set out in the Energy Policy and Conservation Act, as amended (EPCA). (42 U.S.C. 6291-6317) EPCA provides criteria for prescribing new or amended standards that will achieve the maximum improvement in energy efficiency the Secretary of Energy determines to be technologically feasible. (42 U.S.C. 6313(a)(6)(A)(ii)(II)) It also establishes guidelines for determining whether a standard is economically justified. (42 U.S.C. 6313(a)(6)(B)(ii)) In view of the requirements under EPCA for determining whether a standard is technologically feasible and economically justified, section 5 of appendix A to subpart C of 10 CFR Part 430, sets forth procedures to guide DOE in the consideration and promulgation of new or revised residential product and commercial and industrial equipment efficiency standards under EPCA. These procedures elaborate on the statutory criteria provided in EPCA and, in part, eliminate problematic technologies early in the process of revising an energy efficiency standard. Under the guidelines, DOE eliminates from consideration technologies that present unacceptable problems with respect to the following four factors. These factors are described in section 4(a)(4)(i–iv) of appendix A to subpart C of 10 CFR 43:

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

2) <u>Practicability to manufacture, install, and service</u>. 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 product to significant subgroups of consumers, or would result in the unavailability of any covered product type with performance characteristics (including reliability), features, sizes, capacities, and volumes that are substantially the same as products 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 summary, if DOE determines that a technology, or a combination of technologies, has unacceptable impacts based on the factors discussed earlier, then, 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. Further, certain technology options may be removed from consideration if DOE determines that (1) they do not impact the efficiency metric as measured by the current test procedure; (2) they are already found in baseline units; or (3) there is insufficient information documenting the efficiency benefits of the technology in commercial packaged boilers.

4.2 SCREENED-OUT TECHNOLOGIES

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 one technology for failure to meet one of these criteria.

4.2.1 Burner Derating

Decreasing the burner size to increase the ratio of heat transfer area to fuel input, or burner derating, can increase the thermal efficiency rating of commercial gas and oil-fired boilers. However, because heat output rate is directly related to burner size, derating also reduces the amount of heated water or steam available to the customer for space heating. This reduction in heat output adversely affects the utility to consumers. Therefore, DOE did not consider this technology option further in the rulemaking analyses.

4.3 TECHNOLOGIES THAT HAVE NEGLIGIBLE OR NO IMPACT ON THERMAL OR COMBUSTION EFFICIENCY

DOE further refined the list of technology options considered in the successive analyses stages by removing several technology options for which implementation would have minimal or no effect on thermal or combustion efficiency as measured by the DOE test procedure. Thus, DOE believes these technologies are unlikely to be implemented in response to changes to the DOE energy conservation standards. Although these options may not significantly improve the rated efficiency of commercial packaged boilers and are not included in the engineering analysis, DOE does not discourage their use by manufacturers because of their potential to reduce energy consumption and increase efficiency. For each technology removed, DOE has provided an explanation of why the technology does not affect thermal and/or combustion efficiency.

4.3.1 Combustion Preheaters

Combustion preheaters capture heat from flue gases to preheat incoming combustion air. Although combustion preheaters effectively raise the operating efficiency of the boiler in the field, this efficiency is not measured by the test procedure, because the test procedure requires that the inlet air be within ±5 °F of the room ambient temperature. Therefore, DOE did not consider this technology option further in its analysis.

4.3.2 Economizers

An economizer is a device that can be installed on a boiler to save energy by preheating supply water with boiler exhaust gases. Although economizers utilize otherwise wasted heat, and may improve the overall efficiency of the boiler, they have no impact on the thermal efficiency as measured by the DOE test procedure because the test procedure requires the inlet water to have a set temperature. Therefore, DOE did not consider economizers as a technology option for improving CPB efficiency ratings.

4.3.3 Blow-down Waste Heat Recovery

In large steam commercial boilers, salt and sediment residue gets left out in the water stored in the boiler. These dissolved solids are known as total dissolved solids and are removed from the boiler in a process known as blow-down. Depending on size of boiler, blow-down can either be a continuous, periodic, or a maintenance process. In any case, stored heat energy in blow-down water, which would otherwise be wasted away in a drain, can be utilized to preheat incoming water. This blow-down process may require a separator that separates water from steam. By integrating this technology, there is potential to reduce the fuel requirement to achieve the desired water temperature. This technique also may marginally increase efficiency levels as the stored heat derived from combustion gases is utilized to a greater extent.

The DOE test procedure is performed in a laboratory setting on boilers that have not previously been commissioned for service in a building. Therefore, sediment, dissolved solids, and other deposits will not be present in the boiler. As a result, blow-down procedures will not be required, and blow-down is not captured in the current test procedure. Thus, an increase in efficiency from blow-down waste heat recovery would not be measured, and accordingly this technology was not considered further in the analysis.

4.3.4 Jacket Insulation

For any equipment that is insulated to prevent energy loss, there exists a relationship between the overall increase in diameter (or external geometry) due to insulation thickness and the thermal resistance (depending on the thermal conductivity of the insulating material). The optimization of insulation thickness presents an opportunity to apply insulation of only the required amount and that is sufficient to prevent considerable heat loss.

From a review of literature and manufacturer interviews, DOE notes that a blanket from 2 to 3 inches of insulation is typically used on many CPB models. Although there exists an opportunity to optimize the insulation, based on a review of product literature, DOE believes the potential gain in efficiency (combustion or thermal) is negligible.

4.4 TECHNOLOGY OPTIONS FOUND IN BASELINE UNITS

After eliminating those technologies that do not increase thermal efficiency and screening out those technologies that do not meet the requirements of 10 CFR 430, subpart C, appendix A, section 4(a)(4)(i-iv), DOE identified the technologies that are already commonly found in baseline commercial packaged boilers as listed in Table 4.4.1. Although DOE did not consider these technologies as options for improving the efficiency in comparison to the baseline, the costs of these components was captured in the engineering analysis at the baseline efficiency level. For certain components, DOE lists multiple technologies if there is more than one type of component commonly found in baseline equipment.

Table 4.4.1 Technologies Found in Common Baseline CPB Designs

Gas Valve: Single Stage, Two Stage, or Modulating
Primary Heat Exchanger: Cast Iron Sectional; Water Tube; Copper Fin-Tube
Draft Type: Natural or Atmospheric draft systems with draft hood and vent dampers
Jacket Insulation

4.5 REMAINING TECHNOLOGY OPTIONS

After eliminating all the technology options by the methods described above, DOE considered the following technologies for the downstream analysis:

- adopt condensing operation (either through inclusion of a secondary heat exchanger or by using pulse combustion)
- increased primary heat exchanger surface area
- incorporation of heat exchanger surface features (such as dimples) and internal features (such as baffles, turbulators, micro-fins, corrugation, or rifling) with the purpose of inducing turbulent flow on either the air or water side of the heat exchanger
- flat, wavy or louvered tube heat exchanger with or without staggered fin configuration
- premix burners, Low pressure, air atomized oil burner
- oxygen trim systems

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CHAPTER 5. ENGINEERING ANALYSIS

5.1 INTRODUCTION

The engineering analysis establishes the relationship between equipment prices and the energy-efficiency of commercial packaged boilers (CPBs). The price-efficiency relationship serves as a basis for subsequent cost/benefit calculations for individual customers, manufacturers, and the Nation.[a]

To determine the industry price-efficiency relationship, the U.S. Department of Energy (DOE) uses data from the market and technology assessment (chapter 3), publicly available equipment literature and research reports, and price information from manufacturers, distributors/wholesalers, and installers. DOE also conducts manufacturer interviews to gather additional information directly from manufacturers. In conducting the analysis described in this chapter, DOE received bulk of the CPB price data in the form of manufacturer's price books containing list pricing, along with typical discount percentages that are applied by manufacturers when selling their equipment. DOE uses list pricing and the discount percentages to calculate the expected actual manufacturer selling price (MSP) of each equipment to conduct the analysis.

In the market assessment described in chapter 3, DOE compiled a database of commercial packaged boilers available in the market, most of which are offered by member manufacturers of either the Air-Conditioning, Heating, and Refrigeration Institute (AHRI) or the American Boiler Manufacturers Association (ABMA).[b] In this chapter, DOE often refers to this as the equipment database. DOE used the equipment database in the engineering analysis to develop market-weighted averages of the incremental MSPs for higher efficiency levels.

Generally, the methodology for the engineering analysis involves calculating CPB prices for a representative fuel input rate for each manufacturer at an efficiency level higher than the minimum allowable standard (baseline efficiency). The primary output of the analysis is a set of price-efficiency relationships that represent an industry average change in MSP with higher efficiency equipment (incremental price). In the subsequent markups analysis (chapter 6 of the notice of proposed rulemaking (NOPR) Technical Support Document (TSD)), DOE determines customer prices by applying the distribution chain markups and sales tax to the MSP that is calculated in the engineering analysis. After applying these markups, the price estimates serve as an input to the life-cycle cost (LCC) and payback period (PBP) analyses (chapter 8 of the NOPR TSD).

In this chapter, DOE discusses: (1) equipment classes that are analyzed, (2) identification of baseline, intermediate, and maximum technologically possible efficiency levels, (3) methodology for calculating incremental prices for each equipment class, for efficiency levels higher than baseline, and (4) results of the analysis.

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[a] The term 'cost' refers to the manufacturing cost, while the term 'price' refers to the manufacturer selling price. In some of the engineering analysis approaches DOE calculates the manufacturing cost which is multiplied by the appropriate markups to get the manufacturer selling price.

[b] Database includes efficiency ratings, fuel input rate, fuel used, heating medium, etc. For more information see chapter 3 of this NOPR TSD.

5.2 EQUIPMENT CLASSES

Existing energy conservation standards, set forth in subpart E of title 10 of the Code of Federal Regulations (CFR), part 431 (10 CFR 431.87), classify commercial packaged boilers into ten equipment classes. The boilers are classified based on three performance parameters: (1) fuel input rate[c] (small (≥300 kBtu/h to ≤2500 kBtu/h) or large (>2500 kBtu/h)), (2) fuel type (gas or oil), and (3) heating media (hot water or steam). The small and large gas fired steam equipment classes are further divided by draft type (i.e., natural draft and all except natural draft), resulting in 10 total equipment classes.

As discussed in chapter 3 of this TSD, DOE did not find any technical justification to maintain separate equipment classes for mechanical and natural draft boilers. DOE has tentatively determined that natural draft commercial packaged boilers do not have any special or distinct performance related utility that is different from mechanical draft commercial packaged boilers that justifies separation of equipment classes. Consequently, DOE has proposed to discontinue the disaggregation of equipment classes by draft type.

In chapter 3 of this TSD, DOE also discusses the classification of very large commercial packaged boilers (*i.e.*, commercial packaged boilers with fuel input rates >10,000 kBtu/h). DOE has tentatively decided to have separate equipment classes for commercial packaged boilers with fuel input rates greater than 10,000 kBtu/h. DOE made extensive efforts to gather information such as equipment prices, models offered, and annual shipments to analyze commercial packaged boilers with fuel input rates greater than 10,000 kBtu/h; however, DOE was not able to gather sufficient information to establish clear and convincing evidence that more stringent standards would be justified for very large commercial packaged boilers. Consequently, DOE has proposed to maintain the existing standards at current levels for very large commercial packaged boilers with fuel input rates greater than 10,000 kBtu/h.

Table 5.2.1 shows the equipment classes for which DOE was able to collect sufficient data to establish the price-efficiency relationship. This table includes all of the proposed CPB equipment classes except for the “very large” classes with fuel input rates greater than 10,000 kBtu/h.

Table 5.2.1 Commercial Packaged Boiler Equipment Classes with Sufficient Data to Estimate the Price-Efficiency Relationship

Equipment Class	Input Ratings	Equipment Class Acronym
Small Gas Hot Water	≥ 300 kBtu/h and ≤ 2,500 kBtu/h	SGHW
Large Gas Hot Water	>2,500 kBtu/h and ≤ 10,000 kBtu/h	LGHW
Small Oil Hot Water	≥ 300 kBtu/h and ≤ 2,500 kBtu/h	SOHW
Large Oil Hot Water	>2,500 kBtu/h and ≤ 10,000 kBtu/h	LOHW
Small Gas Steam	≥ 300 kBtu/h and ≤ 2,500 kBtu/h	SGST
Large Gas Steam	>2,500 kBtu/h and ≤ 10,000 kBtu/h	LGST

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[c] In this NOPR TSD, DOE uses “fuel input rate,” to refer to the maximum rate at which a commercial packaged boiler uses energy, in order to be consistent with Test Procedure definition and language. The industry also uses terms such as input capacity, input ratings, capacity, and rating, and any such instances should be considered synonymous with fuel input rate.

Equipment Class	Input Ratings	Equipment Class Acronym
Small Oil Steam	≥ 300 kBtu/h and ≤ 2,500 kBtu/h	SOST
Large Oil Steam	>2,500 kBtu/h and ≤ 10,000 kBtu/h	LOST

5.2.1 Representative Fuel Input Rates

When DOE conducts its analysis, it generates a single set of price-efficiency results for each equipment class that are passed on as inputs for the downstream analyses. These results are calculated at a fixed fuel input rate that is representative of each equipment class and, therefore, is known as 'representative fuel input rate.' The representative fuel input rate usually aligns with the fuel input rate that accounts for the highest number of shipments in any given year. Using a representative fuel input rate allows DOE to analyze certain equipment characteristics as proxy for that equipment class.

In this chapter, DOE used 800 kBtu/h as the representative fuel input rate for all small CPB equipment classes (≥300 kBtu/h to ≤2,500 kBtu) and 3,000 kBtu/h for large CPB equipment classes (>2,500 kBtu/h and ≤ 10,000 kBtu/h). DOE chose these representative fuel input rates by taking into account a number of sources, such as previous rulemaking analyses, information obtained during manufacturer interviews, information collected for the market and technology assessment, equipment product literature, and discussions with industry experts.

5.3 EFFICIENCY LEVELS ANALYZED

5.3.1 Baseline Efficiency Levels

DOE uses baseline efficiency levels as a reference point for each equipment class, against which DOE calculates potential changes in MSP and energy use that could result from an amended energy conservation standard. The energy conservation standards for commercial packaged boilers, set forth in 10 CFR 431.87, represent the minimum efficiency that such equipment must have to be distributed in commerce in the U.S.

For commercial packaged boilers, the existing Federal energy conservation standards serve as the basis or reference point from which to calculate the incremental price change to achieve a higher efficiency level, and are used as baseline efficiency levels. DOE uses the term baseline unit or baseline model to describe a commercial packaged boiler that meets, but does not exceed, the required energy conservation standard, and that provides basic consumer utility.

As part of its analyses, DOE also conducts a review of common boiler technology features present in baseline models and compares them with technology features of higher efficiency models. This helps DOE validate incremental prices for higher efficiency models based on the differences in technologies from the baseline model.

DOE uses the baseline efficiency level for comparison in the engineering analysis and also in the downstream analyses, including the LCC analysis, PBP analysis, and national impacts analysis (NIA). To determine energy savings that will result from an amended energy conservation standard, DOE compares energy use at each of the higher energy efficiency levels to the energy use of the baseline model. Similarly, to determine the changes in price to the customer that will result from an amended energy conservation standard, DOE compares the price of a baseline model to the price of a model at each higher efficiency level. Table 5.3.1 includes the baseline efficiency levels.

5.3.2 Max-Tech Efficiency Levels

As part of its engineering analysis, DOE determined the maximum technologically feasible ("max-tech") improvement in energy efficiency for commercial packaged boilers as required under section 342 of EPCA. (42 U.S.C. 6313(a)(6)(A)(ii)(II)) For identifying the max-tech efficiency levels, DOE explored the equipment database and technical literature, and identified max tech efficiency levels for each equipment class. Table 5.3.1 includes the max-tech efficiency level identified for each equipment class analyzed.

5.3.3 Intermediate Efficiency Levels

In the engineering analysis, DOE generally identifies, for each equipment class, several efficiency levels between the baseline efficiency level and max-tech efficiency level. The efficiency levels typically represent the most common efficiencies available on the market or a major design change (*e.g.*, switching to a condensing heat exchanger). DOE identifies several efficiency levels for each equipment class based on an extensive review of publicly available CPB equipment literature and the equipment database.

For hot water equipment classes, DOE considered the option of inserting a low condensing efficiency level such that it serves as an entry point to the higher condensing efficiency levels within the four hot water CPB equipment classes. For the small and large gas-fired hot water equipment classes, DOE selected a thermal efficiency (TE) of 93% and a combustion efficiency (CE) of 94% respectively, as low condensing efficiency levels because the equipment database has several CPB models at these efficiency levels. For the oil-fired CPB equipment classes, DOE did not find any CPB models in the equipment database with efficiency below 96%. Consequently, DOE would be unable to obtain CPB prices at these efficiency levels. Moreover, DOE is also aware of the significant challenges associated with designing and operating oil-fired condensing boilers. Therefore, in this analysis DOE did not analyze low condensing efficiency levels for oil-fired hot water CPB equipment classes.

Table 5.3.1 below shows the baseline, intermediate, and max-tech efficiency levels that DOE analyzed in this chapter.

Table 5.3.1 Baseline, Intermediate, and Max-Tech Efficiency Levels Analyzed

Equipment Class	Efficiency [%]*	Efficiency Level Identifier
Small Gas Hot Water	80	EL - 0 Baseline
	81	EL - 1
	82	EL - 2
	84	EL - 3
	85	EL - 4
	93	EL - 5
	95	EL - 6
	99	EL -7 Max Tech

Equipment Class	Efficiency [%]*	Efficiency Level Identifier
Large Gas Hot Water	82	EL - 0 Baseline
	83	EL - 1
	84	EL - 2
	85	EL - 3
	94	EL - 4
	97	EL - 5 Max Tech
Small Oil Hot Water	82	EL - 0 Baseline
	83	EL - 1
	84	EL - 2
	85	EL - 3
	87	EL - 4
	88	EL - 5
	97	EL - 6 Max Tech
Large Oil Hot Water	84	EL - 0 Baseline
	86	EL - 1
	88	EL - 2
	89	EL - 3
	97	EL - 4 Max Tech
Small Gas Steam	77	EL - 0 Baseline
	78	EL - 1
	79	EL - 2
	80	EL - 3
	81	EL - 4
	83	EL - 5 Max Tech
Large Gas Steam	77	EL - 0 Baseline
	78	EL - 1
	79	EL - 2
	80	EL - 3
	81	EL - 4
	82	EL - 5
	84	EL - 6 Max Tech
Small Oil Steam	81	EL - 0 Baseline
	83	EL - 1
	84	EL - 2
	86	EL - 3 Max Tech
Large Oil Steam	81	EL - 0 Baseline
	83	EL - 1
	85	EL - 2
	87	EL - 3 Max Tech

*Efficiency levels represent thermal efficiency for all equipment classes except for Large Gas Hot Water and Large Oil Hot Water, for which the efficiency levels are in terms of combustion efficiency.

5.4 DATA COLLECTION AND CATEGORIZATION

The first step in conducting the engineering analysis is to collect CPB prices from manufacturers, distributors, and contractors. DOE contacted several contractors and distributors and received CPB prices in the form of manufacturer price books. DOE also received list pricing from certain manufacturers during manufacturer interviews, as well as general feedback on the price of commercial packaged boilers at various efficiency levels in each equipment class. The price books contain listed prices of all CPB models that a manufacturer produces. A distributor or wholesaler is usually the first customer in the CPB distribution chain and receives a discount from the list price when purchasing equipment from the manufacturer. This discount that is applied to the list price typically differs for each manufacturer based on the business relationship between the manufacturer and the customer. While collecting the price books, DOE also received the typical percentages of discounts that the distributors or contractors receive from the manufacturer when purchasing equipment. After obtaining the price books, DOE estimated the actual manufacturer selling price by applying the manufacturer discounts to the trade price listed in the price books. Based on DOE's estimates, manufacturers provide discounts to distributors and wholesalers ranging from 15 percent to 40 percent off of the list price.

DOE also notes that in some price books, manufacturers provide list prices that are broken down by the CPB components and optional technology features. To arrive at the final list price, a contractor assists the customer in choosing the components and features based on the jurisdiction of the installation, customer requirements, and type of commercial installation (*e.g.*, space heating for schools, hospitals, or universities, etc.). For the current analysis, DOE selected the components that need to be assembled in the basic boiler model and ensured that the choice of component and optional features remained consistent for all CPB models. While selecting the prices, DOE also encountered situations where a feature that DOE has consistently selected for all CPB models is not offered for a particular CPB series, or where a particular feature becomes inapplicable for commercial packaged boilers at higher fuel input rates within the same CPB series. In such cases, DOE selected a similar feature that would offer similar functionality. In cases where DOE was able to obtain a trade price of a fully packaged and assembled boiler (with all the required components), DOE selected those list prices directly from the price books. DOE believes this approach helped to minimize the effects of optional auxiliary components on CPB prices.

For this analysis, DOE collected prices for 584 boiler models of different manufacturers. This includes the prices of 326 boiler models that were used in the preliminary TSD. The preliminary analysis prices were collected in 2013, and thus are in 2013$. To obtain prices in terms of 2014$ for analytical consistency, DOE adjusted the preliminary analysis prices to account for inflation. The increase in price to convert from 2013$ to 2014$ was1.014 percent. The list prices that DOE obtained for the NOPR analysis were collected in 2015 and are in 2015$. To adjust these prices to be in terms of 2014$, DOE deflated them by 1.014 percent. For the NOPR analysis, DOE received significant additional price information that allowed DOE to estimate the price-efficiency relationship for all equipment classes (except for "very large" commercial packaged boilers, as discussed in section 5.2). These prices include boilers that are mechanical and natural draft; are made from copper, cast iron, steel, stainless steel, and aluminum; and have fuel input rates ranging from 300 kBtu/h to 9,500 kBtu/h.[d] Consequently, DOE was able to directly conduct the engineering analysis for all equipment classes without needing to use extrapolations, thus, improving the accuracy of the analysis. After calculating the manufacturer selling price for each boiler model for which pricing was obtained, DOE categorized the prices into the eight equipment classes and analyzed each class independently. Table 5.4.1 shows the number of prices DOE used for conducting the engineering analysis for each equipment class:

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[d] In this chapter, DOE presents the incremental price results as a weighted average of the models available on the market. Where sufficient data was available, DOE separated the mechanical and natural draft CPB prices for use in the downstream analyses.

Table 5.4.1 Number of Prices Received for each Equipment Class

Equipment Class	Number of Prices Used in Analysis
SGHW	203
LGHW	52
SHOW	70
LOHW	44
SGST	72
LGST	76
SOST	24
LOST	43
Total	584

5.5 METHODOLOGY

DOE has identified three basic methods for developing price-efficiency curves: (1) the design-option approach, which provides the incremental manufacturing costs of adding design options to a baseline model that will improve its efficiency; (2) the efficiency-level approach, which provides the incremental price of moving to higher efficiency levels without regard to any particular design option; 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 (involving physical teardowns) providing detailed data on costs for parts and material, labor, shipping/packaging, and investment for models that operate at particular efficiency levels.

For this analysis, DOE chose to use the efficiency level approach. Commercial packaged boilers have a variety of heat exchanger and system designs depending on the size, efficiency, fuel used, heating medium, type of draft, and efficiency. The efficiency level approach allowed DOE to collect pricing for a wide variety of CPB designs so that the analysis could capture a variety of different design paths for improving efficiency. This is in contrast to the design-option approach, which would focus on a single design option (or a combination of design options) to achieve an increased efficiency level, and the reverse-engineering approach, which due to practical constraints would require focusing on a small subset of the CPB market.

This section describes in detail the methodology used by DOE for the engineering analysis. In this analysis, DOE used the CPB prices that were collected and the equipment database compiled in the market assessment.

5.5.1 Engineering Analysis

As explained in section 5.4 of this TSD, DOE began the engineering analysis by collecting pricing for commercial packaged boilers and applying the appropriate discounts to list pricing to estimate the manufacturer selling price. Once DOE determined the manufacturer selling price for each boiler model for which the list pricing was obtained, DOE applied the following methodology to determine an industry-average price-efficiency relationship for each equipment class. First, DOE determined the price per fuel input rate for each boiler of that equipment class. Second, DOE determined the weighted average price at each efficiency level based on the fuel input rate frequency distribution for that class. Third, DOE normalized the weighted average price and input at each efficiency level to the price at the representative fuel input rate. Finally, DOE performed a regression analysis to calculate the industry-average MSP at each efficiency level analyzed. These steps were carried out to obtain the price-efficiency curves for each equipment class and are discussed in more detail in the following sections.

5.5.1.1 Determining the Price per Fuel Input Rate

DOE first calculated the ratio of the manufacturer selling price to the fuel input rate for all CPB models for which prices were available. In this chapter, DOE refers to this ratio as the price per input, with units in terms of dollars per kBtu/h. DOE used the price per input instead of the manufacturer selling price for conducting the analysis because the MSPs have strong dependency on CPB fuel input rates. Using the price per input ratio, the fluctuation in price with fuel input rate is significantly lessened, thereby allowing a better comparison of efficiency and price. However, as discussed in later sections, DOE recognizes that the price per input will also vary based on the fuel input rate and accordingly, DOE used the available input and price data to determine the relationship of price per input with fuel input rate and then normalized the results back to the representative fuel input rate.

5.5.1.2 Determining the Weighted Average Price per Fuel Input Rate

In this step, DOE used the equipment database to determine the frequency distribution of fuel input rates of the models available in each equipment class. DOE created fuel input rate bins of 100 kBtu/h size for small (300 kBtu/h to 2,500 kBtu/h) and large (2,500 kBtu/h to 10,000 kBtu/h) equipment classes. DOE then calculated the number of boilers that fall into each fuel input rate bin for each equipment class and used those totals to weight the pricing in the analysis. For example, all commercial packaged boilers with fuel input rate greater than or equal to 450 kBtu/h and less than 549 kBtu/h are counted in the 500 kBtu/h bin. The frequency distribution provides an estimate of the number of CPB models that in the market in each equipment class for the different fuel input rate bins.

After estimating the frequency distribution, DOE assigned weights to each CPB model for which it had pricing based on frequency with which the fuel input rate of that particular model occurs. DOE used the number of boilers that are present in each fuel input rate bin of the frequency distribution table as weights and assigned the appropriate weight to both the price per input and the fuel input rate of the commercial packaged boilers in the price database.

The weight given to each commercial packaged boiler represents the number of commercial packaged boilers with that fuel input rate that are available in the market. Hence, CPB models that have fuel input rates with higher representation in the market are weighted more heavily and have a higher influence on the final results than commercial packaged boilers that have fuel input rates similar to a few models on the market.

For each efficiency that is available in the price database for a given equipment class, DOE calculated the weighted average price per input and the weighted average fuel input rate at that efficiency level.

5.5.1.3 Normalization to Representative Fuel Input Rate

In this step, DOE scaled the weighted average price per input from the weighted average fuel input rate to the representative fuel input rate for each efficiency level. To do this, DOE first created scatter plots of price per input versus fuel input rate for all CPB models in the price database. The scatter plots show that at lower fuel input rates, the price per input is high and decreases rapidly as the fuel input rate increases. As the fuel input rate continues to increase, the rate of decrease in price per input slows, and the scatter plot best resembles a decreasing exponential curve. Therefore, to determine the price per input as a function of input, DOE used the logarithmic equation of the form:

$$Price.per.input = a * \ln(Input.Capacity) + b$$

Where, 'a' and 'b' are constants that are obtained from the non-linear regression.

DOE used this equation to normalize the weighted average price per input to the representative fuel input rate. To do this, DOE substituted the value of the weighted average price per input and weighted average fuel input rate in following equation and obtained the value of b*.

$$b^* = Wtd.Avg.Price.per.input - a * \ln(Wtd.Avg.Input.Capacity)$$

Using 'b*', DOE calculated the weighted average price per input at the representative fuel input rate by using the following equation:

$$Price.per.input_{rep} = a * \ln(Representative.Capacity) + b^*$$

At the end of this step, each efficiency level would have a corresponding price per input that is weighted by fuel input rate based on the equipment database and scaled to the representative fuel input rate. DOE used these price per input values to calculate the final incremental price results.

5.5.1.4 Regression Analysis

After calculating the weighted average price per input at the representative fuel input rate, DOE performed another regression analysis on the weighted average price per input results at the representative fuel input rate and the efficiency levels. The purpose of this regression was to deduce the equation that best represents the industry-average price-efficiency relationship across the range of efficiency levels analyzed. Using this regression equation, DOE calculated the weighted average price per input at representative fuel input rate for all baseline, intermediate, and max-tech efficiency levels for each equipment class.

After obtaining all of the price per inputs at the representative fuel input rate for the efficiency levels that it sought to analyze, DOE multiplied the price per input by the representative fuel input rate to get the final set of MSPs for each efficiency level at the representative fuel input rate. The resulting MSPs are estimates of the industry-average price of a commercial packaged boiler at each efficiency level and at the representative fuel input rate for each equipment class. Lastly, DOE calculated the incremental prices of improving efficiency by subtracting the MSP of the higher efficiency levels from the MSP of the baseline efficiency level.

5.5.2 Supplemental Price Data for Certain Large Equipment Classes

In this NOPR analysis, although DOE had sufficient data to conduct the analysis, DOE decided to supplement some of the large equipment classes with additional prices that would lead to a more robust analysis. There are two reasons for supplementing the analysis of the large equipment classes with additional data. First, DOE had a limited amount of price data for CPB models at certain key efficiency levels (*i.e.*, baseline and max-tech) in some of the large CPB equipment classes. The absence of these prices is mainly due to the low number of CPB models available in the market at the baseline and max-tech efficiency levels. Having accurate price data for baseline and max tech levels is critical because these two levels are on the extreme ends of the price-efficiency curve and the baseline efficiency level serves as a comparison point for all other levels. Second, in some cases where DOE had prices for different efficiency levels, the fuel input rates of the CPB models at these levels deviated significantly from the representative fuel input rate. Thus, the increase in price (or lower price per input) of the boiler is primarily driven by higher fuel input rate rather than improved energy efficiency. The equipment classes that were supplemented with additional prices were large oil-fired hot water, large gas-fired steam, and large oil fired steam

In the preliminary analysis, DOE encountered a similar issue for the large gas-fired and oil-fired mechanical draft hot water equipment classes. To address this issue, DOE used the price of two small commercial packaged boilers at 1,500 kBtu/h as a proxy for the price of one large 3,000 kBtu/h commercial packaged boiler. In this analysis, DOE used the same principle but, with a slightly modified methodology to calculate the price of a large 3,000kBtu/h commercial packaged boiler. . In this analysis, DOE first combined all the MSPs of the small and large equipment classes and created scatter plots of the MSP versus fuel input rate. After creating these scatter plots, DOE conducted a regression analysis and deduced the best fit regression equation for all plots. In all cases, DOE noticed that a linear regression equation provides the best R-squared fit with the data. DOE then derived the regression equation for the scatter plots and used them to extrapolate the price of a small commercial packaged boiler to a 3,000 kBtu/h large commercial packaged boiler at the same efficiency level. Although DOE was only required to perform the extrapolation of prices for large oil-fired hot water, large gas-fired steam, and large oil-fired steam equipment classes, DOE has presented the scatter plots and the linear regression curve for all equipment classes that were analyzed in this chapter. In response to the preliminary analysis, DOE received comments stating that DOE should not assume a linear relationship between price and fuel input rate. (AHRI, No. 37 at p. 3; Raypak, No. 35 at pp. 2-3) The scatter plots indicate that the relationship between fuel input rate and MSP is indeed linear but not one to one proportional as was assumed in the preliminary analysis. For the small gas-fired hot water equipment class, DOE separated the analysis between non-condensing and condensing efficiency levels. All the scatter plots from DOE’s analysis are presented in Figure 5.5.1 to Figure 5.5.5.

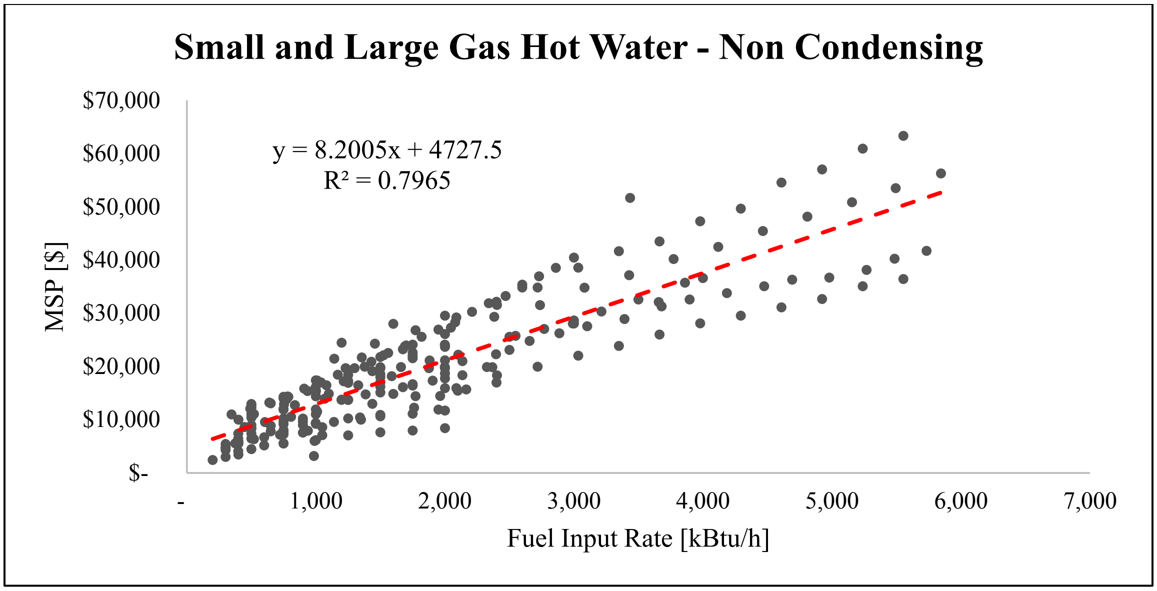

Figure 5.5.1 Variation of Manufacturer Selling Prices of Small and Large Gas-Fired Hot Water Non Condensing Commercial Packaged Boilers With Respect to Fuel Input Rate

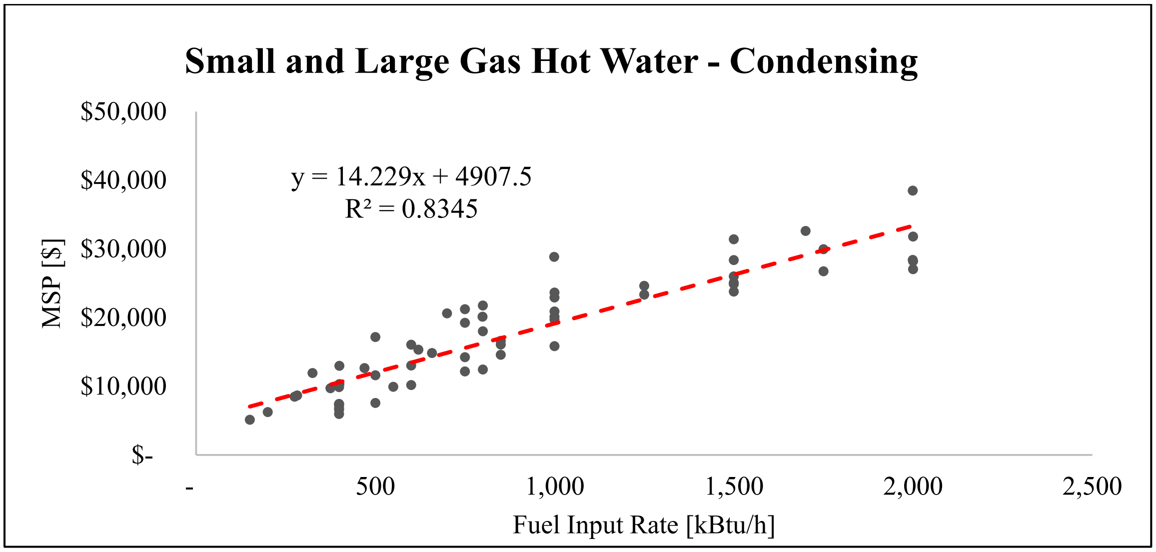

Figure 5.5.2 Variation of Manufacturer Selling Prices of Small and Large Gas-Fired Hot Water Condensing Commercial Packaged Boilers With Respect to Fuel Input Rate

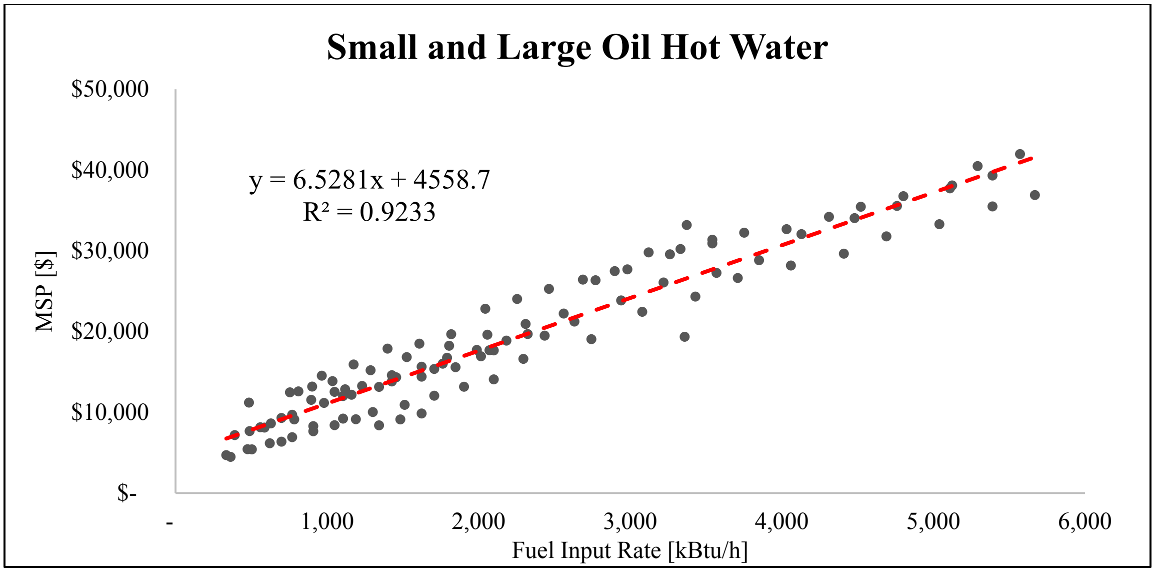

Figure 5.5.3 Variation of Manufacturer Selling Prices of Small and Large Oil-Fired Hot Water Commercial Packaged Boilers With Respect to Fuel Input Rate

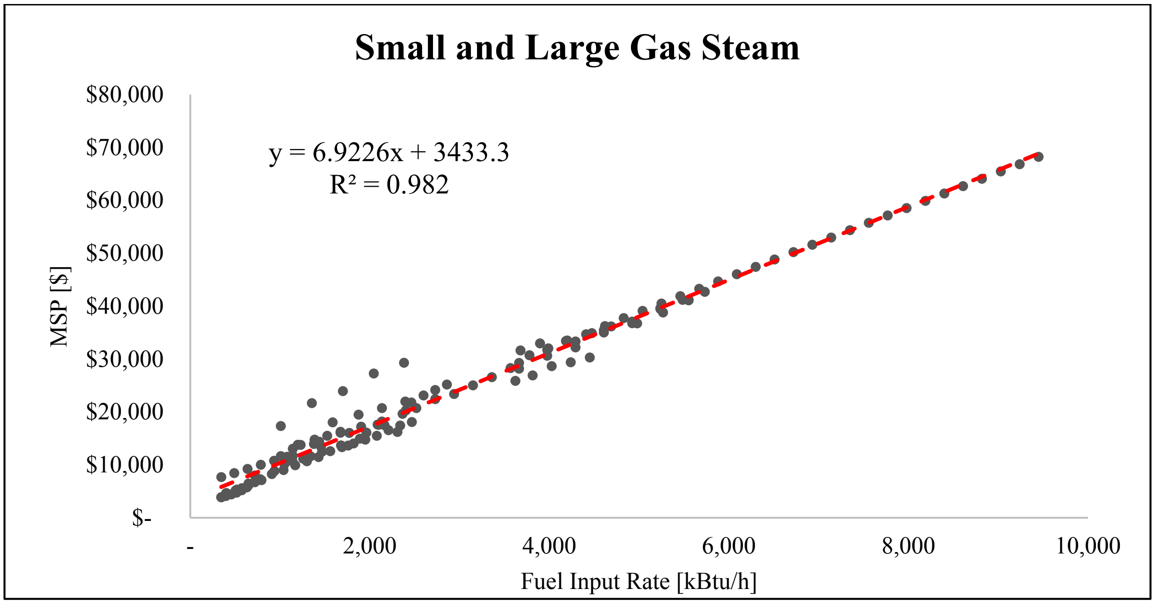

Figure 5.5.4 Variation of Manufacturer Selling Prices of Small and Large Gas-Fired Steam Commercial Packaged Boilers With Respect to Fuel Input Rate

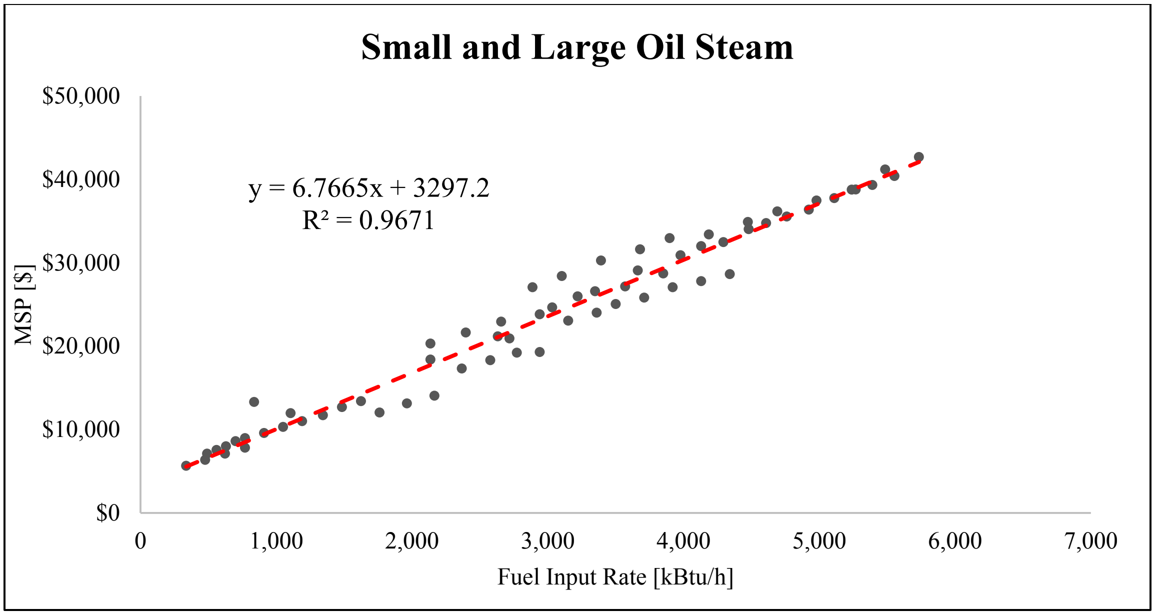

Figure 5.5.5 Variation of Manufacturer Selling Prices of Small and Large Oil-Fired Steam Commercial Packaged Boilers With Respect to Fuel Input Rate

Using this approach, DOE found that if the fuel input rate of oil-fired hot water commercial packaged boiler increases from 1,500 kBtu/h to 3,000 kBtu/h, then the MSP of the large commercial packaged boiler would be 1.68 times the MSP of the small commercial packaged boiler. For large gas-fired steam equipment classes, if the fuel input rate of the commercial packaged boiler increases from 1,500 kBtu/h to 3,000 kBtu/h, then the MSP of the large commercial packaged boiler would be about 1.75 times that of the small commercial packaged boiler. For large oil-fired steam equipment classes, if the fuel input rate of the commercial packaged boiler increases from 800 kBtu/h to 3,000 kBtu/h, then the MSP of the large commercial packaged boiler would be about 2.71 times that of the small boiler. For the large oil-fired steam equipment class, DOE chose 800 kBtu/h because DOE did not have the price for that efficiency level at a fuel input rate of 1,500 kBtu/h. The efficiency levels for which prices were supplemented in the analysis are (1) 84 and 85 percent combustion efficiency for the large oil-fired hot water equipment class; (2) 79, 80, and 83 percent thermal efficiency for the large gas-fired steam equipment class; and (3) 84 and 85 percent thermal efficiency for the large oil-fired steam equipment class.

5.6 RESULTS

The final result of the engineering analysis is a set of price-efficiency relationships. Using the approaches discussed in section 5.5, the final incremental MSP that DOE calculated are given in Table 5.6.1.

Table 5.6.1 Engineering Analysis Results for Commercial Packaged Boilers

Equipment Class	Efficiency Level*	Incremental MSP	Baseline MSP
Small Gas Hot Water	Baseline - 80%	$0	$6,928
	81%	$472	
	82%	$977	
	84%	$2,759	
	85%	$3,561	
	93%	$10,027	

Equipment Class	Efficiency Level*	Incremental MSP	Baseline MSP
	95%	$10,494	
	Max Tech - 99%	$13,966	
Large Gas Hot Water	Baseline - 82%	$0	$21,244
	83%	$2,534	
	84%	$5,370	
	85%	$8,544	
	94%	$32,796	
	Max Tech - 97%	$36,904	
Small Oil Hot Water	Baseline - 82%	$0	$8,404
	83%	$634	
	84%	$1,315	
	85%	$2,048	
	87%	$3,683	
	88%	$4,594	
	Max Tech - 97%	$17,687	
Large Oil Hot Water	Baseline - 84%	$0	$18,915
	86%	$4,785	
	88%	$10,781	
	89%	$14,326	
	Max Tech - 97%	$49,923	
Small Gas Steam	Baseline - 77%	$0	$6,659
	78%	$540	
	79%	$1,124	
	80%	$1,756	
	81%	$2,439	
	Max Tech - 83%	$3,975	
Large Gas Steam	Baseline - 77%	$0	$19,122
	78%	$1,097	
	79%	$2,256	
	80%	$3,483	
	81%	$4,779	
	82%	$6,150	
	Max Tech - 84%	$9,132	
Small Oil Steam	Baseline - 81%	$0	$7,294
	83%	$1,722	
	84%	$2,730	
	Max Tech - 86%	$5,097	
Large Oil Steam	Baseline - 81%	$0	$18,702
	83%	$3,017	
	85%	$6,521	
	Max Tech - 87%	$10,590	

*Efficiency levels represent thermal efficiency for all equipment classes except for Large Gas Hot Water and Large Oil Hot Water, for which the efficiency levels are in terms of combustion efficiency.

CHAPTER 6. MARKUPS ANALYSIS

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CHAPTER 6. MARKUPS ANALYSIS

6.1 INTRODUCTION

To carry out its analyses of markups for commercial packaged boilers (CPBs), 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 estimates of manufacturer selling price (MSP) plus appropriate markups for the various distribution channels for commercial packaged boilers.

For wholesalers and contractors, DOE estimates a baseline markup and an incremental markup. DOE defines a baseline markup as a multiplier that converts the 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 MSP 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, as well as 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 commercial packaged boilers, the majority of boilers are purchased for commercial use, but a small fraction of commercial packaged boilers are purchased for installation in residential buildings. DOE estimates that 94.5 percent of total CPB shipments are to commercial applications and 5.5 percent to residential applications. Hence, DOE calculates the markups separately for both commercial and residential applications of commercial packaged boilers.

Within each application, there are two primary types of markets describing the way most equipment passes from the manufacturer to the commercial consumer: (1) commercial packaged boilers installed in replacement markets or by new owners, and (2) commercial packaged boilers installed in new construction. Depending on the rating and capacity[a] of a commercial packaged boiler, the distribution channels for replacement and new construction markets can vary slightly between small boilers and large boilers.

In the replacement distribution channel for small boilers, the manufacturer generally 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 new construction distribution channel for small boilers includes an additional link in the chain—the general contractor. In the new construction distribution channel, the manufacturer 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 in turn sells it to the commercial consumer.

The replacement and new construction distribution channels for a large boiler with a capacity above 2.5 million Btu/h and below 10 million Btu/h is very similar to that for a small boiler but replaces the wholesaler with a manufacturer's representative. Manufacturers usually sell large commercial packaged boilers through partnered representatives who are specialized in the application of large boilers and have established strong ties with the clientele. The role of the manufacturer's representative is similar to the wholesaler in the distribution channel for small boilers. 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 an additional distribution channel where the manufacturer sells boilers to the commercial customer directly through a national account under both replacement and new construction markets. This national account distribution channel is applicable when the commercial consumer orders a customized boiler directly from a manufacturer, accounting for approximately 17.5 percent of the total CPB market.[b] Figure 6.2.1 illustrates the main distribution channels for both small and large commercial packaged boilers.

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[a] In this NOPR TSD and corresponding NOPR, DOE uses "fuel input rate," to refer to the maximum rate at which a commercial packaged boiler uses energy, in order to be consistent with the test procedure definition and language. The industry also uses terms such as input capacity, input ratings, capacity, and rating, and any such instances should be considered synonymous with fuel input rate.

[b] The market structure for commercial packaged boilers is very similar to that for commercial air conditioners. See Chapter 7, "Markups for Equipment Price Determination," in the 2004 Commercial Air Conditioners Advanced Notice of Proposed Rulemaking technical support document: www.regulations.gov/#!documentDetail;D=EERE-2006-STD-0103-0078 [Docket No. EERE-2006-STD-0103]

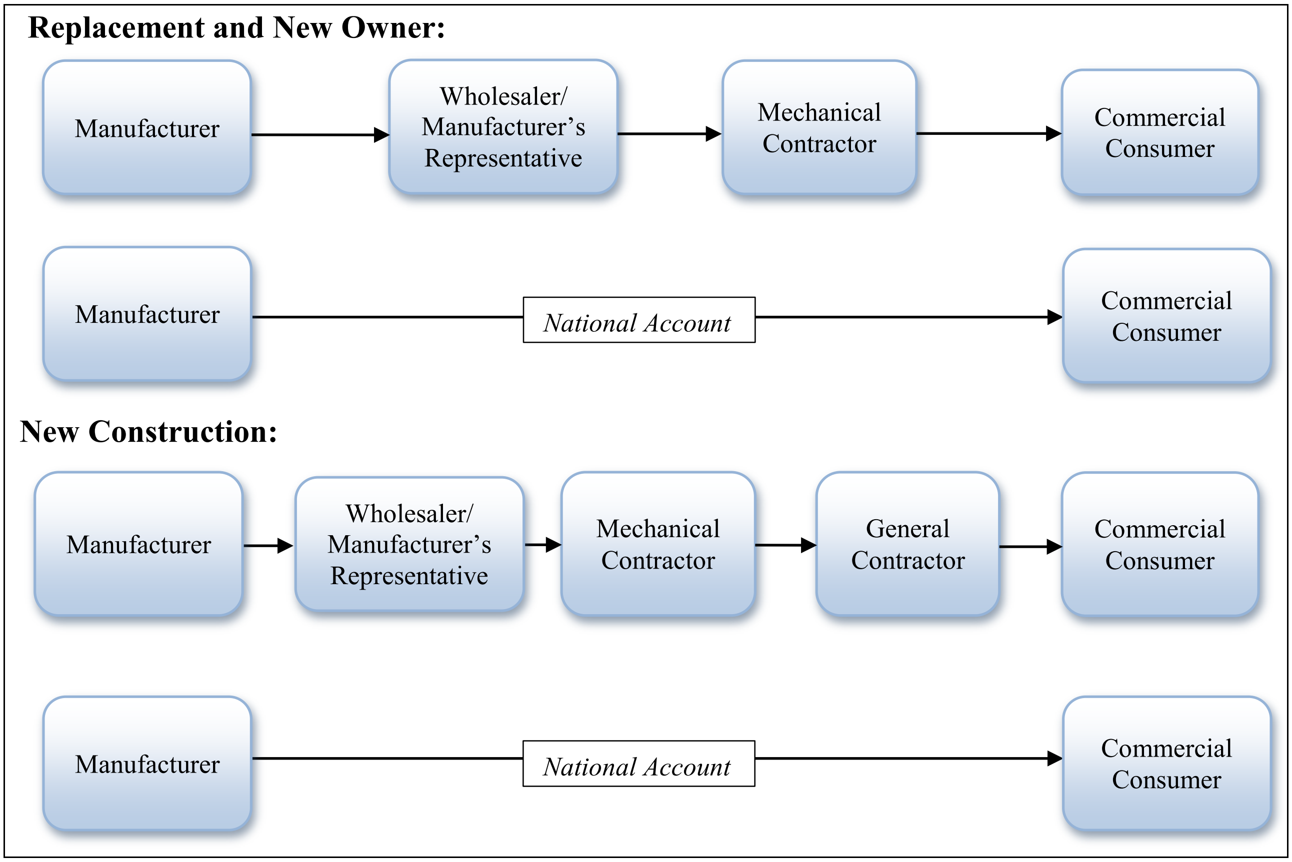

Figure 6.2.1 Distribution Channels for Commercial Packaged Boilers

6.3 APPROACH FOR MANUFACTURER MARKUP

Typically, DOE uses manufacturer markups to transform a manufacturer's production cost into the MSP. As noted in the engineering analysis (chapter 5), DOE used CPB list pricing and typical discount percentages applied by manufacturers when selling their equipment to calculate a manufacturer selling price. The MSP already contains any manufacturer markups as the CPB equipment enters the distribution chain.

6.4 APPROACH FOR WHOLESALER AND CONTRACTOR MARKUPS

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

DOE derived wholesaler and contractor markups from three key assumptions about the costs associated with commercial packaged boilers. In general, DOE bases the wholesaler and mechanical contractor markups on firm-level income statement data and general contractor markups on U.S. Census Bureau data for the residential building construction industry. DOE obtains income statements about a firm from the Heating, Air-conditioning & Refrigeration Distributors International (HARDI) 2013 profit report, and from the Air Conditioning

Contractors of America (ACCA) 2005 financial analysis.[1,2] HARDI and ACCA are trade associations representing wholesalers and mechanical contractors, respectively. DOE uses the financial data from the 2007 U.S. Census of Business for developing general contractor markups in the same form as the income statement data for wholesalers and mechanical contractors. These income statements break down the components of all costs incurred by firms that supply and install heating and air-conditioning equipment.[c] 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 commercial packaged boilers.

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

3) Overall, wholesale and contractor prices for commercial packaged boilers vary in proportion to the wholesaler and contractor costs for commercial packaged boilers 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 and contractors tend to handle multiple commodity lines, the data provide the most accurate available indication of expenses associated with commercial packaged boilers.

Information obtained from the trade literature, 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 and contractor markups vary according to the quantity of labor and materials used to distribute 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 HVAC wholesaler and contractor industry is competitive, and commercial consumer demand for 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 HVAC firms listed in the 2007 Census indicates the competitive nature of the market. For example, there are more than 700 manufacturers of HVAC equipment, 5,300 wholesalers of heat pumps and air-conditioning equipment, more than 170,000 general residential contractors, 36,000 commercial and institutional building contractors, and 91,000 HVAC contractors listed in the 2007 Census.[3,4,5,6] Following standard economic theory, competitive firms facing inelastic demand either set prices in line with costs or quickly go out of business.[7]

DOE concludes that markups for more-efficient equipment are unlikely to be proportional to all direct costs. When the wholesaler's purchase price of equipment increases, for

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

example, only a fraction of a business' expenses increases, while the remainder may stay relatively constant. For example, if the unit price of a CPB unit 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 also. Therefore, DOE assumes that incremental markups cover only those costs that scale with a change in the MSP (variant costs).

6.4.1 Wholesaler Markup

In view of these assumptions, DOE develops baseline and incremental markups for wholesalers using the firm income statement from the HARDI 2013 Profit Report (details of the data used for markup development are provided in appendix 6A of this TSD). The baseline markups cover the wholesaler's costs (both *invariant costs* and *variant costs*). 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 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 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 commercial packaged boilers, DOE collects financial data from the *Plumbing and HVAC Contractors* (NAICS 23822) series from the 2007 Economic Census and from the ACCA 2005 financial analysis. To estimate general contractor markups for commercial packaged boilers in commercial applications, DOE collects data from the 2007 Economic Census Commercial Building Construction series (NAICS 236220). To estimate general contractor markups for commercial packaged boilers in residential applications, DOE collects 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. 6.3

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. 6.4

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. 6.5

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

CPB MSPs, as established in chapter 5 of this TSD, already include any manufacturer markups that may be applied as the equipment enters the distribution chain.

6.5.2 Wholesaler Markup

Wholesalers reported median data in a confidential survey that HARDI conducted of member firms. In the survey, HARDI itemizes 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 of this TSD. Table 6.5.1 summarizes them at the notational aggregated level as cost-per-dollar sales revenue in the first data column. These wholesaler markups are applicable to both small and large commercial packaged boilers in both commercial and residential applications.

Table 6.5.1 Wholesaler Expenses and Markups

Descriptions	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 ($MU_{WHOLE\ BASE}$)	N/A	**1.385**
Incremental Markup ($MU_{WHOLE\ INCR}$)	N/A	**1.109**

Source: Heating, Air Conditioning & Refrigeration Distributors International. 2013. 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 $1.00 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 converts 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 uses the data in the second column to estimate the incremental markup. The incremental markup depends on which of the costs in Table 6.5.1 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 of this TSD for cost details.

6.5.3 Mechanical Contractor Markups

6.5.3.1 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 6.5.2. Appendix 6A of this TSD contains the full set of data.

The first data column in Table 6.5.2 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 converts 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.

Table 6.5.2 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 (***$MUMECH_{BASE}$***): Revenue per dollar cost of goods	N/A	**1.474**
Incremental Markup (***$MUMECH_{INCR}$***): Increased revenue per dollar increase in cost of goods sold	N/A	**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.

DOE is also able to use the data in the second column of Table 6.5.2 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 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.

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

DOE derives 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.[2,8] 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 6.5.3.

Table 6.5.3 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	N/A	**1.372**
Baseline Markup ($MUMECH_{CONT\ BASE}$**)**	N/A	**1.372**

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

Table 6.5.4 summarizes the gross margin and resulting baseline markup data for all mechanical contractors that serve the replacement and new construction markets.

Table 6.5.4 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 ($MUMECH_{CONT\ BASE}$**)**: Revenue per dollar cost of goods	N/A	1.422	N/A	1.342
% Difference from Aggregate Mechanical Contractor Baseline *MU*	N/A	3.63%	N/A	-2.20%

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

Using the baseline markup data from Table 6.5.4 and results from Table 6.5.3, 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 6.5.2. 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 6.5.5.

Table 6.5.5 Markups for the Replacement and New Construction Markets

	Baseline Markup (Res. / Comm.)	Incremental Markup (Res. / Comm.)
Replacement Market	1.53/1.52	1.22/1.21
New Construction Market	1.44/1.43	1.16/1.15

6.5.4 General Contractor Markups

DOE derives markups for general contractors from U.S. Census Bureau data for the commercial building construction and residential building construction sector to reflect the commercial and residential application of commercial packaged boilers.[9] 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.[10] 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 itemized 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 6.5.6 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. Appendix 6A of this TSD includes the full set of data for commercial general contractor expenses and markups.

Table 6.5.6 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 ($MUMECH_{CONT\ BASE}$): Revenue per dollar cost of goods	N/A	**1.32**
Incremental Markup ($MUMECH_{CONT\ INCR}$): Increased revenue per dollar increase in cost of goods sold	N/A	**1.21**

Source: U.S. Census Bureau. 2007. Sector 236220 (Commercial Building Construction). Construction: Industry Series: Preliminary Detailed Statistics for Establishments: 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 converts 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 $1.00 spent on equipment costs. Thus, the general contractor baseline markup ($MU_{GCONTRACT_BASE}$) is 1.31.

DOE is also able to use the data in column two of Table 6.5.6 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 the labor and occupancy costs are invariant, while the other operating costs and profit to 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 $1.19, giving a general contractor incremental markup ($MU_{GCONTRACT_INCR}$) of 1.19.

Table 6.5.7 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. Appendix 6A of this TSD includes the full set of data for residential general contractor expenses and markups.

Table 6.5.7 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 ($MU_{GEN\ CONT\ BASE}$): Revenue per dollar cost of goods	N/A	**1.47**
Incremental Markup ($MU_{GEN\ CONT\ INCR}$): Increased revenue per dollar increase in cost of goods sold	N/A	**1.34**

Source: U.S. Census Bureau. 2007. Residential Building Construction. Sector 23: 236115-236118. Construction: Industry Series: Preliminary Detailed Statistics for Establishments: 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 converts the expenses per dollar sales into revenue per dollar cost of goods sold by dividing each figure in the first data column by $0.68. The data in the second column show that, for every \$1.00 the general contractor spends on equipment costs, the general contractor earns \$1.00 in sales revenue to cover the equipment cost, \$0.12 to cover labor costs, \$0.01 to cover occupancy expenses, \$0.09 for other operating expenses, and \$0.25 in profits. This totals \$1.47 in sales revenue earned for every \$1.00 spent on equipment costs. Thus, the general contractor baseline markup ($MU_{GEN\ CONT\ BASE}$) is 1.47.

DOE is also able to use the data in the second column in Table 6.5.7 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 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 \$1.34, giving a general contractor incremental markup ($MU_{GEN\ CONT\ INCR}$) of 1.34.

6.6 DERIVATION OF CENSUS REGIONS MARKUPS

In this analysis, DOE considers eight different CPB equipment classes. DOE assumes a market saturation rate for each equipment class, which varies between geographical regions that are defined by the Commercial Building Energy Consumption Survey (CBECS) and by Residential Energy Consumption Survey (RECS) and which is based on the population projection for the year of 2019.[11,12] Therefore, regional markups are calculated for each CPB equipment class in both commercial and residential applications.

Wholesalers and mechanical and general contractors in the CPB industry are divided into the nine regions provided by the latest CBECS for the commercial building survey and also are divided into the 30 regions provided by the latest RECS for the residential application.[d] 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 wholesalers of commercial packaged boilers; the markups are shown in Table 6.6.1. 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 and plumbing

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[d] RECS 2009 provides 27 regions (also called reportable domains). The 27th region originally includes Oregon, Washington, Alaska, and Hawaii. Alaska and Hawaii are subdivided into separate regions (28 and 29, respectively), based on cooling and heating degree days. In addition, region 14 originally includes West Virginia, which has been disaggregated into region 30 based on cooling and heating degree days. See appendix 7A for more details.

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. Table 6.6.2 shows the ratios of wholesaler markups for the air conditioning and plumbing segment relative to the wholesaler markups for all business segments.

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	N/A	**1.353**
Incremental Markup – All Business Segments	N/A	**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 Regional Wholesaler Markups for Commercial Packaged Boilers in Commercial Application by Census Division

CBECS Regions	Census Divisions	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 assigns all states and the District of Columbia (D.C.) to one of the 30 RECS regions in the analysis and then calculates population-weighted baselines and incremental markup averages for each region in the residential applications. The results are summarized in Table 6.6.4.

Table 6.6.4 Regional Wholesaler Markups for Commercial Packaged Boilers in Residential Application by RECS Region

RECS Regions	State(s)	Baseline MU	Incremental 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	1.387	1.100
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	Oregon, Washington	1.438	1.118
28	Alaska	1.438	1.118
29	Hawaii	1.438	1.118
30	West Virginia	1.385	1.105

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 6.4.2, DOE is able to estimate baseline markups for each state. Because the Census does not provide more disaggregated cost data, DOE is not able to differentiate between invariant and variant cost.

Alternatively, DOE calculates the national baseline and incremental markups (Table 6.6.5) and finds that the incremental markups are around 20-percent lower than the baseline markups. DOE further derives 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. Appendix 6A of this TSD includes the full set of data for mechanical contractor markup estimation by state.

To estimate the baseline and incremental markups for both replacement and new construction markets for each state, DOE applies the markup deviations (*i.e.,* 3.6 percent higher and 2.2 percent lower for the replacement and new construction markets, respectively), derived in section 6.5.3.2, 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 divides all states among the nine CBECS regions and then calculates 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 Packaged Boilers in Commercial Applications by Census Division

CBECS Regions	Census Divisions	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

Lastly, DOE divides all states among the 30 RECS regions and then calculates 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 Packaged Boilers in Residential Applications by RECS Region

RECS Regions	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	1.479	1.183	1.396	1.117
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	Oregon, Washington	1.568	1.254	1.480	1.184
28	Alaska	1.753	1.402	1.654	1.324
29	Hawaii	1.822	1.458	1.720	1.376
30	West Virginia	1.517	1.213	1.431	1.145

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 uses the Commercial Building Construction series (NAICS 236220) from the 2007 Economic Census. Similarly, DOE combines 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 commercial packaged boilers.

Each series consists of statewide cost data required to calculate baseline markups for each state, as illustrated in section 6.4.2. 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 estimates 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. Last, DOE divides all states among the nine CBECS regions and 30 RECS regions; then calculates 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. Appendix 6A of this TSD includes the full set of data for commercial and residential building general contractor baseline markups by state.

Table 6.6.7 General Contractor Markups for Commercial Packaged Boilers in Commercial Applications by Census Division

CBECS Regions	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 Packaged Boilers in Residential Applications by RECS Region

RECS Regions	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	1.418	1.290
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

RECS Regions	State(s)	Baseline MU	Incremental MU
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	Oregon, Washington	1.464	1.333
28	Alaska	1.854	1.687
29	Hawaii	1.417	1.289
30	West Virginia	1.545	1.406

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 which 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 commercial packaged boilers in the new construction market, is that general contractors (or builders) 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.[13] These data represent weighted averages that include county and city rates. DOE then derives population-weighted average tax values for each CBECS and RECS region 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 is included in appendix 6A of this TSD.

Table 6.7.1 Average Sales Tax Rates by CBECS Region

CBECS Regions	Census Divisions	Population Estimation (2013)	Tax Rate (2014) %
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	7.09%
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			**7.13%**

Table 6.7.2 Average Sales Tax Rates by RECS Region

RECS Regions	State(s)	Population Estimation (2013)	Tax Rate (2014) %
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	7,501,012	5.24%
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	Oregon, Washington	10,901,471	5.69%
28	Alaska	735,132	1.30%
29	Hawaii	1,404,054	4.35%
30	West Virginia	1,854,304	6.05%
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. 6.6

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. 6.7

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 participant are summarized in Table 6.8.1 for commercial packaged boilers. The values represent the weighted-average markups based on the state-level markup values and population by state as weights. Note that the overall markup values may not equal the product of associated markup values shown in Table 6.8.1 because of the rounding. In view of CPB shipment forecasts for the year 2019 (see chapter 9 of this TSD for name abbreviations by equipment class), DOE estimates the percentage of commercial packaged boilers that are sold through conventional channels vs. national accounts, commercial vs. residential consumers, and retrofit vs. new construction, each by equipment class. These are used to arrive at a total markup by equipment class, which is an aggregation of all the possible scenarios and provides an overall baseline and incremental markup by equipment class based on the weighting of each distribution chain. The percentage estimates for the various channels that commercial packaged boilers may take en route to consumers are shown in Table 6.8.2. By applying these percentages across the various channels in the distribution chain, a set of aggregate weighting factors was developed by equipment class, as shown in Table 6.8.3. The total markups were then derived by applying these weighting factors to the overall markup values shown in Table 6.8.1, and those total markups are shown in Table 6.8.4.

Table 6.8.1 Summary of Overall Markups for Small and Large Commercial Packaged Boilers

	Replacement			**New Construction**		
	Baseline Markup	**Incremental Markup**	**National Account: Baseline/ Incr. MU**	**Baseline Markup**	**Incremental Markup**	**National Account: Baseline/ Incr. MU**
Manufacturer	-			-		
Wholesaler/ Manufacturer's Representative	1.39	1.11	1.39/1.11	1.39	1.11	1.39/1.11
Mechanical Contractor	1.52	1.21	-	1.43	1.15	-
General Contractor (commercial/residential)	-	-	-	1.32/1.47	1.21/1.34	-
Sales Tax	1.07			-	-	1.07
Overall Markup (commercial/residential)	2.27	1.44	1.49/1.19	2.65/2.94	1.53/1.71	1.49/1.19

Table 6.8.2 Estimated Market and Sector Weights by Commercial Packaged Boiler Equipment Class*

Equipment Class	Conventional Distribution Channels				National Accounts			
	82.5%				17.5%			
	Commercial		**Residential**		**Commercial**		**Residential**	
SGHW	91%		9%		91%		9%	
LGHW	98%		2%		98%		2%	
SOHW	71%		29%		71%		29%	
LOHW	93%		7%		93%		7%	
SGST	93%		7%		93%		7%	
LGST	99%		1%		99%		1%	
SOST	92%		8%		92%		8%	
LOST	99%		1%		99%		1%	
	Repl.	**New Constr.**	**Repl.**	**New Constr.**	**Repl.**	**New Constr.**	**Repl.**	**New Constr.**
SGHW	72%	28%	95%	5%	72%	28%	95%	5%
LGHW	64%	36%	93%	7%	64%	36%	93%	7%
SOHW	32%	68%	88%	12%	32%	68%	88%	12%
LOHW	100%	0%	100%	0%	100%	0%	100%	0%
SGST	100%	0%	100%	0%	100%	0%	100%	0%
LGST	100%	0%	100%	0%	100%	0%	100%	0%
SOST	100%	0%	100%	0%	100%	0%	100%	0%
LOST	100%	0%	100%	0%	100%	0%	100%	0%

* The CPB equipment abbreviations are SGHW = Small Gas-fired Hot Water, LGHW = Large Gas-fired Hot Water, SOHW = Small Oil-fired Hot Water, LOHW = Large Oil-fired Hot Water, SGST = Small Gas-fired Steam, LGST = Large Gas-fired Steam, SOST = Small Oil-fired Steam, and LOST = Large Oil-fired Steam.

Table 6.8.3 Aggregate Weighting Factors Used for Computing Total Markup by Commercial Packaged Boiler Equipment Class*

Equipment Class	Conventional Distribution Channels				National Accounts			
	Commercial		**Residential**		**Commercial**		**Residential**	
	Repl.	**New Constr.**	**Repl.**	**New Constr.**	**Repl.**	**New Constr.**	**Repl.**	**New Constr.**
SGHW	53.9%	21.2%	7.1%	0.4%	11.4%	4.5%	1.5%	0.1%
LGHW	51.6%	29.6%	1.2%	0.1%	11.0%	6.3%	0.2%	0.0%
SOHW	19.0%	39.7%	20.9%	2.9%	4.0%	8.4%	4.4%	0.6%
LOHW	76.5%	0.0%	6.0%	0.0%	16.2%	0.0%	1.3%	0.0%
SGST	77.0%	0.0%	5.5%	0.0%	16.3%	0.0%	1.2%	0.0%
LGST	81.6%	0.0%	0.9%	0.0%	17.3%	0.0%	0.2%	0.0%
SOST	75.6%	0.0%	6.9%	0.0%	16.0%	0.0%	1.5%	0.0%
LOST	81.7%	0.0%	0.8%	0.0%	17.3%	0.0%	0.2%	0.0%

* The CPB equipment abbreviations are SGHW = Small Gas-fired Hot Water, LGHW = Large Gas-fired Hot Water, SOHW = Small Oil-fired Hot Water, LOHW = Large Oil-fired Hot Water, SGST = Small Gas-fired Steam, LGST = Large Gas-fired Steam, SOST = Small Oil-fired Steam, and LOST = Large Oil-fired Steam.

Table 6.8.4 Summary of Total Markup by Commercial Packaged Boiler Equipment Class

Equipment Class	Baseline Markup	Incremental Markup
Gas-Fired Hot Water Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h	2.21	1.42
Gas-Fired Hot Water Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h	2.23	1.43
Oil-Fired Hot Water Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h	2.29	1.44
Oil-Fired Hot Water Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h	2.13	1.40
Gas-Fired Steam Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h	2.13	1.40
Gas-Fired Steam Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h	2.13	1.40
Oil-Fired Steam Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h	2.13	1.40
Oil-Fired Steam Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h	2.13	1.40

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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 this 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 expenses scale with both the baseline and incremental markups. As described in chapter 6, 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	
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 (collection, credit card fees)	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**	

Item[*]	Percent of Revenue %	Scaling
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 expense items are the sum of the unbolded items listed below each expense sum.

6A.2 DETAILED MECHANICAL CONTRACTOR DATA

Mechanical contractor data tables in chapter 6 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.2.1 both by dollar value and percentage terms from the 2007 Census of Business. As the ACCA data are used to calculate the baseline markup, in Table 6A.2.1 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.2.1 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

Source: 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 Chapter 6 of the TSD.

6A.3 DETAILED GENERAL CONTRACTOR COST DATA

General contractor data tables in chapter 6 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.3.1 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 to 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.3.2 shows the similar analysis for residential building contractors.

Table 6A.3.1 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 chapter 6 of the TSD.

Table 6A.3.2 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 chapter 6 of the TSD.

6A.4 ESTIMATION OF CONTRACTOR MARKUP BY STATE

Table 6A.4.1 provides a breakdown of the mechanical contractor markup estimates by state. Table 6A.4.2 provides these estimates by state for commercial building general contractors, and Table 6A.4.3 provides the estimates for residential building general contractors.

Table 6A.4.1 Mechanical Contractor Markup Estimation by State, 2007

State*	Value of Const. *$1,000*	Cost of Goods Sold *$1,000***	Baseline MU	Incremental MU	Replacement 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
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

State*	Value of Const. *$1,000*	Cost of Goods Sold *$1,000***	Baseline MU	Incremental MU	Replacement Baseline MU	Replacement Incremental MU	New Const. Baseline MU	New Const. Incremental MU
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.

* 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 Subcontract, Materials, and Fuels fields. 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.4.2 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.4.3 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

State*	Value of Residential Construction *\$1,000***	Cost of Goods Sold *\$1,000***	Baseline Markup	Incremental Markup
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
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.
* 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 Subcontract, Materials, and Fuels fields. In these cases, the state markup ratio is calculated as an average of neighboring states (ex. North Dakota).
** The Census Bureau withheld data for the states denoted with a D.

6A.5 STATE SALES TAX RATES

DOE derives state and local taxes from data provided by the Sales Tax Clearinghouse. Table 6A.5.1 provides the disaggregated state tax rates that DOE used to develop the aggregated state tax rates in chapter 6 of the TSD.

Table 6A.5.1 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.

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 packaged boilers (CPBs) in use in the United States (U.S.) and to assess the energy savings potential of increases in efficiency (thermal efficiency (E_T) and combustion efficiency (E_C)). In contrast to the CPB 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 commercial packaged boilers 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 boilers at specified energy efficiency levels across a range of climate zones, building characteristics, and space and water heating applications.

For the calculation of the energy consumed by commercial packaged boilers, DOE considers the energy use associated with providing space heating and water heating in either commercial or residential buildings. Space heating applications for commercial packaged boilers include forced air using fan coils or central air handlers and radiant heating (*e.g*., in-floor, radiant panels, radiators, baseboard). Water heating applications for commercial packaged boilers include indirect water heating, combination equipment, and tankless coil-type. The energy use analysis provides estimates of the distribution of annual energy consumption for boilers at each efficiency standard level considered.

DOE develops energy consumption estimates for the analyzed equipment classes listed in Table 7.1.1. The boilers analyzed utilize gas or oil fuel for heating water or steam and the associated electric energy to power a water pump, a draft inducer, an igniter, and other auxiliary equipment.

Table 7.1.1 Commercial Packaged Boiler Equipment Classes Analyzed

Heating Medium	Subcategory	Size Category (fuel input rate)	Abbreviation
Hot Water	Gas-fired	≥300,000 Btu/h and ≤2,500,000 Btu/h	SGHW
Hot Water	Gas-fired	>2,500,000 Btu/h and ≤10,000,000 Btu/h	LGHW
Hot Water	Oil-fired	≥300,000 Btu/h and ≤2,500,000 Btu/h	SOHW
Hot Water	Oil-fired	>2,500,000 Btu/h and ≤10,000,000 Btu/h	LOHW
Steam	Gas-fired	≥300,000 Btu/h and ≤2,500,000 Btu/h	SGST
Steam	Gas-fired	>2,500,000 Btu/h and ≤10,000,000 Btu/h	LGST
Steam	Oil-fired	≥300,000 Btu/h and ≤2,500,000 Btu/h	SOST
Steam	Oil-fired	>2,500,000 Btu/h and ≤10,000,000 Btu/h	LOST

* The CPB equipment abbreviations are SGHW = Small Gas-fired Hot Water, LGHW = Large Gas-fired Hot Water, SOHW = Small Oil-fired Hot Water, LOHW = Large Oil-fired Hot Water, SGST = Small Gas-fired Steam, LGST = Large Gas-fired Steam, SOST = Small Oil-fired Steam, and LOST = Large Oil-fired Steam.

DOE estimates the energy consumption of commercial packaged boilers in commercial buildings and housing units by developing a building sample for each of the eight equipment classes analyzed 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 of this TSD. As discussed in chapter 3 of this TSD, DOE proposed 12 equipment classes in the CPB NOPR. However, all sample buildings are assigned to only eight equipment classes, leaving out four equipment classes from the "very large" category of commercial packaged boilers. Since DOE is unable to undertake any detailed analysis on the very large boiler categories, DOE did not assign any building sample to these product categories.

DOE used CBECS 2003- or RECS 2009-reported heating energy consumption (based on the existing heating system) to calculate the space heating load of each building. The heating load represents the amount of heating required to keep a building comfortable throughout an average year. In buildings where DOE finds that the boiler also serves hot water heating needs, DOE uses the CBECS 2003- or RECS 2009- reported water heating energy (based on the existing water heating system) to calculate the water heating load of each building.

DOE assigns the energy efficiency of existing systems based on a historical distribution of energy efficiency for boilers by equipment class. In addition, DOE makes adjustments based on historical weather data, average estimated return water temperature part-load and cycling effects, projections of shell efficiency and building square footage, and for buildings that had secondary heating equipment that used the same fuel as the boiler. To complete the analysis, DOE calculates the energy consumption of alternative (more energy-efficient) equipment if they replaced existing systems in each commercial building or housing unit.

7.2 BUILDING SAMPLE SELECTION AND METHODOLOGY

In its energy analysis for the CPB NOPR, DOE's estimation of the annual energy use of commercial packaged boilers relies on building sample data from CBECS 2003, CBECS 2012 (in part[b]), and RECS 2009.[1,2] CBECS 2003 includes energy-related data from 5,215 buildings representing 4.9 million buildings. RECS 2009 includes energy-related data from 12,083 housing units that represent almost 113.6 million households.

The subset CBECS 2003 and RECS 2009 records used in the analysis meet all the following criteria:

- used boiler(s) as one of the main heating equipment components in the building,
- used a heating fuel that is natural gas (including propane and liquid petroleum gas (LPG)) or fuel oil or a dual fuel combination of natural gas and fuel oil,
- served a building with estimated design condition building heating load exceeding the lower limit of CPB qualifying size (300,000 Btu/h), and
- had a non-trivial consumption of heating fuel allocable to the boiler.

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[a] EIA is currently conducting the 2015 version of RECS, with data gathering slated to start in 2016. Additionally, EIA determined that the 2007 Commercial Buildings Energy Consumption Survey 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.

[b] EIA released only building characteristic micro-data tables for CBECS 2012 in June 2015. These buildings could not be used as sample buildings for this rulemaking because they did not have energy consumption. However this partial set of data in CBECS 2012 was used to determine useful trends for developing the final sample distribution across various equipment classes during the analysis period.

DOE analyzed commercial packaged boilers in the qualifying building samples. DOE disaggregated the selected sample set of commercial packaged boilers into subsets based on fuel types (gas or oil), fuel input rate (small or large), and heating medium (steam or hot water). DOE then used these boiler subsets to group the sample buildings equipped with the same class of equipment evaluated in its NOPR analysis. See Table 7.2.1 for commercial applications and Table 7.2.2 for residential applications. In the life-cycle cost (LCC) analysis, DOE used the ratio of the weighted floor space of the groups of commercial and residential building samples, associated with each equipment class, to determine the respective sample weights for the commercial and residential sectors. DOE's new construction sample was based on the same selection algorithms as the replacement sample but only includes buildings built after 1990, which DOE tentatively concluded would have building characteristics more similar to the new construction buildings in the start of the analysis period in 2019 (*e.g.,* building insulation, regional distribution of the buildings, and so forth.).

To disaggregate between large and small equipment classes, DOE used a sizing methodology using a statistical approach to estimate the likely size of the boilers installed in the building. First, the total sizing of the heating equipment is determined from the heated square footage of the building, the percentage of area heated, an assumed uniform heating load requirement of 30 Btu/h per square foot of heated area, and an equipment efficiency mapped to the construction year. DOE's sizing methodology also takes outdoor design conditions into consideration. The outdoor design condition for the building is based on the specific weather location of the building. The estimated total boiler sizing (MMBtu/h[c]) is the aggregate heating equipment sizing prorated using the area fraction heated by the boilers and multiplied by an oversize factor of 1.1. For the sample of residential multi-family buildings, the heating equipment sizing methodology for commercial buildings is modified to calculate the heating load for each residential unit of the multi-family buildings and this value is multiplied by the number of units, assuming each unit to have identical area and design heating load. The modified methodology for residential multi-family buildings further assumes that a centrally located single or multiple boiler installation would meet the entire design heating load of the building.

DOE computed the size of each boiler in each sample building by dividing the aggregate boiler sizing heating load (MMBtu/h) by an estimated number of boilers of equal capacity. To estimate the number of boilers in a given sample building, DOE established a boiler count distribution for a given sizing load range in a set of sample buildings from CBECS data of 1979 and 1983, the only two CBECS surveys where the boiler count data were available for the sample buildings. DOE assigned the number of boilers to all the qualified sample buildings of 2003 CBECS based on this distribution. The number of boilers in each sample building was multiplied by the respective building sample weights in CBECS to obtain an estimate of the overall boiler population and their respective capacities. Boiler size distributions obtained by this method were compared with the size distribution of the space heating boilers obtained in an EPA database[d] having size information of over 120,000 space heating boilers. The comparison from

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[c] It is typical in the industry to use the letter "M" to represent thousand and "MM" to represent million. MBtu/h refers to 1,000 Btu/h and MMBtu/h refers to 1,000,000 Btu/h. For example, 300 MBtu/h (300,000 Btu/h) represents the lower limit of small CPBs. DOE recognizes that SI units, and some industry references, use "k" to represent thousand and will use that convention wherever it is used as such.

[d] Environmental Protection Agency. 13 State Boiler Inspector Inventory Database with Projections (Area Sources). EPA-HQ-OAR-2006-0790-0013. April 2010. Available at www.epa.gov/ttnatw01/boiler/boilerpg.html.

these two different datasets did not reveal any significant differences. Minor tweaks were made to the statistical assignment of the number of boilers so as to maximize the utility of the sampled buildings used for the NOPR analysis; *i.e.*, the number of boilers assigned to very large buildings in cold climates with large design sizing loads were high enough to ensure that the capacity of a single unit of the multiple boiler installation was lower than 10 MMBtu/h, the maximum boiler size for the equipment classes analyzed. At the lower end of the heating load spectrum, for buildings having sizing heating load exceeding 300,000 Btu/h, the number of boilers assigned to the installation were matched to ensure that any boiler in the installation has a capacity higher than 300,000 Btu/h—the minimum size for a covered commercial package boiler. For the multi-family residential buildings, DOE matched the design heating load for the sample building to a sample in the CBECS subset and assigned an identical number of boilers.

Data from CBECS allowed DOE to identify the buildings with gas boilers or with oil boilers. However, for some sample buildings, the heating energy consumption indicated concurrent use of both gas and oil. Since the boiler was sized to cater to the entire design heating load, DOE assumed that the boiler in the sample building uses ‘dual fuel’. DOE assigned the sample building to either a gas or an oil equipment class based on the dominant usage of either gas or oil. The heating energy consumption for the gas and the oil were also aggregated for the detail analysis.

From the CBECS 2012 data, DOE noted that the share of oil as fuel type in the area heated by boilers in commercial buildings declined from 15% in 2003 to 8% in 2012. From the recently released *AEO2015* data, DOE further noted that significant fuel switching from oil to gas took place even after 2012. In spite of the decline, DOE did not make any adjustment to the sample set of buildings assigned to the oil-fired boilers. Any such downward adjustment would have significantly reduced the number of sample buildings with oil boilers impacting the significance of LCC results of DOE’s analysis for these equipment classes.

CBECS data does not capture the heating medium of the boiler, and consequently, DOE assigned a fraction of the sample buildings constructed before 1970 to steam. It is assumed that the remaining fraction would have switched to hot water boilers even if the original heating medium could have been steam. From the EPA database statistics and the observed trend in the decline of use of steam boilers for space heating, DOE estimated that for the older (pre-1970) buildings, the steam fraction would be 25% and 55% for gas-fired and oil-fired boilers, respectively, in 2019. For the residential multi-family buildings, steam boilers are assumed to be installed in 14 percent of buildings built before 1970 and in 0 percent of buildings built after 1970.[3]

DOE made further adjustment to the statistical distribution of the number of boilers for the sample buildings to capture the recent trend for deploying multiple boilers in large installations to improve reliability of operation and efficiency. For new construction buildings with design heating loads exceeding 1 MMBtu/h, it modified the future sizing methodology in the analysis period (2019–2048) to have a minimum count of at least two boilers of the same size.

Commercial packaged boilers are considered in residential applications when the total heated square footage of the building (equal to the heated square footage of each unit multiplied by the number of units in the building) is larger than 10,000 square feet (usually multi-family buildings).

The CBECS 2003 and RECS 2009 weighting indicates how commonly each commercial building, or multi-unit residential building, configuration occurs on the national level in 2003 and 2009, respectively. Appendix 7A of this TSD presents the variables included and their definitions. Table 7.2.1 and Table 7.2.2 provide information about the building samples, the sample weights, and sampling fractions for each of the four samples, commercial and residential, both disaggregated between new construction and replacement.

Table 7.2.1 Selection of CBECS 2003 Records for Commercial Packaged Boilers

Equipment Class	**Number of Records**	**CBECS 2003**	**DOE 2019**	**Fraction of New Construction**
		Number of Commercial Buildings	**Number of Boilers**	
Gas-Fired Hot Water Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h	587	168,116	238,695	17%
Gas-Fired Hot Water Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h	313	21,402	38,366	21%
Oil-Fired Hot Water Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h	79	28,277	36,108	25%
Oil-Fired Hot Water Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h	31	3,736	5,177	0%
Gas-Fired Steam Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h	321	32,525	42,892	0%
Gas-Fired Steam Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h	146	3,006	4,867	0%
Oil-Fired Steam Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h	59	17,100	22,706	0%
Oil-Fired Steam Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h	25	3,701	5,269	0%

Table 7.2.2 Selection of RECS 2009 Records for Commercial Packaged Boilers

Equipment Class	Number of Records	RECS 2009	DOE 2019	Fraction of New Construction
		Number of Multi-Family Buildings	Number of Boilers	
Gas-Fired Hot Water Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h	138	34,097	42,997	8%
Gas-Fired Hot Water Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h	5	272	543	37%
Oil-Fired Hot Water Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h	57	13,260	17,279	10%
Oil-Fired Hot Water Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h	5	122	268	0%
Gas-Fired Steam Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h	76	3,305	4,114	0%
Gas-Fired Steam Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h	3	28	55	0%
Oil-Fired Steam Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h	45	1,810	2,351	0%
Oil-Fired Steam Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h	4	15	33	0%

To sample between the new construction and replacement markets, DOE uses the fractions derived in the National Impact Analysis (NIA) of commercial packaged boilers shipped to new and replacement construction (see Table 7.2.3).

Table 7.2.3 Fractions of Commercial Boilers in New Construction Buildings based on the Shipment Model Developed in the NIA, 2019 (Commercial Sample)

Equipment Class	New Construction Fractions
Gas-Fired Hot Water Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h	28%
Gas-Fired Hot Water Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h	36%
Oil-Fired Hot Water Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h	68%
Oil-Fired Hot Water Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h	0%
Gas-Fired Steam Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h	0%
Gas-Fired Steam Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h	0%
Oil-Fired Steam Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h	0%
Oil-Fired Steam Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h	0%

7.3 COMMERCIAL PACKAGED BOILER ENERGY CONSUMPTION

To calculate the energy use of commercial packaged boilers in each equipment class, DOE determines the energy consumption associated with space heating, water heating, and electricity use during periods of space and water heating. For the space heating energy consumption determination, DOE estimates the fuel input rate and burner operating hours of the existing boiler using the building heating energy consumption and boiler characteristics. For the water heating energy consumption determination, DOE identifies the building water heating energy consumption and the recovery efficiency of the existing boiler. The electricity consumption is determined using the burner operating hours associated with space and water heating and individual electrical measurements of all electrical components. The sum of the space heating, water heating, and electrical energy consumption represents the estimated annual energy use of a sampled boiler. Additional details used for determining the total energy use can be found in the following sections.

The calculation for the determination of the total energy use is as follows:

$$Energy\ Use_{total} = FuelUse_{SH} + FuelUse_{WH} + ElecUse_{total}$$

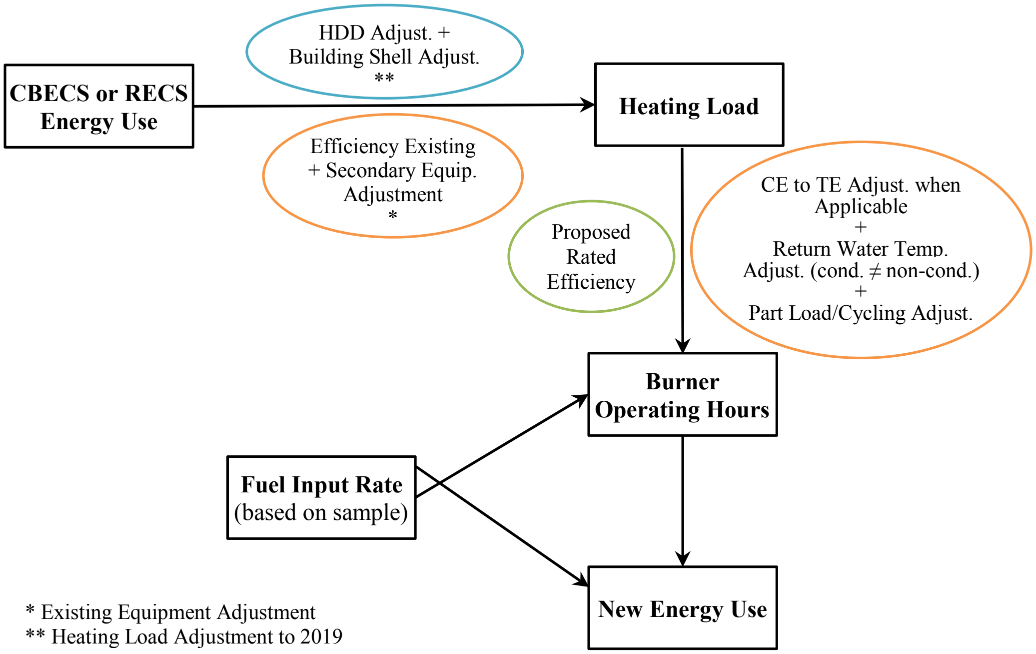
Eq. 7.1

Where:

$FuelUse_{SH}$ = total fuel consumption as a result of space heating loads,
$FuelUse_{WH}$ = total fuel consumption as a result of water heating loads, and
$ElecUse_{total}$ = electrical consumption of all electrical components.

7.3.1 Space Heating Fuel Consumption

The space heating energy use methodology is illustrated by Figure 7.3.1.



* Existing Equipment Adjustment
** Heating Load Adjustment to 2019

Figure 7.3.1 Space Heating Energy Use Methodology

DOE calculated the annual space heating fuel consumption ($FuelUse_{SH}$) for each boiler using the following formula:

$$FuelUse_{SH} = BOH_{SH} \times Q_{in}$$

Eq. 7.2

Where:

BOH_{SH} = full load space heating burner operating hours (hr/yr), and
Q_{in} = fuel input rate of existing boiler (kBtu/h).

DOE derives the BOH from the building heating load served by a single boiler. The building heating load is determined from annual fuel consumption for heating reported in CBECS and RECS based on the efficiency of the existing boiler.

7.3.1.1 Determination of Space Heating Burner Operating Hours (BOHSH)

DOE calculates space heating burner operating hours at full load for a boiler as:

$$BOH_{SH} = \frac{BHL_{boiler}}{Q_{in} \times TE_{rated,adj}}$$

Eq. 7.3

Where:

$TE_{rated,\ adj}$ = rated thermal efficiency proposed, adjusted to account for the conversion between combustion efficiency and thermal efficiency when applicable,[e] part-load operation (for multi-stage equipment) or cycling losses (for single-stage equipment), and return water temperature[f] (see appendix 7B for more detail),
Q_{in} = as defined in Eq. 7.2, and
BHL_{boiler} = building heating load (BHL) served by a single boiler operating at full load (kBtu/yr).

See appendix 7B of this TSD for more details on the adjustments made to rated thermal efficiency.

The annual building heating load (BHL_{boiler}) is the total amount of heat output from the boiler that the building needs during the heating season.[g] DOE determined BHL_{total} for each sampled building or housing unit, based on the efficiency of the existing boiler, using the following calculation:

$$BHL_{boiler} = Q_{YR} \times TE_{ex,adj}$$

Eq. 7.4

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[e] DOE determines a relationship between the combustion efficiency and thermal efficiency for equipment classes using combustion efficiency as the efficiency metric. See appendix 7B of this TSD for more details.

[f] Return water temperature represents the average annual return water temperature for the different space heating applications.

[g] BHL is the load served by a single boiler. DOE assumes that 50 percent of buildings are served by two boilers that share the load equally, while the remaining 50 percent are served by one boiler.

Where:

Q_{YR} = annual fuel consumption for space heating based on CBECS 2003 or RECS 2009 (kBtu/yr),
$TE_{ex,adj}$ = thermal efficiency of the existing boiler (TE_{ex}) adjusted for the same considerations as in the case of $TE_{rated,\ adj}$.

Both CBECS 2003 and RECS 2009 report space heating energy use (Q_{YR}) for each of the sampled buildings. See appendix 7B of this TSD for more details about the derivation of the BHL.

The thermal efficiency of the existing boiler (TE_{ex}) is determined by matching historical efficiency data to the distribution of boiler age for CBECS 2003 buildings or reported age of the boiler in RECS 2009.[h] The efficiency of the existing boiler is adjusted to account for differences in average return water temperature (RWT) and cycling losses. Appendix 7B of this TSD provides additional detail regarding the derivation of the adjustment values.

Section 7B.2.1 of appendix 7B of this TSD provides the adjustments to the efficiency of the existing boiler based on RWT application types, cycling losses, and part-load operation. High RWT is applied to all non-condensing boiler installations. For condensing boiler installations, low RWT is applied to all boilers in the new construction market, 25 percent of replacement boilers in buildings built after 1990, and 5 percent of replacement boilers in buildings built before 1990. DOE assumes that all other condensing boiler installations are high RWT applications. The efficiency adjustment for low and high RWT is dependent on climate.

DOE adjusts the efficiency of two-stage and modulating condensing boilers to account for increased efficiency at part-load operation. In addition, for non-condensing boilers, DOE accounts for the decrease in efficiency due to cycling. See appendix 7B of this TSD for the adjustment factors used for RWT, part-load operation, and cycling by climate zone.

DOE adjusts the BHL to reflect the expectation that the buildings in 2019 will have a somewhat different BHL than the buildings in the CBECS 2003 and RECS 2009 building sample. The adjustment involves multiplying the calculated BHL for each CBECS 2003 or RECS 2009 building by the building shell efficiency index from *AEO2014.*[i,4,5] This factor differs for commercial and residential buildings, as well as new construction and replacement buildings. The factor in the analysis for commercial buildings ranges from 0.75 to 0.98 for replacements (depending on building type) and from 0.84 to 1.00 for new construction, while for residential buildings, it ranges from 0.79 to 0.97 for replacements and from 0.91 to 1.03 for new construction. This means that buildings on average will have lower or slightly lower space heating load compared to commercial buildings in 2003 or residential buildings in 2009.

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[h] CBECS 2003 does not report the age of the equipment, so DOE created a uniform distribution to estimate the age of the equipment.

[i] The building shell efficiency index sets the heating load value at 1.00 for an average commercial building in 2003 and an average residential building (by type) in 2009 in each census division. The current analysis is based on information from the National Energy Modeling System (NEMS) simulation performed for EIA's Annual Energy Outlook (*AEO2013*[4] for commercial buildings and *AEO2014*[5] for residential buildings). See appendix 7B for more details.

DOE also adjusts the BHL_{TOTAL} calculated using heating degree days reported in CBECS 2003 and RECS 2009 for each building, using National Oceanic and Atmospheric Administration (NOAA) data by region to reflect historical average climate conditions.[6] The adjustment factors are calculated using the following equation:

$$Adj_{factor_{average_{climate}}} = \frac{HDD_{10\_yr\_avg}}{HDD_{bldg}}$$

Eq. 7.5

Where:

HDD_{bldg}= HDD in 2003 or 2009 for commercial or residential buildings (respectively), for the specific region where the building is located, and
$HDD_{10\_yr\_avg}$ = 10-year average HDD (2004–2013) based on NOAA data for the specific region where the building is located.[j]

The adjustment factors for commercial buildings range from 0.94 to 0.97 (*i.e.*, 2003 was in general colder than the 10-year average), while the residential sample factors range from 0.94 to 1.05.

DOE understands that some of the sampled buildings use multiple heating appliances with the same fuel as the boiler(s), such as a central furnace, wall furnace, room heater, stove, or fireplace. Therefore, DOE adjusts the calculated BHL when necessary to reflect the use of secondary heating equipment using the same fuel as the boiler(s). The adjustment factors are calculated using reported survey information from both CBECS 2003 and RECS 2009 regarding the fraction of heating that is met by different heating equipment. See appendix 7B of this TSD for more details.

7.3.1.2 Determination of Equipment Sizing

To support the calculation of space heating energy use, DOE establishes a methodology for deriving the boiler fuel input rate of each of the sampled buildings. The determination of the fuel input rate of the boiler accounts for the adjusted heating load of the building (adjusted with the considerations described above), the efficiency of the existing boiler, and the oversize factor. The boiler fuel input rate is assumed to be the same for the existing boiler and the boiler being considered under the standard.

$$Q_{in} = \frac{AdjustedHeatLoad}{TE_{existing}} \times OversizeFactor$$

Eq. 7.6

Where:

AdjustedHeatLoad = estimated building heat loss adjusted for building weather location (kBtu/h) (see appendix 7B),

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[j] The last 10-year average is used to normalize the HDD values, which is similar to what is done in *AEO2014*.

$TE_{existing}$ = thermal efficiency of the existing boiler for each product class (appendix 7B of this TSD), and,
OversizeFactor = 1.1, based on input from consultants on typical sizing practices.

DOE calculates the adjusted heating load for each sample building or housing unit based on the applicable building characteristics and outdoor conditions derived from the CBECS and RECS data.

DOE develops a methodology to derive the total heat loss of the building (*i.e.*, adjusted heating load). Appendix 7B of this TSD presents the variables used as well as further information about the building characteristics and heating load values used for the sizing of boiler equipment.

7.3.2 Water Heating Energy Consumption

Commercial packaged boilers are often used to provide hot water in addition to space heating. The most common means of doing so are through an indirect water heater, a tankless coil, or as an integrated part of the boiler.

CBECS 2003 and RECS 2009 do not provide information about when a commercial packaged boiler is used to provide hot water. Where CBECS or RECS report that the buildings used the same fuel for both space and water heating, DOE assumes that 20 percent of the installations also use boilers for water heating.

To calculate the water heating energy use, DOE calculates the boiler fuel use for water heating based on the following equation:

$$FuelUse_{WH} = \frac{WHL}{TE - Adj\_Factor_{WH}}$$

Eq. 7.7

Where:

WHL = water heating energy use based on CBECS 2003 or RECS 2009,
TE = thermal efficiency of the selected efficiency level, and
Adj_Factor_{WH} = adjustment factor to take into account the difference between thermal efficiency and recovery efficiency for water heating, which is assumed to be 4.5 percent thermal efficiency for non-condensing units and 2.25 percent thermal efficiency for condensing units. A heat loss of 0.5 kBtu/h was considered for indirect water heaters.

DOE uses the following equation to calculate the water heating load (WHL):

$$WHL = Q_{YR,HW} \times (TE_{ex} - Adj\_Factor_{WH})$$

Eq. 7.8

Where:

$Q_{YR,HW}$ = annual fuel consumption for water heating based on CBECS 2003 or RECS 2009 (kBtu/yr),
TE_{ex} = TE of the existing boiler (appendix 7B of this TSD), and
Adj_Factor_{WH} = as defined previously.

7.3.3 Electricity Consumption

DOE calculates boiler electricity consumption for the circulating pump, the draft inducer (in the case of mechanical draft equipment), and the igniter. The circulating pump moves water through the building whenever the boiler burner is on (adjusted for delay times between burner and pump operation). If the boiler provides water heating, the circulating pump also operates in the cooling season (summer) when there is a call for water heating. In the case of modulating condensing boilers, to accommodate for lower firing rates, the inducer provides lower combustion airflow to regulate the excess air in the combustion process.

DOE also takes into account the electricity consumption of auxiliary equipment, such as condensate pumps, which are sometimes installed with higher efficiency equipment. If a building requires a condensate pump, DOE assumes that the pump consumes 60 watts and operates at the same time as the burner. Details regarding how DOE determines whether a building requires a condensate pump can be found in appendix 8D of this TSD.

DOE calculates the electricity consumption as:[k]

$$ElecUse_{total} = BOH_{SH} \times Adj_{BOH} \times ElecPower + ElecBOH_{WH} \times ElecPower + StdbyHrs \times StdbyPower$$

Eq. 7.9

Where:

BOH_{SH} = as defined in Eq. 7.2,
Adj_{BOH} = adjustment factor that takes into account part-load operation (for condensing units only),
$ElecPower$ = power of multiple electrical components required during boiler operation, (kW),
$ElecBOH_{WH}$ = assumed to be 20 percent of BOH_{SH} adjusted for part-load operation,
$StdbyPower$ = total standby power of the equipment, and
$StdbyHrs$ = standby hours, taking into account periods of water heating in the summer

Further details for calculating electricity consumption appear in appendix 7B of this TSD.

7.4 SUMMARY OF ENERGY USE RESULTS

This section presents the average annual energy use and the average energy savings for each considered energy efficiency level compared to the baseline energy efficiency for each CPB

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[k] For two-stage and modulating equipment, this formula includes parameters for the operation at full, modulating, and reduced load. See appendix 7B.

equipment class. The results reflect energy use in both the commercial and residential samples. The LCC and payback period (PBP) analyses use the results calculated for each sample building. Negative results indicate that energy use increases.

Table 7.4.1 Average Annual Energy Consumption and Savings for Commercial Packaged Boilers

EL	**Design Option**	**Annual Fuel Use**		**Annual Electricity Consumption of Auxiliary Components**	
		Total *MMBtu/yr*	**Savings** *MMBtu/yr*	**Total** *kWh/yr*	**Savings** *kWh/yr*
Gas-Fired Hot Water Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h					
0	80% TE - Baseline	1123.0	-	752.3	-
1	81% TE	1109.2	13.7	743.7	8.6
2	82% TE	1095.9	27.1	735.2	17.1
3	84% TE	1070.1	52.9	719.0	33.3
4	85% TE	1057.7	65.3	711.1	41.2
5	93% TE	1015.9	107.1	1006.6	-254.3
6	95% TE	993.4	129.5	985.4	-233.1
7	99% TE - Max Tech	951.4	171.6	945.7	-193.4
Gas-Fired Hot Water Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h					
0	82% CE - Baseline	4954.5	-	1481.2	-
1	83% CE	4889.1	65.4	1462.1	19.0
2	84% CE	4825.4	129.1	1443.6	37.6
3	85% CE	4763.3	191.2	1425.5	55.7
4	94% CE	4509.9	444.6	1961.8	-480.6
5	97% CE - Max Tech	4349.7	604.9	1893.4	-412.2
Oil-Fired Hot Water Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h					
0	82% TE - Baseline	717.7	-	558.1	-
1	83% TE	709.0	8.7	551.6	6.5
2	84% TE	700.5	17.2	545.3	12.8
3	85% TE	692.2	25.5	539.1	19.0
4	87% TE	676.2	41.5	527.2	30.9
5	88% TE	668.5	49.2	521.4	36.6
6	97% TE - Max Tech	635.7	82.0	706.5	-148.4
Oil-Fired Hot Water Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h					
0	84% CE - Baseline	4777.9	-	2031.0	-
1	86% CE	4672.9	105.0	1987.3	43.7
2	88% CE	4572.4	205.5	1945.5	85.5
3	89% CE	4523.8	254.2	1925.3	105.7
4	97% CE - Max Tech	4399.5	378.4	2714.5	-683.4
Gas-Fired Steam Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h					
0	77% TE - Baseline	1014.4	-	534.4	-
1	78% TE	1001.3	13.1	527.8	6.6
2	79% TE	988.6	25.8	521.4	13.1
3	80% TE	976.2	38.3	515.1	19.4
4	81% TE	964.0	50.4	508.9	25.5
5	83% TE - Max Tech	940.7	73.8	497.1	37.4

EL	Design Option	Annual Fuel Use		Annual Electricity Consumption of Auxiliary Components	
		Total *MMBtu/yr*	**Savings** *MMBtu/yr*	**Total** *kWh/yr*	**Savings** *kWh/yr*
Gas-Fired Steam Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h					
0	77% TE - Baseline	5203.1	-	1508.6	-
1	78% TE	5135.8	67.4	1489.5	19.1
2	79% TE	5070.2	133.0	1470.8	37.8
3	80% TE	5006.2	197.0	1452.6	55.9
4	81% TE	4943.8	259.3	1434.9	73.7
5	82% TE	4883.0	320.2	1417.6	91.0
6	84% TE - Max Tech	4765.6	437.5	1384.3	124.3
Oil-Fired Steam Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h					
0	81% TE - Baseline	902.0	-	739.1	-
1	83% TE	880.1	21.9	722.0	17.1
2	84% TE	869.6	32.4	713.8	25.3
3	86% TE - Max Tech	849.3	52.8	697.9	41.2
Oil-Fired Steam Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h					
0	81% TE - Baseline	4732.5	-	2034.8	-
1	83% TE	4617.7	114.8	1986.7	48.2
2	85% TE	4508.3	224.2	1940.8	94.1
3	87% TE - Max Tech	4404.0	328.5	1897.0	137.9

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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 database, using Microsoft ACCESS, which contains a subset of the records and variables from the Energy Information Administration (EIA) Commercial Buildings Energy Consumption Surveys (CBECS) and Residential Energy Consumption Survey (RECS)—CBECS 2003,[1] CBECS 2012,[2] and RECS 2009.[3] DOE uses the subsets from these records in the life-cycle cost (LCC) analysis of the commercial packaged boiler (CPB) 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 CBECS 2012 partial dataset, refer to www.eia.gov/consumption/commercial/data/2012/index.cfm?view=microdata.

For the entire RECS 2009 dataset, refer to www.eia.gov/consumption/residential/data/2009/index.cfm?view=microdata.

7A.2 CBECS 2003 SAMPLE DETERMINATION

Table 7A.2.1 presents the main CBECS 2003 variables used in the development of the CPB data sample.

Table 7A.2.1 List of CBECS 2003 Variables Used for the Development of the Commercial Packaged Boiler Sample

Variable	Description
Location Variables	
CENDIV8	Census division
HDD658	Heating degree days (base 65)
CDD658	Cooling degree days (base 65)
REGION8	Census region
Building Characteristics Variables	
PUBID8	Building identifier
ADJWT8	Final full sample building weight
YRCON8	Year of construction category
SQFT8	Square footage category
PBA8	Principal building activity
OWNER8	Owner
MAINHT8	Main heating equipment
HEATP8	Percent heated
BOILP8	Percent heated by boilers
BOILER8	Boilers inside the building
StationID*	ID number of weather station identified with household (See appendix 7C of this TSD)
ASHRAE Climate Region*	Representative climate based on heating and cooling degree days.

Variable	Description
PRHT18	Propane used for main heating
PRHT28	Propane used for secondary heating
NGHT18	Natural gas used for main heating
NGHT28	Natural gas used for secondary heating
ELHT18	Electricity used for main heating
ELHT28	Electricity used for secondary heating
FKHT18	Fuel oil used for main heating
FKHT28	Fuel oil used for secondary heating
NWMNHT8	Main heating replaced since 1990
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)

* The American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) Climate Region is not part of CBECS 2003 variables.

** mBtu is the notation used in CBECS to denote a thousand Btu.

7A.3 CBECS 2003 DATABASE VARIABLE RESPONSE CODES

Table 7A.3.1 provides the response codes for all CBECS 2003 variables used in the CPB data sample.

Table 7A.3.1 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

Variable	Response Codes	
SQFT8	0–9999999996	0,000,000,009
	9999999997	Not ascertained
	9999999998	Refused
	9999999999	Don't know
HDD658	Heating degree days in 2003, base temperature 65 °F	
CDD658	Cooling degree days in 2003, base temperature 65 °F	
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
OWNER8	01	Property management company
	02	Other corporation/partnership/LLC
	03	Religious organization
	04	Other non-profit organization
	05	Privately-owned school
	06	Individual owner
	07	Other nongovernment owner
	08	Federal government
	09	State government
	10	Local government
MAINHT8	1	Furnaces that heat air directly
	2	Boilers inside the building
	3	Packaged heating units
	4	Individual space heaters
	5	Heat pumps for heating
	6	District steam or hot water
	7	Other heating equipment
HEATP8	0–996	009
	997	Not ascertained
	998	Refused
	999	Don't know
BOILP8	0–996	009
	997	Not ascertained
	998	Refused
	999	Don't know

Variable	Response Codes
BOILER8	1 Yes 2 No 7 Not Ascertained 8 Refused 9 Don't Know
StationID*	Three character identifier for weather station
ASHRAE Climate Region*	1 Miami, Florida 2 Houston, Texas 3 Phoenix, Arizona 4 Atlanta, Georgia 5 Los Angeles, California 6 Las Vegas, Nevada 7 San Francisco, California 8 Baltimore, Maryland 9 Albuquerque, New Mexico 10 Seattle, Washington 11 Chicago, Illinois 12 Denver, Colorado 13 Minneapolis, Minnesota 14 Helena, Montana 15 Duluth, Minnesota 16 Fairbanks, Alaska
NGHT18	1 Yes 2 No 7 Not Ascertained 8 Refused 9 Don't Know
NGHT28	1 Yes 2 No 7 Not Ascertained 8 Refused 9 Don't Know
PRHT18	1 Yes 2 No 7 Not Ascertained 8 Refused 9 Don't Know
PRHT28	1 Yes 2 No 7 Not Ascertained 8 Refused 9 Don't Know
ELHT18	1 Yes 2 No 7 Not Ascertained 8 Refused 9 Don't Know
ELHT28	1 Yes 2 No 7 Not Ascertained 8 Refused 9 Don't Know

Variable	Response Codes
FKHT18	1 Yes 2 No 7 Not Ascertained 8 Refused 9 Don't Know
FKHT28	1 Yes 2 No 7 Not Ascertained 8 Refused 9 Don't Know
NWMNHT8	1 Yes 2 No 7 Not Ascertained 8 Refused 9 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
FKWATR8	1 Yes 2 No 7 Not Ascertained 8 Refused 9 Don't Know
NGHTBTU8	Thousand BTU
FKHTBTU8	Thousand BTU
ELHTBTU8	Thousand BTU
NGWTBTU8	Thousand BTU
FKWTBTU8	Thousand BTU
ELWTBTU8	Thousand BTU

* Not part of CBECS 2003 variables.

7A.4 CBECS 2012 DATABASE

EIA released only building characteristic micro-data tables for CBECS 2012 in June 2015. These buildings could not be used as sample buildings for this rulemaking because they did not have energy consumption details. The CBECS 2012 dataset, though partial in nature, was used for developing the trends in the shipment analysis and distribution of samples across various equipment classes during the analysis period.

DOE noted that that the CBECS variable definitions in 2012 are nearly the same as those used in 2003 except that the 2012 CBECS variable names do not end with any number, which earlier indicated the survey series sequence number starting from 1979. EIA, however, has withheld the response on climate zones in CBECS 2012, which would be useful information for

DOE's analysis. In this series, CBECS has additional data on the types of thermal distribution systems that pair with the boilers in commercial buildings.

7A.5 RECS SAMPLE DETERMINATION

Table 7A.5.1 presents the main RECS 2009 variables used in the development of the CPB data sample.

Table 7A.5.1 List of RECS 2009 Variables Used for the Development of the Commercial Packaged Boiler Sample

Variable	Description
Location Variables	
REGIONC	Census Region
DIVISION	Census Division
REPORTABLE_DOMAIN	Reportable states and groups of states
HDD65	Heating degree days in 2009, base temperature 65 °F
CDD65	Heating degree days in 2009, base temperature 65 °F
Household Characteristics Variables	
NWEIGHT	Final sample weight
DOEID	Unique identifier for each respondent
TYPEHUQ	Type of housing unit
YEARMADE	Year housing unit was built
BTUNGSPH	Natural Gas usage for space heating, in thousand Btu, 2009
BTULPSPH	LPG/Propane usage for space heating, in thousand Btu, 2009
BTUFOSPH	Fuel Oil usage for space heating, in thousand Btu, 2009
BTUELSPH	Electricity usage for space heating, in thousand Btu, 2009
BTUNGWTH	Natural Gas usage for water heating, in thousand Btu, 2009
BTULPWTH	LPG/Propane usage for water heating, in thousand Btu, 2009
BTUFOWTH	Fuel Oil usage for water heating, in thousand Btu, 2009
BTUELWTH	Electricity usage for water heating, in thousand Btu, 2009
EQUIPM	Type of main space heating equipment used
FUELHEAT	Main space heating fuel
HEATOTH	Main space heating equipment heats other homes, business, or farm
MAINTHT	Routine service or maintenance performed on main space heating equipment
EQUIPAGE	Age of main space heating equipment
RADFUEL	Fuel used by hot water system for secondary space heating
EQMAMT	Portion of space heating provided by main space heating equipment (for homes with main and secondary heating only)
COOLTYPE	Type of air conditioning equipment used
CENACHP	Central air conditioner is a heat pump
NUMH2ONOTNK	Number of tankless water heaters
NUMH2OHTRS	Number of storage water heaters
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)
WHEATAGE	Main water heater age
NHSLDMEM	Number of household members
Seniors[*]	Number of household members age 65 or older
POVERTY100	Household income at or below 100% of poverty line
StationID[*]	ID number of weather station identified with household (See Appendix 7D)

Variable	Description
STORIES	Number of stories in a single-family home
ASHRAE Climate Region	Representative climate region based on heating and cooling degree days.
MONEYPY	2009 gross household income
NUMAPTS	Number of apartment units in a 5+ unit apartment building
NAPTFLRS	Number of floors in an apartment (Number of levels in housing unit that is an apartment)
HIGHCEIL	High ceilings
CATHCEIL	Cathedral ceilings
WALLTYPE	Major outside wall material
TOTSQFT	Total square footage (includes all attached garages, all basements, and finished/heated/cooled attics)
TOTSQFT_EN	Total square footage (includes heated/cooled garages, all basements, and finished/heated/cooled attics). Used for EIA data tables.
TOTHSQFT	Total heated square footage

* Not part of RECS 2009 variables.

7A.6 RECS 2009 DATABASE VARIABLE RESPONSE CODES

Table 7A.6.1 provides the response codes for all RECS 2009 variables used in the CPB sample.

Table 7A.6.1 Definitions of RECS 2009 Variables Used in Life-Cycle Cost Analysis

Variable	Response Codes
BTUELSPH	Thousand Btu
BTUELWTH	Thousand Btu
BTUFOSPH	Thousand Btu
BTUFOWTH	Thousand Btu
BTULPSPH	Thousand Btu
BTULPWTH	Thousand Btu
BTUNGSPH	Thousand Btu
BTUNGWTH	Thousand Btu
CATHCEIL	0 No 1 Yes -2 Not Applicable
CDD65	Cooling degree days in 2009, base temperature 65 °F
CENACHP	0 No 1 Yes -2 Not Applicable
COOLTYPE	1 Central system 2 Window/wall units 3 Both a central system and window/wall units -2 Not Applicable

Variable	Response Codes	
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)
DOEID	00001–12083	Unique identifier for each respondent
EQMAMT	1	Almost all
	2	About three-fourths
	3	Closer to half
	-2	Not Applicable
EQUIPAGE	1	Less than 2 years old
	2	2 to 4 years old
	3	5 to 9 years old
	41	10 to 14 years old
	42	15 to 19 years old
	5	20 years or older
	-2	Not Applicable
EQUIPM	2	Steam or Hot Water System
	3	Central Warm-Air Furnace
	4	Heat Pump
	5	Built-In Electric Units
	6	Floor or Wall Pipeless Furnace
	7	Built-In Room Heater
	8	Heating Stove
	9	Fireplace
	10	Portable Electric Heaters
	11	Portable Kerosene Heaters
	12	Cooking Stove
	21	Other Equipment
	-2	Not Applicable
FUELH2O	1	Natural Gas
	2	Propane/LPG
	3	Fuel Oil
	4	Kerosene
	5	Electricity
	7	Wood
	8	Solar
	21	Other Fuel
	-2	Not Applicable

Variable	Response Codes
FUELHEAT	1 Natural Gas 2 Propane/LPG 3 Fuel Oil 4 Kerosene 5 Electricity 7 Wood 8 Solar 9 District Steam 21 Other Fuel -2 Not Applicable
H2OTYPE1	1 Storage water heater 2 Tankless water heater -2 Not Applicable
HDD65	Heating degree days in 2009, base temperature 65 °F
HEATOTH	0 No 1 Yes -2 Not Applicable
HIGHCEIL	0 No 1 Yes -2 Not Applicable
MAINTHT	0 No 1 Yes -2 Not Applicable
NAPTFLRS	1–9 Number of floors in apartment -2 Not Applicable
NHSLDMEM	0–15 Number of household members
NUMAPTS	5–995 Number of apartment units -2 Not Applicable
NUMH2OHTRS	0–9 Number of Storage Water Heaters
NUMH2ONOTNK	0–9 Number of Tankless Water Heaters
NWEIGHT	Final sample weight
RADFUEL	1 Natural Gas 2 Propane/LPG 3 Fuel Oil 4 Kerosene 5 Electricity 7 Wood 8 Solar 9 District Steam 21 Other Fuel -2 Not Applicable
REGIONC	1 Northeast Census Region 2 Midwest Census Region 3 South Census Region 4 West Census Region

Variable	Response Codes
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
Seniors*	0 No 1 Yes
POVERTY100	0 No 1 Yes
StationID*	Three character identifier for weather station

Variable	Response Codes
ASHRAE Climate Region	1 Miami, Florida 2 Houston, Texas 3 Phoenix, Arizona 4 Atlanta, Georgia 5 Los Angeles, California 6 Las Vegas, Nevada 7 San Francisco, California 8 Baltimore, Maryland 9 Albuquerque, New Mexico 10 Seattle, Washington 11 Chicago, Illinois 12 Denver, Colorado 13 Minneapolis, Minnesota 14 Helena, Montana 15 Duluth, Minnesota 16 Fairbanks, Alaska
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
STORIES	10 One story 20 Two stories 31 Three stories 32 Four or more stories 40 Split-level 50 Other type -2 Not Applicable
TOTHSQFT	Square Feet
TOTSQFT	Square Feet
TOTSQFT_EN	Square Feet

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
WALLTYPE	1	Brick
	2	Wood
	3	Siding (Aluminum, Vinyl, Steel)
	4	Stucco
	5	Composition (Shingle)
	6	Stone
	7	Concrete/Concrete Block
	8	Glass
	9	Other
WHEATAGE	1	Less than 2 years old
	2	2 to 4 years old
	3	5 to 9 years old
	41	10 to 14 years old
	42	15 to 19 years old
	5	20 years or older
	-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
YEARMADE	1600–2009	Year housing unit was built

* Not part of RECS 2009 variables.

REFERENCES

1. U.S. Department of Energy–Energy Information Administration. *Commercial Buildings Energy Consumption Survey*. 2003. www.eia.doe.gov/emeu/cbecs/. Last accessed July 2015.

2. U.S. Department of Energy–Energy Information Administration. *Commercial Buildings Energy Consumption Survey*. 2012. www.eia.doe.gov/emeu/cbecs/. Last accessed July 2015.

3. U.S. Department of Energy–Energy Information Administration. *Residential Energy Consumption Survey, 2009 RECS Survey Data*. 2013. www.eia.gov/consumption/residential/data/2009/. Last accessed March 2015.

APPENDIX 7B. DETERMINATION OF BOILER ENERGY USE IN THE LIFE-CYCLE COST ANALYSIS

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APPENDIX 7B. DETERMINATION OF BOILER ENERGY USE IN THE LIFE-CYCLE COST ANALYSIS

7B.1 INTRODUCTION

For calculating the energy consumed by commercial packaged boilers, the U.S. Department of Energy (DOE) considers the energy use associated with providing space heating and domestic water heating. DOE develops a methodology for estimating the space heating and water heating energy use provided by boilers. The calculation to determine the total energy use per unit is as follows:

$$Energy\ Use_{Total} = FuelUse_{SH} + FuelUse_{WH} + ElecUse_{Total}$$

Eq. 7B.1

Where:

$FuelUse_{SH}$ = fuel used for space heating,
$FuelUse_{WH}$ = fuel used for water heating, and
$ElecUse_{Total}$ = electrical energy use

Refer to Chapter 7 for the space heating and water heating energy use calculation methodology. This appendix provides details on some of the inputs used in the calculations.

7B.2 DETERMINATION OF SPACE HEATING ANNUAL FUEL ENERGY CONSUMPTION

DOE calculates the annual fuel consumption (*FuelUse*) for each boiler using the following formula:

$$FuelUse_{SH} = BOH_{SH} \times Q_{in}$$

Eq. 7B.2

Where:

BOH_{SH} = space heating burner full-load operating hours (h/year), and
Q_{in} = input capacity of existing boiler (kBtu/h).

DOE derives space heating burner operating hours (BOH) from the building heating load served by a single boiler. Building heating load is determined from annual fuel consumption for heating reported in the U.S. Energy Information Administration (EIA) Commercial Buildings

Energy Consumption Survey (CBECS) and Residential Energy Consumption Survey (RECS), and is based on the efficiency of the existing boiler.[a]

7B.2.1 Thermal Efficiency Adjustments

In the determination of the annual fuel energy consumption, DOE adjusts the rated thermal efficiency (TE) to account for the conversion between combustion efficiency and thermal efficiency when applicable, part-load operation (in the case of multi-stage equipment) and cycling losses (for single-stage equipment), as well as return water temperature (RWT).

7B.2.1.1 Conversion Between Combustion Efficiency and Thermal Efficiency

DOE uses the Air-Conditioning, Heating, and Refrigeration Institute (AHRI) database to determine the relationship between combustion efficiency and thermal efficiency for equipment classes with combustion efficiency as the efficiency metric.[1] DOE develops a linear relationship between the two efficiency metrics from boiler models where both combustion efficiency and thermal efficiency are listed and where the thermal efficiency listed is less than or equal to the combustion efficiency value listed. The parameters are determined separately for gas-fired and oil-fired boilers. The following formula illustrates the relationship between the two efficiency metrics:

$$TE = a \times CE + b$$

Eq. 7B.3

The linear fit parameters are in Table 7B.2.1

Table 7B.2.1 Linear Fit Parameters for Converting Combustion Efficiency to Thermal Efficiency

	Oil	Gas
a	0.9228	1.0671
b	5.1667	-6.9213

7B.2.1.2 Adjustment to Rated Thermal Efficiency Based on Return Water Temperature Application, Part Load, and Cycling

Rated thermal efficiency and combustion efficiency for commercial packaged boilers are determined during laboratory testing under subpart E of Title 10 of the Code of Federal

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[a] CBECS is a national sample survey that collects information on the stock of U.S. commercial buildings, including their energy-related building characteristics and energy usage data (consumption and expenditures). See www.eia.gov/consumption/commercial/about.cfm. RECS is a nationally representative data sample of information about the energy characteristics of housing units, including usage patterns, and household demographics. This information is combined with data from energy suppliers to the homes to estimate energy costs and usage for heating, cooling, appliances and other end uses. See www.eia.gov/consumption/residential/index.cfm.

Regulations, Part 431 (10 CFR Part 431), section 431.86.[b] DOE is proposing revisions to the current test procedure for commercial packaged boilers.[c] The proposed test procedure prescribes a supply water temperature of 180 °F for non-condensing boilers and a supply water temperature of 120 °F for condensing boilers. The proposed test procedure provides for non-condensing boilers to be tested with a 140 °F entering water temperature to the boiler, and for condensing boilers to be tested with an 80 °F entering water temperature to the boiler. DOE's existing test procedure provided for an 80 °F supply water temperature for condensing boilers to the testing apparatus, while for non-condensing boilers the entering water temperature to the testing apparatus had an allowable range between 35 °F and 80 °F. The current test procedure provides for the use of a recirculating line to temper the entering water temperature to the boiler for non-condensing boilers but does not measure the entering water temperature to the boiler. An additional requirement when using the recirculating line is that the temperature rise through the boiler itself shall not be less than 20 °F. DOE assumes that the actual entering water temperature for non-condensing boiler testing is 140 °F during testing of non-condensing boilers, a value assumed to be representative of typical testing conditions under both proposed and current test procedures.[d] For condensing boilers, DOE assumes that condensing boilers are rated at a return water temperature of 80 °F.

The boiler return water temperature in typical installations varies by heating load and by heating application. DOE assumes that all boilers operate with supply water temperature reset. That is, at the peak heating load the supply water temperature is at its design temperature, or the highest temperature. At lower heating loads, the supply water temperature resets down to lower temperatures. In typical non-condensing boiler installations the design supply water temperature is 180 °F and can reset down to 155 °F. In typical condensing boiler installations the design supply water temperature is 160 °F and can reset down to 104 °F. While not optimal, some condensing boilers are installed in replacement situations, in which the supply water temperatures are higher, with a design of 180 °F and resetting down to 130 °F. DOE's analysis assumes an average temperature drop between the supply water temperature and the return water temperature of 20 °F. See Table 7B.2.2 for the assumed return water temperature as it varies with outside air temperature.

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[b] See www.ecfr.gov/cgi-bin/text-idx?type=simple;c=ecfr;cc=ecfr;sid=26fa9f9a78e320d5d603e37c3675a135;idno=10;region=DIV1;q1=431;rgn=div5;view=text;node=10%3A3.0.1.4.19

[c] The DOE website for commercial packaged boilers provides additional information about the test procedure development. See https://www1.eere.energy.gov/buildings/appliance_standards/rulemaking.aspx?ruleid=87

[d] Since it is desirable to keep non-condensing boilers from condensing, DOE assumes that the actual entering water temperature to a non-condensing boiler during testing with the current test procedure is typically higher than 135 °F and can best be approximated as providing non-condensing performance values similar to that of the proposed test procedure which uses a 140 °F entering water condition.

Table 7B.2.2 Return Water Temperatures at Each Outside Air Temperature Bin

Temperature Bin	Condensing Units - Low RWT *°F*	Condensing Units – High RWT *°F*	Non-Condensing Units – High RWT *°F*
Over 68 °F	-	-	-
50–68 °F	84	110	135
41–50 °F	112	132	150
28–41 °F	116	136	155
14–28 °F	129	149	160
At or below 14 °F	140	160	160

The relationship between RWT and efficiency for both condensing and non-condensing commercial packaged boilers is described below.

Several manufacturers publish a relationship between boiler TE and RWT for certain boiler series.[2,3,4,5,6] DOE uses the information to develop an average TE versus RWT relationship representative of boiler performance for a range of return water temperatures. The analysis assumes that the efficiencies scale according to the relationship reported for the TE. Figure 7B.2.1 presents the information from these sources and the derived average efficiency curve for condensing boilers.[e]

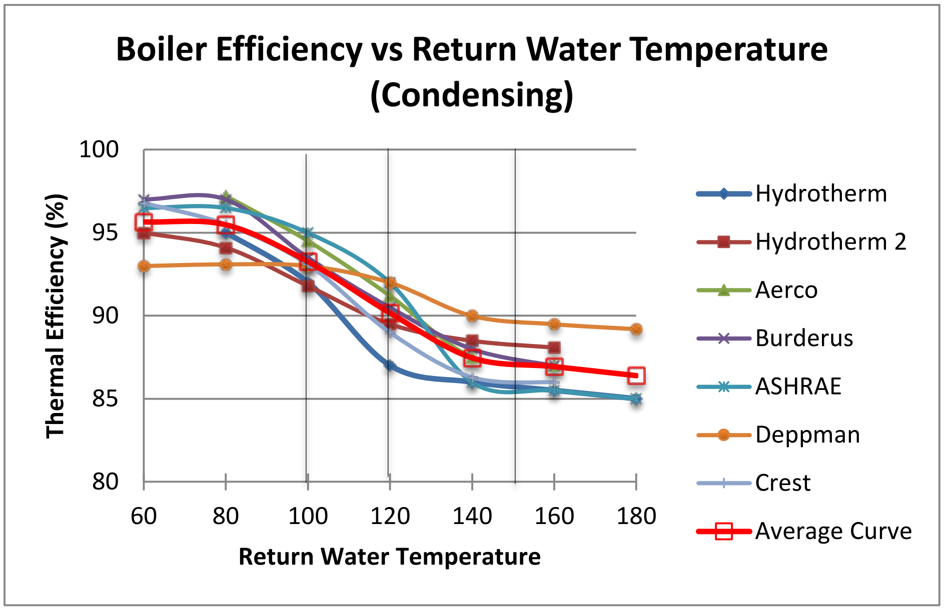

Figure 7B.2.1 Efficiency vs. Return Water Temperature, Condensing Boilers

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[e] The average efficiency curve represents the mean efficiency at each return water temperature reported in the manufacturers' information.

For condensing boilers, the analysis uses the average relationship shown in Figure 7B.2.2 to establish the magnitude of the efficiency adjustment required for the high and low temperature condensing boiler applications. As shown in Figure 7B.2.2, the relationship indicates an approximate reduction of 8 percent thermal efficiency for an average return water temperature of 140 °F and approximate reduction of 4.5 percent thermal efficiency for an average return water temperature of 115 °F, in both cases as compared to a return water temperature at 80 °F.

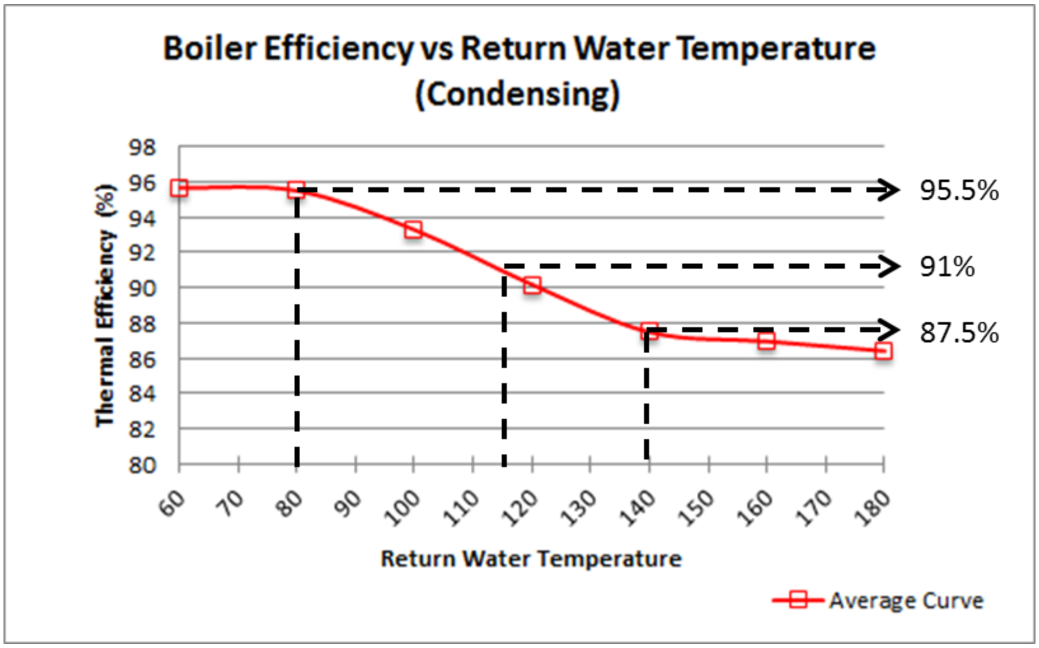

Figure 7B.2.2 Average Curve for Condensing Boilers

For non-condensing boilers, the analysis uses the average efficiency/RWT relationship at the 140-180 °F temperature range to establish the efficiency adjustment required for the high temperature applications. The data for temperatures between 140 °F and 180 °F is used to extrapolate the efficiency of the boiler under different return water temperatures in order to perform an adjustment to the rated efficiency of a boiler, which is assumed to be tested at 140 °F RWT. As shown in Figure 7B.2.3, the relationship may result in an adjustment of between +0.1% and -0.5% from its rated efficiency for return water temperatures between 135 °F and 160 °F, respectively.

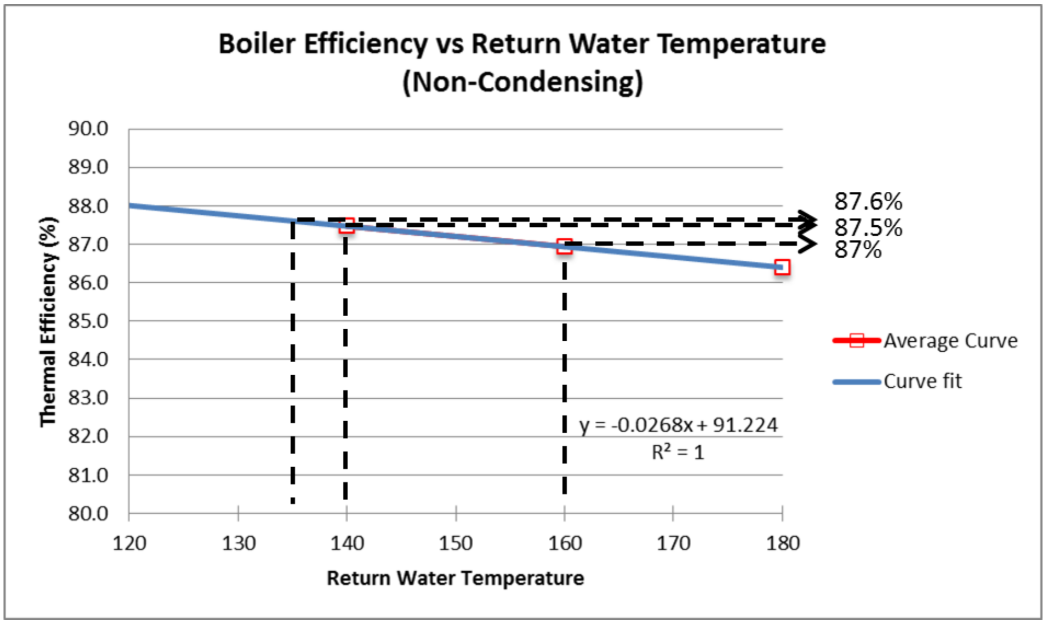

Figure 7B.2.3 Efficiency vs. Return Water Temperature, Non-Condensing Boilers

As described above, DOE addresses three different water temperature scenarios: high temperature non-condensing (RWT 135 °F to 160 °F), high temperature condensing (RWT 110 °F to 160 °F), and low temperature condensing (RWT 84 °F to 140 °F). DOE analyzes each of these three scenarios in each of the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) 16 climate zones. For each scenario, the annual average return water temperature is determined in each climate zone. For each average return water temperature, a thermal efficiency adjustment is determined per the figures above. The thermal efficiency adjustments in the analysis are shown in Table 7B.2.3.

Table 7B.2.3 Adjustment to Thermal Efficiency Based on RWT Application and Part Load or Cycling Operation for Commercial Packaged Boilers

ASHRAE Climate	ASHRAE Climate	Condensing		Non-Cond
Zone #	Zone Code	Low RWT Operation	High RWT Operation	High RWT Operation
1	1A	-4.1	-7.1	-0.3
2	2A	-4.6	-7.5	-0.4
3	2B	-4.2	-7.2	-0.3
4	3A	-5.1	-7.9	-0.4
5	3B-CA	-4.0	-7.1	-0.3
6	3B-other	-4.5	-7.4	-0.4
7	3C	-4.1	-7.2	-0.3
8	4A	-5.5	-8.1	-0.4
9	4B	-5.0	-7.8	-0.4
10	4C	-4.5	-7.5	-0.4
11	5A	-6.1	-8.4	-0.5
12	5B	-5.8	-8.3	-0.4
13	6A	-6.3	-8.5	-0.5
14	6B	-6.1	-8.4	-0.5
15	7	-6.7	-8.6	-0.5
16	8	-7.1	-8.6	-0.5

7B.2.1.3 Adjustment to Rated Thermal Efficiency Based on Part Load and Cycling

Typical non-condensing boilers may be single stage or two-stage, but do not often modulate beyond that. DOE assumes that all non-condensing boilers are single-stage. In a single-stage boiler when the load is low, the boiler cycles on and off to meet the load. The cycling produces losses as heat is lost to the mechanical room when the boiler cycles off. In view of information from consultants and relevant literature, DOE understands that the cycling losses increase as the heating load decreases. However, for boilers in multiple boiler systems, there exists an inherent turn-down capability for the boiler plant due to staging of individual boilers that may reduce the instance of boiler cycling in individual boilers, and, thus, the cycling related losses. DOE reviewed available literature to attempt to quantify the magnitude of cycling losses as a function of part load condition, and to then develop a relationship between the number of boilers and the actual cycling losses in single and multiple boiler systems.

A report prepared by the Center for Energy and the Urban Environment for the Legislative Commission on Minnesota Resources on field measurements of off-cycle losses and seasonal efficiency provided data on various types of commercial packaged boilers[f] used in multifamily residential applications. Three of the 15 boilers investigated were instrumented for intensive, long-term monitoring. DOE investigated the impact on efficiency of these boilers and developed an average curve fit for the normalized efficiency of a boiler, relative to its full load performance, as a function of boiler run time considering this data, as well as the data provided by consultants. Figure 7B.2.4 shows the normalized efficiency as a function of boiler run time, and the average curve used to establish the cycling adjustment factors.

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[f] Landry, R. W. et al. *Field Measurement of Off-Cycle Losses and Seasonal Efficiency for Major Classes of Multifamily Boilers*. May 1993. Center for Energy and Environment: Minneapolis, MN. Report No. CEE/TR93-5 MF.

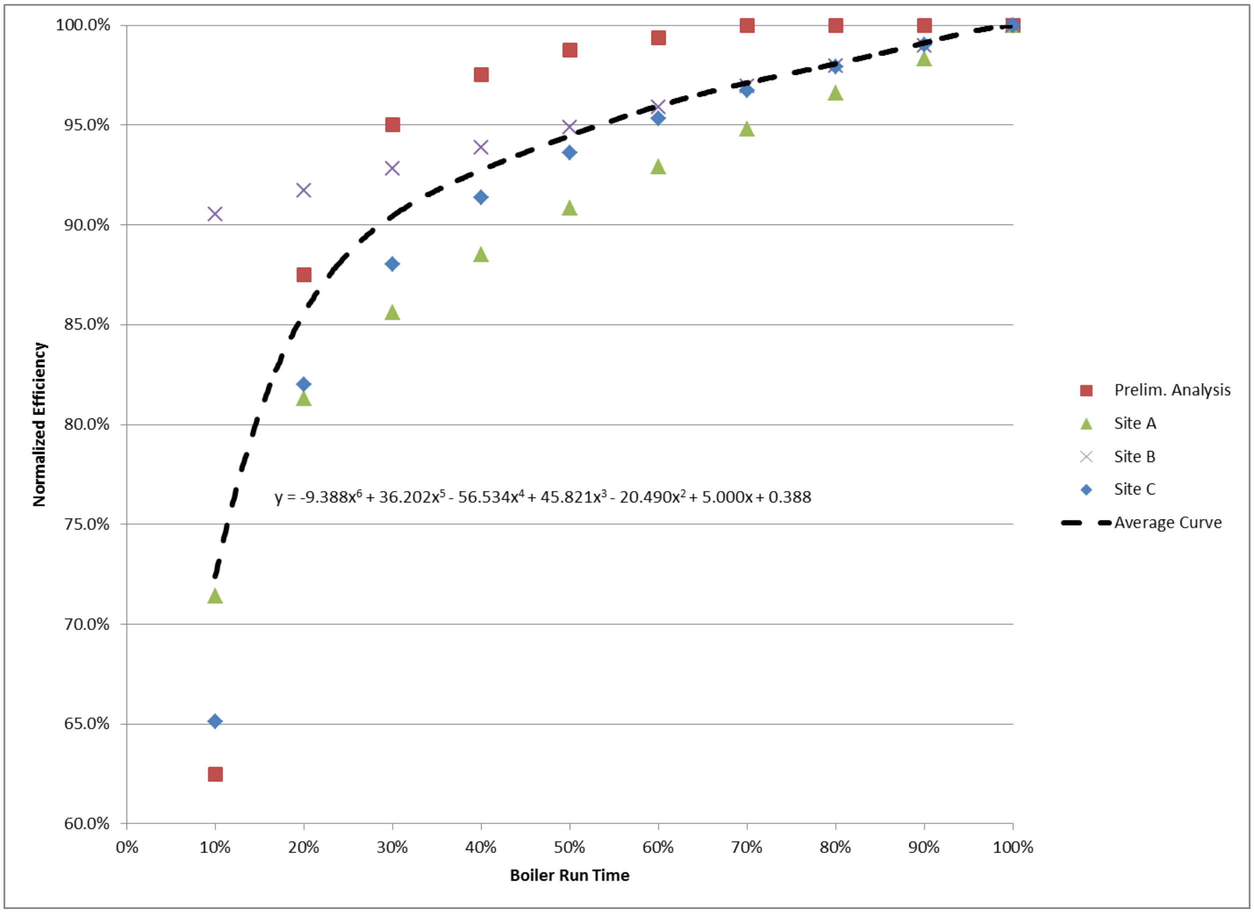

Figure 7B.2.4 Normalized Efficiency as a Function of Boiler Run Time for Three Commercial Packaged Boiler Sites and Consultant Provided Data.

DOE recognizes the inherent turn-down capability of multiple boiler systems and applied a factor that effectively scales the x-axis (i.e. boiler run time) based on the number of boilers in a system. For example, in a two-boiler system one of the boilers will be able to run continuously to provide heating as long as the system needs exceed 50% of the total system capacity. In essence, when the building load fraction is at 50%, the boiler run time for a single boiler would be 100%. Below a 50% building load fraction, the boiler would then start to experience cycling losses. The same principle may be applied to three, or more, boiler systems. DOE considered the cycling losses for boilers in systems with four or more boilers installed to be negligible and applied no cycling loss adjustment to such. Figure 7B.2.5 illustrates the impact on cycling losses of multiple boilers in a system and how DOE has applied an x-axis scaling factor to consider the turn-down capability of these multiple boiler systems.

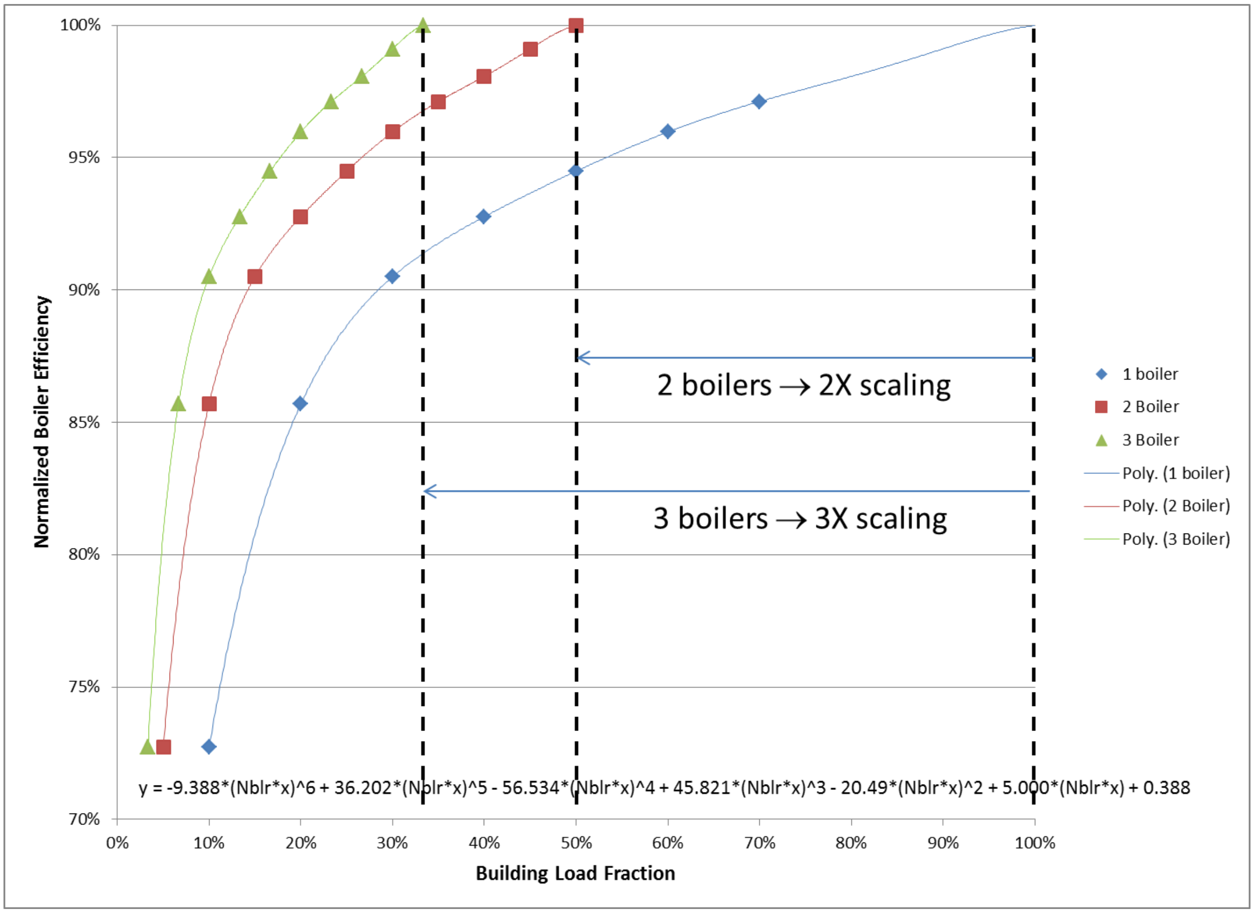

Figure 7B.2.5 Normalized Boiler Efficiency of a Commercial Packaged Boiler in a Multiple Boiler System.

Based on this analysis, DOE established cycling loss factors that it applied to systems with 1, 2, and 3 boilers in each climate zone.

Condensing boilers, on the other hand, typically modulate to meet the heating load. That is, if the heating load is low, then the firing rate will reduce in order to meet the load. Thermal efficiency increases as the boiler firing rate decreases. A typical relationship between burner input ratio and thermal efficiency is shown for one manufacturer in Figure 7B.2.6. See Table 7B.2.4 for the fraction of boiler input capacity required at different outside air temperatures.

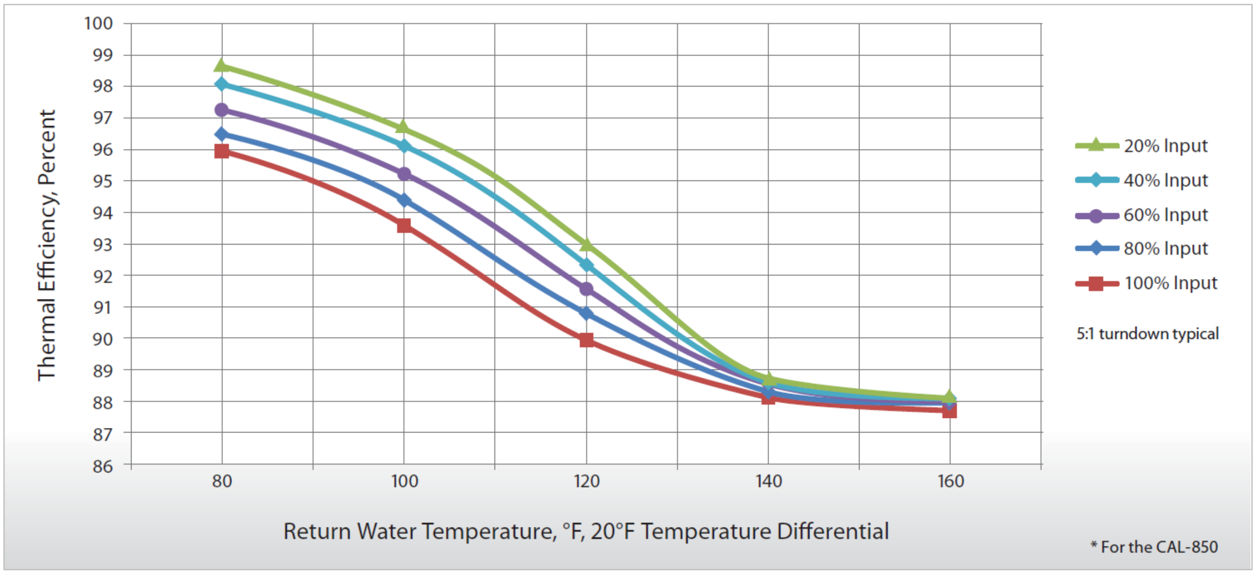

Figure 7B.2.6 Example Condensing Boiler Relationship between Burner Input Ratio and Thermal Efficiency[g]

Table 7B.2.4 Part Load at Each Outside Air Temperature Bin

Temperature Bin	Fraction of Boiler Capacity
Over 68 °F	-
50–68 °F	20%
41–50 °F	40%
28–41 °F	60%
14–28 °F	80%
At or below 14 °F	100%

For each of the 16 ASHRAE Climate Zones, the average percentage that the boiler is loaded compared to its full capacity is calculated based on outside air temperature. In view of the average load percentage, a cycling-load adjustment and a part-load adjustment can be calculated for non-condensing boilers and condensing boilers, respectively. See Table 7B.2.5 for the efficiency adjustment factors,[h] applied to condensing and non-condensing boilers as a function of climate region.

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[g] Fulton Caliber Condensing Boiler. www.fulton.com/product-profile.php?ptc=hw&uid=40.

[h] In applying adjustment factors to CPB efficiencies, two approaches were taken. The first is a simple percentage value addition or subtraction of the adjustment noted, as is done for part-load adjustment. The second, as was done for cycling loss adjustment, was to apply a multiplicative percentage factor to the efficiency of the CPB. For example, an 85% boiler with a -2.5% adjustment implies that the normalized efficiency under part-load condition is 97.5%. As such, the adjustment factor applied is (85% * 97.5%) - 85%, or -2.125 percentage points, resulting in an adjusted efficiency of 82.875%.

Table 7B.2.5 Adjustment to Thermal Efficiency Based on Part-Load and Cycling Operation

ASHRAE Climate Zone #	ASHRAE Climate Zone Code	Condensing Part Load Adj.	Non-Cond Adjustment for Cycling by Number of Boilers			
			1	2	3	>3
1	1A	2.15	-7.05%	-1.87%	-0.76%	0.00
2	2A	1.65	-4.74%	-1.42%	-0.58%	0.00
3	2B	2.03	-6.34%	-1.74%	-0.71%	0.00
4	3A	1.41	-3.78%	-1.20%	-0.49%	0.00
5	3B-CA	2.20	-7.23%	-1.93%	-0.77%	0.00
6	3B-other	1.73	-5.04%	-1.49%	-0.60%	0.00
7	3C	2.07	-6.69%	-1.80%	-0.73%	0.00
8	4A	1.10	-3.20%	-1.04%	-0.42%	0.00
9	4B	1.41	-3.78%	-1.20%	-0.49%	0.00
10	4C	1.70	-4.89%	-1.46%	-0.59%	0.00
11	5A	0.80	-2.59%	-0.85%	-0.35%	0.00
12	5B	0.95	-2.88%	-0.95%	-0.39%	0.00
13	6A	0.66	-2.31%	-0.76%	-0.31%	0.00
14	6B	0.76	-2.50%	-0.82%	-0.33%	0.00
15	7	0.51	-1.93%	-0.63%	-0.26%	0.00
16	8	0.33	-1.33%	-0.44%	-0.18%	0.00

7B.2.2 Assigning Boiler Equipment Characteristics to Sampled Buildings

To estimate the heating load of each sample building, DOE represents the existing boiler by assigning an input capacity and efficiencies to the boiler in the CBECS and RECS sample building units.

Table 7B.2.6 shows the original CBECS 2003 and RECS 2009 heating energy use.

Table 7B.2.6 Range of Existing Heating Energy Use Based on CBECS 2003 and RECS 2009 Data for Each Boiler Equipment Class, MMBtu/year

Equipment Class	Min	Max	Average	Percentiles				
				5%	25%	50%	75%	95%
Gas-Fired Hot Water Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h	8	20,216	1,221	148	499	832	1,458	3,728
Gas-Fired Hot Water Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h	79	54,867	5,487	891	2,040	3,634	6,617	15,457
Oil-Fired Hot Water Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h	62	10,516	871	62	516	602	1,223	2,002
Oil-Fired Hot Water Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h	424	16,346	5,741	1,757	4,321	5,227	6,699	10,245
Gas-Fired Steam Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h	13	20,216	1,160	187	436	832	1,477	2,906
Gas-Fired Steam Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h	79	26,998	5,865	999	2,119	3,974	8,594	18,289
Oil-Fired Steam Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h	114	10,516	1,094	243	580	835	1,404	3,272
Oil-Fired Steam Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h	424	15,608	5,771	1,757	4,182	5,227	6,796	10,245

Table 7B.2.7 shows the results for the range in adjusted heating load among sample buildings and households.

Table 7B.2.7 Range of Adjusted Heating Load for Each Boiler Equipment Class, MMBtu/year

Equipment Class	Min	Max	Average	Percentiles				
				5%	25%	50%	75%	95%
Gas-Fired Hot Water Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h	5	14,148	843	101	336	574	1,003	2,507
Gas-Fired Hot Water Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h	52	38,126	3,621	567	1,352	2,413	4,515	10,590
Oil-Fired Hot Water Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h	39	6,879	573	39	338	407	781	1,363
Oil-Fired Hot Water Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h	280	11,289	3,751	1,132	2,818	3,410	4,434	6,706
Gas-Fired Steam Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h	8	12,736	724	123	273	519	955	1,803
Gas-Fired Steam Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h	49	17,488	3,700	645	1,345	2,597	5,229	11,796
Oil-Fired Steam Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h	72	6,859	705	165	375	542	874	2,001
Oil-Fired Steam Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h	274	9,922	3,636	1,132	2,661	3,286	4,291	6,481

Table 7B.2.8 shows the results for the baseline heating boiler operating hours among sample buildings and households.

Table 7B.2.8 Range of Baseline Boiler Heating Annual Operating Hours for Each Boiler Equipment Class, hours

Equipment Class	Min	Max	Average	Percentiles				
				5%	25%	50%	75%	95%
Gas-Fired Hot Water Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h	8	8,760	1,264	173	589	1,016	1,472	3,459
Gas-Fired Hot Water Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h	8	6,520	906	216	333	733	1,206	2,129
Oil-Fired Hot Water Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h	53	5,091	1,104	53	735	1,095	1,483	2,459
Oil-Fired Hot Water Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h	135	3,474	1,169	419	908	1,165	1,308	1,949
Gas-Fired Steam Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h	21	8,760	1,140	324	611	1,000	1,376	2,676
Gas-Fired Steam Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h	8	4,408	990	149	476	963	1,334	2,095
Oil-Fired Steam Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h	146	4,974	1,281	315	821	1,353	1,660	2,085
Oil-Fired Steam Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h	134	3,205	1,127	520	893	1,146	1,189	1,846

7B.2.2.1 Input Capacity of Existing and New Equipment

The determination of the input capacity of the boiler accounts for the adjusted heating load of the building (adjusted with the considerations described above), the efficiency of the existing boiler, and the oversize factor. The boiler input capacity is assumed to be the same for the existing boiler and the boiler being considered under the standard.

$$Q_{in} = \frac{AdjustedHeatLoad}{TE_{existing}} \times OversizeFactor$$

Eq. 7B.4

Where:

AdjustedHeatLoad = estimated building heat loss adjusted for building weather location (kBtu/h),
$TE_{existing}$ = TE of the existing boiler for each equipment class, and
OversizeFactor = 1.1, based on input from consultants on typical sizing practices.

DOE calculates the adjusted heating load for the boilers in each sample building based on the applicable building characteristics and outdoor conditions derived from the CBECS and RECS data. DOE assumed a nominal heating load of 30 Btu/h/ft^2 corresponding to a design outdoor condition of 0 °F based on industry standard.[7] DOE determined the heated building area by multiplying the reported building area by the reported percentage of area heated and the percentage of heated area assignable to boilers. DOE then adjusted this load by the design outdoor air temperature of the climate region.

The derivation of the existing boiler efficiency is described in Section 7B.2.3. The boiler input capacity is assumed to be the same for the existing boiler and the boiler being considered under the standard.

7B.2.3 Derivation of Existing Efficiencies

As described in Chapter 7, the efficiency of existing equipment already installed is required to calculate the building heating load. DOE develops the historical distributions of efficiencies by equipment class for existing boilers based on the AHRI database from 2007 to 2009. DOE calculates the average efficiency of all boilers in each equipment class from the 2009 AHRI database to determine the existing efficiency for the year 2009. This calculated average is assumed to be the representative efficiency for that equipment class in 2009. The same process was used to determine the existing efficiencies in 2007 and 2008. DOE assumes that in 2005 and 2006 the existing efficiencies were equal to those in 2007. From 1973 to 2004 DOE has assumed that the existing efficiency reduced by 1 percent every 5 years. For all years prior to 1973 DOE has assumed that the efficiency was equal to that in 1973. See the historical efficiencies for natural draft and mechanical draft boilers by equipment class in Table 7B.2.9 and Table 7B.2.10, respectively.

Table 7B.2.9 Historical Efficiencies by Equipment Class, Natural Draft Boilers

Natural Draft	SGHW TE	LGHW CE	SOHW TE	LOHW CE	SGST TE	LGST TE	SOST TE	LOST TE
1973	75	75	76	78	71	72	74	75
1974	75	75	76	78	71	72	74	75
1975	76	76	77	79	72	73	75	76
1976	76	76	77	79	72	73	75	76
1977	76	76	77	79	72	73	75	76
1978	76	76	77	79	72	73	75	76
1979	76	76	77	79	72	73	75	76
1980	77	77	78	80	73	74	76	77
1981	77	77	78	80	73	74	76	77
1982	77	77	78	80	73	74	76	77
1983	77	77	78	80	73	74	76	77
1984	77	77	78	80	73	74	76	77
1985	78	78	79	81	74	75	77	78
1986	78	78	79	81	74	75	77	78
1987	78	78	79	81	74	75	77	78
1988	78	78	79	81	74	75	77	78
1989	78	78	79	81	74	75	77	78
1990	79	79	80	82	75	76	78	79
1991	79	79	80	82	75	76	78	79
1992	79	79	80	82	75	76	78	79
1993	79	79	80	82	75	76	78	79
1994	79	79	80	82	75	76	78	79
1995	80	80	81	83	76	77	79	80
1996	80	80	81	83	76	77	79	80
1997	80	80	81	83	76	77	79	80
1998	80	80	81	83	76	77	79	80
1999	80	80	81	83	76	77	79	80
2000	81	81	82	84	77	78	80	81
2001	81	81	82	84	77	78	80	81
2002	81	81	82	84	77	78	80	81
2003	81	81	82	84	77	78	80	81
2004	81	81	82	84	77	78	80	81
2005	82	82	83	85	78	79	81	82
2006	82	82	83	85	78	79	81	82
2007	82	82	83	85	78	79	81	82
2008	82	82	83	85	78	79	81	82
2009	82	82	83	85	78	79	81	82

Table 7B.2.10 Historical Efficiencies by Equipment Class, Mechanical Draft Boilers

Mechanical Draft	SGHW TE	LGHW CE	SOHW TE	LOHW CE	SGST TE	LGST TE	SOST TE	LOST TE
1973	78	77	76	78	73	73	75	75
1974	78	77	76	78	73	73	75	75
1975	79	78	77	79	74	74	76	76
1976	79	78	77	79	74	74	76	76
1977	79	78	77	79	74	74	76	76
1978	79	78	77	79	74	74	76	76
1979	79	78	77	79	74	74	76	76
1980	80	79	78	80	75	75	77	77
1981	80	79	78	80	75	75	77	77
1982	80	79	78	80	75	75	77	77
1983	80	79	78	80	75	75	77	77
1984	80	79	78	80	75	75	77	77
1985	81	80	79	81	76	76	78	78
1986	81	80	79	81	76	76	78	78
1987	81	80	79	81	76	76	78	78
1988	81	80	79	81	76	76	78	78
1989	81	80	79	81	76	76	78	78
1990	82	81	80	82	77	77	79	79
1991	82	81	80	82	77	77	79	79
1992	82	81	80	82	77	77	79	79
1993	82	81	80	82	77	77	79	79
1994	82	81	80	82	77	77	79	79
1995	83	82	81	83	78	78	80	80
1996	83	82	81	83	78	78	80	80
1997	83	82	81	83	78	78	80	80
1998	83	82	81	83	78	78	80	80
1999	83	82	81	83	78	78	80	80
2000	84	83	82	84	79	79	81	81
2001	84	83	82	84	79	79	81	81
2002	84	83	82	84	79	79	81	81
2003	84	83	82	84	79	79	81	81
2004	84	83	82	84	79	79	81	81
2005	85	84	83	85	80	80	82	82
2006	85	84	83	85	80	80	82	82
2007	85	84	83	85	80	80	82	82
2008	87	85	84	85	80	81	82	82
2009	87	85	84	86	80	81	82	82

7B.3 DETERMINATION OF ANNUAL ELECTRICAL ENERGY CONSUMPTION

DOE calculates the electricity consumption as:

$$ElecUse_{total} = BOH_{SH} \times Adj_{BOH} \times ElecPower + ElecBOH_{WH} \times ElecPower$$
$$+ StdbyHrs \times StdbyPower$$

Eq. 7B.5

Where:

BOH_{SH} = as defined previously,
Adj_{BOH} = adjustment factor that takes into account part-load operation (for condensing units only),
ElecPower = power of multiple electrical components required during boiler operation, (kW),
$ElecBOH_{WH}$ = assumed to be 20 percent of BOH_{SH} adjusted for part-load operation,
StdbyPower = total standby power of the equipment, and
StdbyHrs = standby hours, takes into account water heating times in the summer

7B.3.1 Boiler Electrical Components

DOE assumes that all hot water boilers have a circulating water pump. DOE assumes that small boilers have the same size pump and, likewise, large boilers have the same size pump. Table 7B.3.1 depicts the applicable input power in watts for the circulating water pump and the draft inducer.

Table 7B.3.1 Electrical Component Power

	Water Pump Electrical Power *watts*	**Draft Inducer Electrical Power** *watts*	
		Natural Draft	**Mechanical Draft**
SGHW	250	0	250
LGHW	950	0	500
SOHW	250	0	250
LOHW	950	0	500
SGST	250	0	250
LGST	950	0	500
SOST	250	0	250
LOST	950	0	500

7B.3.2 Standby Energy

DOE assumes that mechanical draft boilers have a standby power of 10.5 watts, based on the engineering analysis done for the Residential Boilers rulemaking.[8] Also, DOE assumes that natural draft boiler does not use any power while in standby mode.

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APPENDIX 7C. WEATHER STATION DATA MAPPING TO RECS AND CBECS 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) provide annual data about heating and cooling degree-days.[1,2] However, neither provide data about outdoor design temperature (ODT), monthly heating degree days (HDDs) and monthly cooling degree days (CDDs), and average outdoor temperature, which are important for the analysis. ODTs are used for sizing commercial packaged boiler (CPB) equipment as described in Appendix 7B. Energy price data used in this analysis are available on a monthly basis. Monthly HDDs are used to disaggregate the annual energy use provided by RECS and CBECS by month. Monthly energy use is combined with monthly energy prices to find the monthly operating cost.

7C.2 MAPPING METHODOLOGY

To derive the additional weather data that are needed for the analysis (*e.g.*, ODT, HDDs), for each building in the sample, the U.S. Department of Energy (DOE) assigns a physical location to each CBECS building and RECS household.[a] The methodology consists of the following steps:

1) DOE assembles National Oceanic and Atmospheric Administration (NOAA) monthly weather data from 360 weather stations. The data consist of reported heating and cooling degree days at base temperature 65 °F for year 2003 (for the CBECS sample), and year 2009 (for the RECS sample).[3] The 2003 and 2009 heating and cooling degree days match the time period used to determine the degree days in CBECS 2003 and in RECS 2009, respectively.

2) DOE gathers ODT data from the 1993 American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE) Handbook and only selects the weather stations for which NOAA provides HDDs and CDDs, thus reducing the number of weather stations in the matching process to 339.[4]

3) CBECS and RECS report both HDDs and CDDs to base temperature 65 °F for each building record. DOE assigns each building to one of the 339 weather stations by calculating which weather station (within the appropriate region) is the closest using the best linear least-squares fit of the CBECS/RECS data to the weather data. The following equation calculates the U.S. weather station closest (or with minimum "distance") to the CBECS/RECS building:

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[a] For confidentiality, heating and cooling degree day values were altered slightly by EIA to mask the exact geographic location of the housing unit.

$$"Distance" = \sqrt{(HDD_2 - HDD_1)^2 + (CDD_2 - CDD_1)^2}$$

Eq. 7C.1

Where:

HDD_1 = heating degree days from U.S. weather data,
HDD_2 = heating degree days from CBECS/RECS data,
CDD_1 = cooling degree days from U.S. weather data, and
CDD_2 = cooling degree days from CBECS/RECS data.

7C.3 MAPPING RESULTS

Table 7C.3.1 shows the weather station results for all CBECS and RECS locations. Note that some U.S. weather station data match several CBECS/RECS weather data. The “Count” column indicates the number of CBECS/RECS buildings that match a specified weather station. Table 7C.3.1 shows data matches, including heating ODT, for 321 weather stations.

Table 7C.3.1 Weather Station Data

Station Location		Code	CBECS 2003			RECS 2009			Heating ODT
State	City		HDD	CDD	Count	HDD	CDD	Count	
AK	Anchorage	ANC	9300	25	1	10335	2	8	-18
AK	Bethel	BET	11261	14	1	12530	0	1	-24
AK	Cold Bay	CDB	8693	0	0	9668	0	2	10
AK	Cordova	CDV	8332	0	1	9511	0	2	1
AK	Homer	HOM	8686	0	0	9817	0	10	4
AK	Juneau	JNU	8198	2	1	8536	6	2	1
AK	Kenai	ENA	9819	3	0	10423	0	1	-14
AK	Ketchikan	KTN	7160	0	11	7359	68	2	20
AK	King Salmon	AKN	9773	10	1	11088	0	1	-19
AK	Kodiak	ADQ	8051	15	1	8903	0	1	13
AK	Sitka	SIT	6515	2	3	-	-	-	-
AK	St Paul Island	SNP	9790	0	0	11420	0	4	3
AK	Talkeetna	TKA	8824	85	1	-	-	-	-
AK	Valdez	VWS	8735	6	0	7074	23	2	7
AK	Yakutat	YAK	8591	0	0	9295	1	1	2
AL	Birmingham	BHM	2664	1874	20	2605	1958	25	21
AL	Huntsville	HSV	3121	1633	24	2982	1863	26	16
AL	Mobile	MOB	1667	2695	6	1594	2681	59	29
AL	Montgomery	MGM	2248	2212	9	2137	2367	3	25
AL	Muscle Shoals	MSL	3138	1533	9	2948	1773	12	21
AL	Tuscaloosa	TCL	2510	2047	13	2349	2136	10	23
AR	Fayetteville	FYV	4017	1202	12	3957	1185	48	12
AR	Fort Smith	FSM	3144	1998	0	3174	1906	3	17
AR	Little Rock	LIT	3105	2187	0	2946	1943	27	20
AR	Texarkana	TXK	2259	2573	5	2573	2006	10	23
AZ	Douglas	DUG	2340	2206	7	2160	2204	27	31
AZ	Flagstaff	FLG	6326	193	0	6741	176	2	4
AZ	Phoenix	PHX	702	4975	24	807	4942	26	34
AZ	Tucson	TUS	1279	3480	15	1268	3626	85	32
AZ	Winslow	INW	4377	1459	16	4233	1395	4	10
AZ	Yuma	NYL	558	4747	16	671	4757	82	39

Station Location		Code	CBECS 2003			RECS 2009			Heating ODT
State	City		HDD	CDD	Count	HDD	CDD	Count	
CA	Bakersfield	BFL	1931	2692	25	1873	2644	177	32
CA	Blythe	BLH	853	4649	4	968	4580	8	33
CA	Eureka	EKA	4670	12	3	5137	2	2	33
CA	Fresno	FAT	2147	2412	48	2239	2390	50	30
CA	Los Angeles	LAX	1237	677	99	1294	569	117	43
CA	Mt Shasta	MHS	5294	418	24	5474	433	5	21
CA	Paso Robles	PRB	2699	1219	14	2676	1095	144	29
CA	Red Bluff	RBL	2635	2097	8	2452	2122	70	32
CA	Redding	RDD	2697	2247	0	2750	2086	63	31
CA	Sacramento	SAC	2417	1463	49	2531	1357	30	32
CA	San Diego	SAN	1060	724	98	1050	813	540	44
CA	San Francisco	SFO	2494	269	64	2614	220	278	38
CA	Stockton	SCK	2497	1525	21	2451	1468	122	30
CO	Alamosa	ALS	7762	151	4	8229	49	27	-16
CO	Colorado Spring	COS	5846	603	4	6301	356	90	2
CO	Denver	DEN	5796	800	6	5988	541	69	1
CO	Eagle	EGE	6889	369	5	7593	124	15	-7
CO	Pueblo	PUB	4891	1115	2	5427	818	77	0
CO	Trinidad	TAD	5109	944	31	5323	719	17	3
CT	Bridgeport	BDR	5800	824	47	5484	669	57	9
CT	Hartford	BDL	6359	723	32	6072	610	94	7
DC	Washington	DCA	4338	1288	49	4124	1427	39	17
DE	Wilmington	ILG	5206	1010	15	4789	1031	14	14
FL	Daytona Beach	DAB	849	3153	35	753	3321	99	35
FL	Fort Myers	FMY	370	4062	28	294	4151	63	44
FL	Ft Lauderdale	FLL	194	4622	10	118	4839	30	46
FL	Gainesville	GNV	1288	2700	26	1181	2789	118	31
FL	Jacksonville	JAX	1450	2605	8	1339	2772	60	32
FL	Key West	EYW	127	5071	11	108	5017	11	57
FL	Melbourne	MLB	632	3469	16	526	3718	80	43
FL	Miami	MIA	166	4721	9	109	4914	2	47
FL	Orlando	MCO	661	3528	11	588	3620	103	38
FL	Pensacola	PNS	1565	2642	10	1443	2729	44	29
FL	Tallahassee	TLH	1673	2538	2	1574	2802	31	30
FL	Tampa	TPA	639	3666	39	496	3876	112	40
FL	Vero Beach	VRB	544	3582	16	477	3604	26	43
FL	West Palm Beach	PBI	294	4388	26	239	4314	169	45
GA	Albany	ABY	1927	2413	0	1767	2686	5	29
GA	Athens	AHN	2831	1564	45	2882	1903	253	22
GA	Atlanta	ATL	2732	1614	33	2813	1838	87	22
GA	Augusta	AGS	2561	1820	9	2475	2068	55	23
GA	Brunswick	SSI	1557	2513	15	-	-	-	-
GA	Columbus	CSG	2053	2284	2	2183	2194	2	24
GA	Macon	MCN	2261	2195	34	2288	2133	17	25
GA	Savannah	SAV	1851	2434	5	1739	2497	21	27
GA	Waycross	AYS	1424	2689	17				
HI	Hilo-Hawaii	ITO	0	3669	7	0	3050	14	62
HI	Honolulu-Oahu	HNL	0	5030	4	0	4816	14	63
HI	Kahului-Maui	OGG	0	4270	2	1	3746	21	61
HI	Lihue-Kauai	LIH	0	4136	3	2	3611	5	62
IA	Burlington	BRL	6031	870	10	5687	810	24	-3

Station Location		Code	CBECS 2003			RECS 2009			Heating ODT
State	City		HDD	CDD	Count	HDD	CDD	Count	
IA	Cedar Rapids	CID	6861	721	17	6977	419	15	-5
IA	Des Moines	DSM	6263	1130	2	6124	898	33	-5
IA	Dubuque	DBQ	7189	602	10	7204	345	1	-7
IA	Mason City	MCW	7699	556	16	7856	338	15	-11
IA	Ottumwa	OTM	6335	883	12	6317	588	43	-4
IA	Sioux City	SUX	6699	833	17	6913	678	75	-7
IA	Waterloo	ALO	6962	849	8	7253	448	58	-10
ID	Boise	BOI	4877	1316	1	5592	1199	9	10
ID	Burley	BYI	5978	568	15	6697	397	1	2
ID	Idaho Falls	IDA	7069	409	8	-	-	-	-
ID	Lewiston	LWS	4803	1081	15	5386	1008	3	6
ID	Pocatello	PIH	6443	675	16	7463	321	17	-1
IL	Chicago	ORD	6446	697	37	6417	585	40	0
IL	Moline	MLI	6207	933	17	6250	636	35	-4
IL	Peoria	PIA	5846	906	46	5841	752	62	-4
IL	Quincy	UIN	5580	938	7	5460	849	12	3
IL	Rockford	RFD	6738	732	52	6738	433	58	-4
IL	Springfield	SPI	5549	916	10	5234	933	41	2
IN	Evansville	EVV	4530	1143	22	4397	1283	13	9
IN	Fort Wayne	FWA	6481	576	24	6077	601	41	1
IN	Indianapolis	IND	5551	883	7	5203	953	22	2
IN	South Bend	SBN	6416	626	10	6426	545	54	1
IN	West Lafayette	LAF	5690	825	32	5436	826	32	3
KS	Concordia	CNK	5231	1465	14	5558	1094	18	3
KS	Dodge City	DDC	4926	1490	8	4975	1257	27	5
KS	Garden City	GCK	5025	1367	24	5014	1154	31	4
KS	Goodland	GLD	5494	1096	22	6016	722	11	0
KS	Russell	RSL	5157	1459	3	5298	1194	46	4
KS	Salina	SLN	4608	1771	8	-	-	-	-
KS	Topeka	TOP	4887	1499	21	4968	1195	9	4
KS	Wichita	ICT	4502	1620	56	4552	1506	68	7
KY	Bowling Green	BWG	4087	1183	34	3808	1407	52	10
KY	Jackson	JKL	4299	917	5	4237	984	15	14
KY	Lexington	LEX	4750	954	8	4670	1020	40	8
KY	Louisville	SDF	4201	1307	9	4155	1316	29	10
KY	Paducah	PAH	4365	1258	10	4198	1239	39	12
LA	Baton Rouge	BTR	1683	2674	17	1404	2985	24	29
LA	Lafayette	LFT	1581	2787	14	1296	3086	3	30
LA	Lake Charles	LCH	1525	2823	18	1380	2980	10	31
LA	Monroe	MLU	2381	2353	7	2118	2547	11	25
LA	New Orleans	MSY	1327	3162	11	1156	3221	35	33
LA	Shreveport	SHV	2143	2504	3	-	-	-	-
MA	Boston	BOS	6067	745	13	5694	581	243	9
MA	Worcester	ORH	7006	479	32	6699	370	258	4
MD	Baltimore	BWI	5010	1020	22	4745	1088	34	13
MD	Salisbury	SBY	4870	1010	55	4345	1149	19	16
ME	Augusta	AUG	7746	420	11	7487	276	18	-3
ME	Bangor	BGR	8161	403	21	8098	246	19	-6
ME	Caribou	CAR	9754	214	2	9415	149	13	-13
ME	Houlton	HUL	9458	238	3	9316	178	24	-13
ME	Portland	PWM	7508	355	21	7107	294	108	-1

Station Location		Code	CBECS 2003			RECS 2009			Heating ODT
State	City		HDD	CDD	Count	HDD	CDD	Count	
MI	Alpena	APN	8468	241	7	-	-	-	-
MI	Detroit	DTW	6398	659	19	6224	588	81	6
MI	Flint	FNT	6891	494	22	7068	328	40	1
MI	Grand Rapids	GRR	7030	487	17	6580	444	35	5
MI	Houghton Lake	HTL	8311	197	1	-	-	-	-
MI	Jackson	JXN	6955	392	2	6585	420	11	5
MI	Lansing	LAN	7239	385	10	6830	372	36	1
MI	Marquette	MQT	9288	248	3	-	-	-	-
MI	Muskegon	MKG	6740	516	32	6719	371	38	6
MI	Saginaw	MBS	7313	406	8	6960	350	19	4
MI	Sault St Marie	SSM	8809	168	2	-	-	-	-
MI	Traverse City	TVC	7826	345	13	7695	253	14	1
MN	Alexandria	AXN	8675	553	9	8922	340	8	-16
MN	Duluth	DLH	9526	265	0	9517	118	10	-16
MN	Hibbing	HIB	10000	203	0	10159	64	4	-20
MN	Int'l Falls	INL	10115	220	5	10648	72	8	-25
MN	Minneapolis	MSP	7538	880	3	7613	646	48	-12
MN	Rochester	RST	7957	512	16	7884	321	9	-12
MN	Saint Cloud	STC	8489	496	2	8704	301	74	-11
MO	Columbia	COU	5010	1151	5	4999	958	125	4
MO	Joplin	JLN	3974	1677	11	4216	1382	98	10
MO	Kansas City	MCI	5053	1419	0	5084	1093	213	6
MO	Saint Louis	STL	4445	1485	3	4438	1457	70	6
MO	Springfield	SGF	4529	1321	6	4596	1114	180	9
MS	Greenwood	GWO	2668	2080	0	2376	2250	1	20
MS	McComb	MCB	1909	2482	0	1833	2472	34	26
MS	Tupelo	TUP	3002	1722	4	2842	1947	20	19
MT	Billings	BIL	6623	1017	0	6948	627	9	-10
MT	Butte	BTM	8967	180	6	-	-	-	-
MT	Cut Bank	CTB	8419	313	6	-	-	-	-
MT	Great Falls	GTF	7431	576	5	7941	300	1	-15
MT	Havre	HVR	8190	683	6	-	-	-	-
MT	Helena	HLN	7066	798	2	7704	444	1	-16
MT	Kalispell	FCA	7681	317	2	-	-	-	-
MT	Lewistown	LWT	7878	493	4	-	-	-	-
MT	Miles City	MLS	7377	1064	0	7700	716	1	-15
MT	Missoula	MSO	7073	518	1	7588	355	2	-6
NC	Asheville	AVL	4207	718	0	4194	768	23	14
NC	Cape Hatteras	HAT	2446	1687	30	-	-	-	-
NC	Charlotte	CLT	3311	1308	50	3346	1611	71	22
NC	Greensboro	GSO	3622	1210	28	3605	1510	41	18
NC	Hickory	HKY	3703	1032	31	3593	1353	42	18
NC	New Bern	EWN	2797	1818	25	2769	1788	16	24
NC	Raleigh Durham	RDU	3413	1459	42	3164	1865	55	20
NC	Wilmington	ILM	2625	1864	2	2521	1937	14	26
ND	Bismarck	BIS	8505	738	9	9130	332	16	-19
ND	Devil's Lake	P11	9544	454	3	10245	236	8	-21
ND	Fargo	FAR	8862	616	17	9304	362	17	-18
ND	Grand Forks	GFK	9575	417	3	9928	269	8	-22
ND	Minot	MOT	9066	609	20	9559	314	9	-20
ND	Williston	ISN	9603	670	14	9721	297	8	-21

Station Location		Code	CBECS 2003			RECS 2009			Heating ODT
State	City		HDD	CDD	Count	HDD	CDD	Count	
NE	Grand Island	GRI	5942	1059	16	6431	788	26	-3
NE	Lincoln	LNK	6027	1131	5	6159	912	14	-2
NE	Norfolk	OFK	6312	962	8	6789	643	4	-4
NE	North Platte	LBF	6249	926	2	6946	534	14	-4
NE	Omaha	OMA	6130	1158	3	6288	851	32	-3
NE	Scottsbluff	BFF	6293	867	4	6689	579	6	-3
NE	Valentine	VTN	6861	917	4	7279	527	2	-8
NH	Concord	CON	7666	541	2	7462	325	5	-3
NH	Lebanon	LEB	8434	362	6	7312	371	18	-3
NJ	Atlantic City	ACY	5328	1012	58	4693	994	57	13
NJ	Newark	EWR	5165	1098	38	4790	1021	147	14
NM	Albuquerque	ABQ	3663	1678	0	3823	1435	17	16
NM	Carlsbad	CNM	2322	2370	0	2398	2376	2	19
NM	Clayton	CAO	4390	1025	9	4517	1143	31	9
NM	Gallup	GUP	5827	550	8	6134	442	6	5
NM	Roswell	ROW	2678	2063	0	3098	1961	7	18
NV	Elko	EKO	6266	597	25	6948	450	1	-2
NV	Ely	ELY	6856	404	8	7925	125	4	-4
NV	Las Vegas	LAS	1882	3846	41	1882	3818	66	28
NV	Lovelock	LOL	5463	975	8	-	-	-	-
NV	Reno	RNO	4556	1184	11	-	-	-	-
NV	Tonopah	TPH	5102	1127	4	5298	874	5	10
NV	Winnemucca	WMC	5696	736	13	6236	611	2	3
NY	Albany	ALB	7023	613	12	6644	433	149	-1
NY	Binghamton	BGM	7580	316	3	7067	261	59	1
NY	Buffalo	BUF	6909	429	18	6651	361	54	6
NY	Glens Falls	GFL	8024	376	15	7612	285	26	-5
NY	Massena	MSS	8752	381	6	7980	298	2	-8
NY	New York	LGA	5025	1155	43	4647	1041	469	15
NY	Rochester	ROC	6986	477	9	6765	315	46	5
NY	Syracuse	SYR	6939	522	15	6687	439	23	2
NY	Utica	UCA	7580	386	33	-	-	-	-
NY	Watertown	ART	8018	379	5	7707	298	11	-6
OH	Akron Canton	CAK	6361	543	17	6131	497	6	6
OH	Cincinnati	CVG	5229	838	70	4950	874	13	6
OH	Cleveland	CLE	6077	685	50	5833	664	44	5
OH	Columbus	CMH	5504	765	46	5243	874	32	5
OH	Dayton	DAY	5832	676	65	5602	732	45	4
OH	Findlay	FDY	6156	643	52	5901	698	34	3
OH	Mansfield	MFD	6493	476	7	6214	468	10	5
OH	Toledo	TOL	6311	630	34	6283	592	32	1
OH	Youngstown	YNG	6566	394	6	6239	443	8	4
OK	Hobart	HBR	3439	2129	6	3392	2034	1	16
OK	McAlester	MLC	3082	1973	47	3136	1845	6	19
OK	Oklahoma City	OKC	3529	1881	46	3519	1849	37	13
OK	Tulsa	TUL	3473	2053	13	3608	1885	24	13
OR	Astoria	AST	4517	22	0	4871	39	4	29
OR	Baker	BKE	6650	315	30	7529	220	2	6
OR	Eugene	EUG	4269	350	6	4999	331	89	22
OR	Medford	MFR	4002	1060	4	-	-	-	-
OR	Pendleton	PDT	4739	895	32	5713	720	6	5

Station Location		Code	CBECS 2003			RECS 2009			Heating ODT
State	City		HDD	CDD	Count	HDD	CDD	Count	
OR	Portland	PDX	3908	623	13	4357	635	32	23
OR	Redmond	RDM	6020	353	41	6737	313	17	9
OR	Salem	SLE	4162	467	4	4660	457	50	23
PA	Allentown	ABE	5935	797	61	5725	622	22	9
PA	Altoona	AOO	6515	439	12	6109	433	17	5
PA	Bradford	BFD	8029	125	1	-	-	-	-
PA	Du Bois	DUJ	7092	243	9	6753	254	5	5
PA	Erie	ERI	6496	489	42	6183	423	9	9
PA	Harrisburg	CXY	5534	856	76	5097	866	111	11
PA	Philadelphia	PHL	4894	1269	106	4557	1219	46	14
PA	Pittsburgh	PIT	5892	587	51	5661	617	6	5
PA	Williamsport	IPT	6233	611	62	5636	644	69	7
RI	Providence	PVD	5961	742	13	5717	579	69	9
SC	Charleston	CHS	1981	2272	3	1941	2390	13	27
SC	Columbia	CAE	2562	1908	33	2561	2220	19	24
SC	Florence	FLO	2644	1839	11	2541	2061	13	25
SC	Greenville	GSP	3108	1379	58	3116	1735	42	22
SD	Aberdeen	ABR	8324	605	33	8872	329	13	-15
SD	Huron	HON	7598	860	7	8070	469	105	-14
SD	Pierre	PIR	7200	961	5	7738	577	36	-10
SD	Rapid City	RAP	7034	905	5	7738	362	12	-7
SD	Sioux Falls	FSD	7463	724	17	7670	481	42	-11
TN	Bristol	TRI	4294	860	1	4267	930	28	14
TN	Chattanooga	CHA	3206	1498	34	3168	1808	35	18
TN	Crossville	CSV	4240	839	4	4100	940	33	15
TN	Jackson	MKL	3603	1394	14	3379	1597	22	16
TN	Knoxville	TYS	3584	1282	34	3643	1392	91	19
TN	Memphis	MEM	2954	1961	17	2906	2091	3	18
TN	Nashville	BNA	3595	1449	23	3615	1558	37	14
TX	Abilene	ABI	2366	2374	3	2359	2494	217	20
TX	Alice	ALI	1022	3628	28	738	4832	23	34
TX	Amarillo	AMA	3787	1410	43	4034	1340	33	11
TX	Austin	AUS	1888	2793	4	1722	3214	45	28
TX	Brownsville	BRO	587	4025	8	525	4300	20	39
TX	College Station	CLL	1662	2965	34	1404	3476	29	29
TX	Corpus Christi	CRP	968	3462	8	811	4058	8	35
TX	Dallas-Ft. Worth	DFW	2239	2752	25	2097	2745	61	22
TX	Del Rio	DRT	1338	3406	16	1252	3807	29	31
TX	El Paso	ELP	2207	2696	4	2106	2783	43	24
TX	Galveston	GLS	1058	3343	17	907	3640	3	36
TX	Houston	IAH	1386	3185	20	1267	3410	170	32
TX	Laredo	LRD	826	4348	37	602	5330	1	36
TX	Lubbock	LBB	2960	1950	28	3178	1965	10	15
TX	Lufkin	LFK	1966	2600	7	1803	2839	64	29
TX	McAllen	MFE	707	4415	26	393	5387	3	39
TX	Midland Odessa	MAF	2366	2509	15	2495	2445	81	21
TX	San Angelo	SJT	2180	2497	0	2020	2814	56	22
TX	San Antonio	SAT	1485	3039	25	1270	3598	28	30
TX	Victoria	VCT	1270	3217	10	1123	3608	35	32
TX	Waco	ACT	1975	2776	16	1927	3086	18	26
TX	Wichita Falls	SPS	2752	2485	20	2838	2394	14	18

Station Location		Code	CBECS 2003			RECS 2009			Heating ODT
State	City		HDD	CDD	Count	HDD	CDD	Count	
UT	Cedar City	CDC	5606	810	17	6058	645	56	5
UT	Salt Lake City	SLC	5060	1544	0	5716	1147	29	8
VA	Lynchburg	LYH	4434	884	6	4433	1003	159	16
VA	Norfolk	ORF	3279	1761	51	3330	1659	41	22
VA	Richmond	RIC	3971	1336	51	3781	1564	47	17
VA	Roanoke	ROA	4216	1002	10	3931	1173	34	16
VT	Burlington	BTV	7833	576	1	-	-	-	-
VT	Montpelier	MPV	8793	305	13	7998	237	12	-6
WA	Bellingham	BLI	5124	54	5	5568	115	8	15
WA	Olympia	OLM	5095	144	0	5614	178	24	22
WA	Quillayute	UIL	5411	20	2	5869	44	7	27
WA	Seattle Tacoma	SEA	4509	277	11	4879	319	94	26
WA	Spokane	GEG	6295	592	0	6942	599	5	2
WA	Walla Walla	ALW	4498	1189	0	5062	1144	12	7
WA	Yakima	YKM	5433	734	0	6204	699	25	5
WI	Eau Claire	EAU	7949	623	20	8208	333	23	-11
WI	Green Bay	GRB	7878	386	18	8005	275	55	-9
WI	Lacrosse	LSE	7126	854	14	7334	536	16	-9
WI	Madison	MSN	7356	560	58	7343	368	66	-7
WI	Milwaukee	MKE	7058	601	48	6816	474	28	-4
WI	Wausau	AUW	8299	466	14	8337	277	54	-12
WV	Beckley	BKW	5439	487	2	5325	404	16	4
WV	Charleston	CRW	4628	789	3	4443	960	3	11
WV	Elkins	EKN	6291	322	2	5993	284	3	6
WV	Huntington	HTS	4487	881	6	4557	922	3	10
WV	Martinsburg	MRB	5411	783	19	5046	854	63	10
WV	Morgantown	MGW	5358	628	1	4957	836	15	8
WV	Parkersburg	PKB	5138	729	4	4910	850	19	11
WY	Casper	CPR	7192	587	6	-	-	-	-
WY	Cheyenne	CYS	6680	577	11	7390	203	11	-1
WY	Cody	COD	6992	686	7	7551	410	2	-13
WY	Lander	LND	7475	713	0	7743	351	1	-11
WY	Rock Springs	RKS	7574	540	2	8204	230	3	-3
WY	Sheridan	SHR	7401	652	5	7844	287	2	-8
WY	Worland	WRL	7336	1010	0	7757	467	2	-13

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CHAPTER 8. LIFE-CYCLE COST AND PAYBACK PERIOD ANALYSIS

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CHAPTER 8. LIFE-CYCLE COST AND PAYPACK PERIOD ANALYSIS

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.

- The life-cycle cost (LCC) is the total consumer cost of an appliance or product, generally over the life of the appliance or product. The LCC calculation includes total installed cost (equipment manufacturer selling price, distribution chain markups, sales tax, and installation costs), operating costs (energy, repair, and maintenance costs), equipment lifetime, and discount rate. Future operating costs are discounted to the time of purchase and summed over the lifetime of the appliance or product.
- 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) conducted 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 some of the key parameters as discussed further in section 8.1.2.

Inputs to the LCC and PBP analysis of commercial packaged boiler (CPB) 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 (https://www1.eere.energy.gov/buildings/appliance_standards/rulemaking.aspx?ruleid=79).

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 boilers is unique, DOE analyzed variability and uncertainty through LCC and PBP probability calculations addressed here for a representative sample of individual commercial buildings and households. 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. The LCC and PBP analysis explicitly model both the uncertainty and the variability in the model's inputs using Monte Carlo simulation and probability distributions (see appendix 8B).

The LCC analysis used the estimated energy use for each CPB unit as described in the energy use analysis in chapter 7 of this technical support document (TSD). Energy use of commercial packaged boilers is sensitive to climate 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.

A certain fraction of commercial packaged boilers is used for commercial applications. This fraction determines the frequency at which the model's sampling process will select an item from the commercial category. Furthermore, a certain fraction of commercial packaged boilers installed, or being replaced, is assumed to be natural draft equipment and, as such, has significantly different installation costs than mechanical draft CPB equipment. The LCC analysis performs side-by-side analysis of natural draft CPB equipment and mechanical draft CPB equipment. In order to develop the LCC and PBP results for each product class, the results from the side-by-side analysis were sampled based on statistics observed in the Air-Conditioning, Heating, and Refrigeration Institute (AHRI) Certification Directory.[1] Table 8.1.1 provides the assumed fraction of natural draft CPB equipment by equipment class in the no-new-standards case that was used for sampling the LCC and PBP results.

Table 8.1.1 Assumed Fractions of Draft Type for Commercial Packaged Boilers by Equipment Class

Equipment Class	Natural Draft	Mechanical Draft
Gas-Fired Hot Water Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h	22%	78%
Gas-Fired Hot Water Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h	29%	71%
Oil-Fired Hot Water Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h	48%	52%
Oil-Fired Hot Water Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h	11%	89%
Gas-Fired Steam Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h	59%	41%
Gas-Fired Steam Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h	44%	56%
Oil-Fired Steam Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h	25%	75%
Oil-Fired Steam Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h	0%	100%

As mentioned previously, DOE generated 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. As a result, 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 addition to the average LCC savings or average PBP for that efficiency level.

The LCC and PBP results are displayed as distributions of impacts compared to a no-new-standards base case. The no-new-standards efficiency is for 2019 and reflects the expected distribution of efficiency levels by equipment class.

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 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 as follows:

- *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 efficiency (or baseline) standards.
- *Standard-level manufacturer selling price increase*: 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 operating cost are as follows:

- *Equipment energy consumption*: The equipment energy consumption is the site energy use associated with the use of the boiler to provide space conditioning to the building.
- *Energy Prices*: Electricity, natural gas, and fuel oil prices are determined using average monthly energy prices.
- *Electricity, natural gas, and fuel oil price trends*: The Energy Information Administration's (EIA's) *Annual Energy Outlook 2015 (AEO2015)* is used to forecast energy prices into the future.[2] For the results presented in this chapter, DOE uses the *AEO2015* Reference case to forecast future energy prices.

- *Maintenance costs*: The labor and material costs associated with maintaining the operation of the equipment.
- *Repair costs*: The labor and material costs associated with repairing or replacing components that have failed.
- *Lifetime*: The age at which the boiler 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.

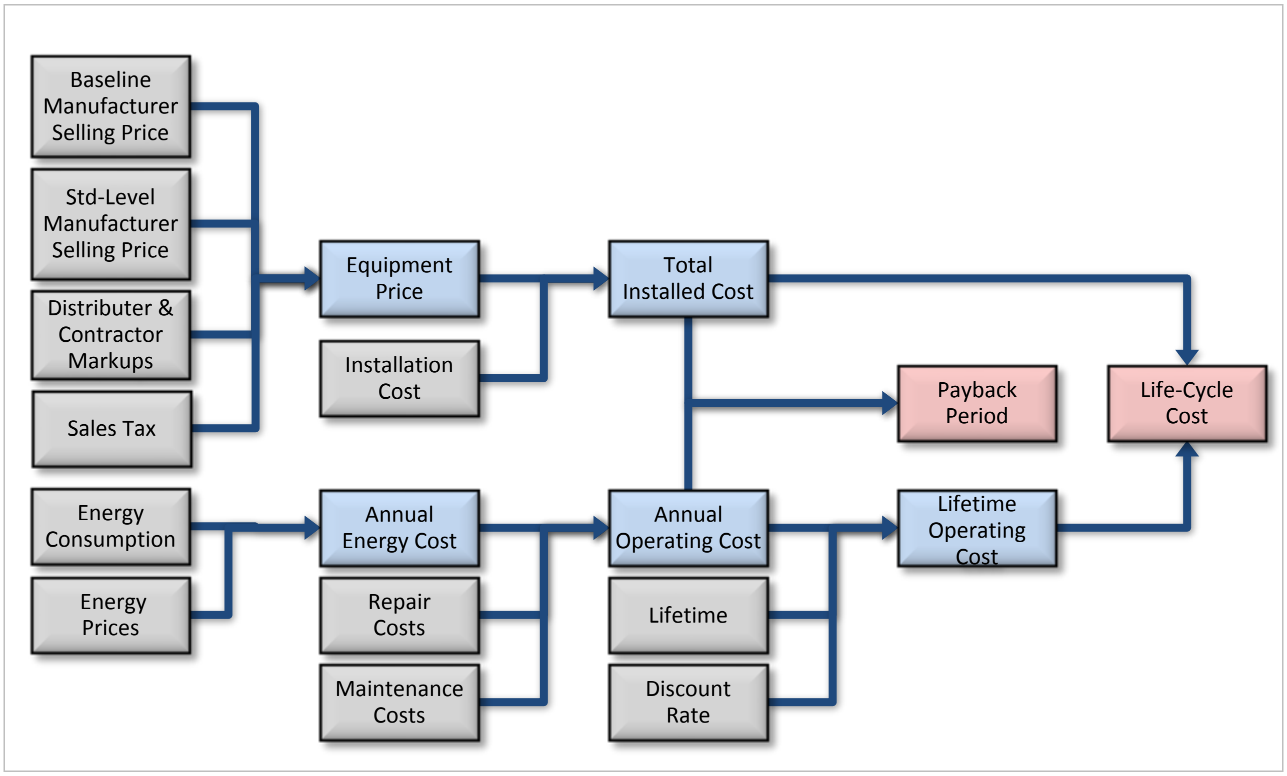

Figure 8.1.1 Flow Diagram of Inputs for the Determination of LCC and PBP

Table 8.1.2 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 8.1.2 Summary of Inputs and Key Assumptions Used in the LCC and PBP Analysis

Inputs	Description
Affecting Installed Costs	
Equipment Price	Derives MSP for boiler units at different heating input capacities (from the engineering analysis) and multiplied by wholesaler markups and contractor markups plus sales tax (from markups analysis). Uses the probability distribution for the different markups to describe their variability.
Installation Cost	Includes installation labor derived from *2015 RS Means Facilities Construction Cost Data*. Overhead and materials costs and profits are assumed to be included in the contractor's markup. Thus, the total installed cost equals the commercial consumer equipment price (manufacturer cost multiplied by the various markups plus sales tax) plus the installation cost.
Affecting Operating Costs	
Annual Energy Use	Annual energy use includes electricity and natural gas or fuel oil used by a commercial packaged boiler providing space heating and water heating in either commercial or residential buildings. The energy use analysis provides estimates of the distribution of annual energy consumption for boilers at the efficiency standard levels considered.
Energy Efficiency	Rated thermal efficiency and combustion efficiency are the efficiency descriptors for commercial packaged boilers. At each efficiency level, the rated thermal efficiency is adjusted based on assumed operating conditions. The adjusted thermal efficiency is used to determine the annual energy consumption associated with each considered efficiency level.
Energy Prices	Costs are calculated for Commercial Buildings Energy Consumption Survey (CBECS) 2003 buildings from monthly marginal average electricity and natural gas or fuel oil prices in each of 9 divisions in CBECS 2003. Commercial prices are escalated by the *AEO2015* forecasts to estimate future electricity prices. Escalation is performed at the census division level. Costs are calculated for Residential Energy Consumption Survey (RECS) 2009 households from monthly marginal average electricity and natural gas or fuel oil prices in each of 30 states and groups of states in RECS 2009.* Residential prices are escalated by the *AEO2015* forecasts to estimate future electricity prices. Escalation is performed at the census division level and aggregated to the regions used in the study.
Maintenance Cost	The cost associated with maintaining the operation of the equipment (*e.g.*, checking blower). Annual maintenance cost does not change as a function of MSP.
Repair Cost	Estimates the annualized repair cost for baseline efficiency boiler equipment, based on costs of major repair (such as heat exchanger replacement), from a variety of published sources. It is assumed that repair costs would vary for higher efficiency levels.
Affecting Present Value of Annual Operating Cost Savings	
Equipment Lifetime	Uses the probability distribution of lifetimes developed for boilers.
Discount Rate	Mean real discount rates ranging from 4.90% to 5.96% for various classes of commercial consumers based on financial data from Damodaran Online valuation database (see section 8.2.2.7 for details). Probability distributions are used for the discount rates.
Date Compliance is Required	2019 (generally 3 years after the "effective date," as published in the final rule)

*RECS 2009 provides 27 regions (also called reportable domains). The 27th region originally included Oregon, Washington, Alaska, and Hawaii. Alaska and Hawaii were subdivided into separate regions (28 and 29, respectively), based on cooling and heating degree days. In addition, region 14 originally included West Virginia, which has been disaggregated into region 30 based on cooling and heating degree days. See appendix 7A for more details.

All of the inputs depicted in Figure 8.1.1 and summarized in Table 8.1.2 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 boiler users. The commercial packaged boilers are assumed to be installed both in commercial and residential buildings.

As explained in chapter 7, the EIA's CBECS 2003 serves as the basis for determining the representative commercial sample, while EIA's RECS 2009 serves as the basis for determining the representative residential sample.[3,4] 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. Available CBECS 2012 releases and data were also used to better inform the analysis regarding the representative commercial sample. More information on the use of CBECS 2012 data can be found in chapter 9 and appendix 9A.

Appendix 7A presents the variables used and their definitions, as well as further information about the derivation of the household and building samples.

8.2 LIFE-CYCLE COST ANALYSIS INPUTS

The LCC 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. The LCC is defined by the following equation:

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

Eq. 8.1

Where:

LCC = life-cycle cost (\$),
IC = total installed cost (\$),
$\sum$ = sum over the lifetime, from year 1 to year N,
  where N = 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 commercial packaged boilers.

8.2.1 Total Installed Cost Inputs

The total installed cost to the 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. As discussed in chapter 6, DOE defines two major distribution channels for units installed in new construction to describe how the equipment passes from the manufacturer to the commercial consumer. In the first distribution channel, the manufacturer sells the equipment to a wholesaler or manufacturer's representative, who sells to a mechanical contractor who is hired by a general contractor. The general contractor purchases and installs the equipment on behalf of the commercial consumer and adds its markup to the mechanical contractor's price. Replacement equipment follows the same distribution channel, except that there is no general contractor. Instead, the mechanical contractor takes on the general contractor's function. In the second distribution channel, the commercial consumer purchases the boiler directly from the manufacturer through a national account.

The remainder of this section provides information about the variables DOE uses to calculate the total installed cost for CPB equipment.

8.2.1.1 Manufacturer Costs

DOE develops the manufacturer sale price for CPB equipment as described in chapter 5, Engineering Analysis. As noted in the engineering analysis, where sufficient data were available to establish separate pricing for mechanical and natural draft CPB equipment, it was provided to downstream analyses. Such was the case only for the small gas-fired hot water (SGHW) commercial packaged boiler class. The MSP at each efficiency level and MSP for SGHW CPB equipment by draft type are shown in Table 8.2.1.

Table 8.2.1 Manufacturer Sale Price for Commercial Packaged Boilers by Efficiency Level

Equipment Class		Efficiency Level	Manufacturer Sale Price *2014$*	Incremental Manufacturer Sale Price *2014$*
Gas-Fired Hot Water Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h	Natural Draft	80% TE - Baseline	$6,828	-
		81% TE	$7,206	$379
		82% TE	$7,606	$778
		84% TE[*]	-	-
		85% TE	-	-
		93% TE	-	-
		95% TE	-	-
		99% TE - Max Tech	-	-
	Mechanical Draft	80% TE - Baseline	$7,047	-
		81% TE	$7,631	$583
		82% TE	$8,262	$1,215
		84% TE	$9,687	$2,639
		85% TE	$10,488	$3,441
		93% TE	$16,954	$9,907
		95% TE	$17,421	$10,374
		99% TE - Max Tech	$20,894	$13,846
Gas-Fired Hot Water Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h		82% CE - Baseline	$21,244	-
		83% CE	$23,778	$2,534
		84% CE	$26,614	$5,370
		85% CE	$29,788	$8,544
		94% CE	$54,040	$32,796
		97% CE - Max Tech	$58,148	$36,904
Oil-Fired Hot Water Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h		82% TE - Baseline	$8,404	-
		83% TE	$9,038	$634
		84% TE	$9,719	$1,315
		85% TE	$10,452	$2,048
		87% TE	$12,087	$3,683
		88% TE	$12,999	$4,594
		97% TE - Max Tech	$26,091	$17,687
Oil-Fired Hot Water Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h		84% CE - Baseline	$18,915	-
		86% CE	$23,701	$4,785
		88% CE	$29,697	$10,781
		89% CE	$33,242	$14,326
		97% CE - Max Tech	$68,838	$49,923
Gas-Fired Steam Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h		77% TE - Baseline	$6,659	-
		78% TE	$7,199	$540
		79% TE	$7,783	$1,124
		80% TE	$8,415	$1,756
		81% TE	$9,098	$2,439
		83% TE - Max Tech	$10,634	$3,975
Gas-Fired Steam Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h		77% TE - Baseline	$19,122	-
		78% TE	$20,219	$1,097
		79% TE	$21,378	$2,256
		80% TE	$22,605	$3,483
		81% TE	$23,901	$4,779
		82% TE	$25,272	$6,150
		84% TE - Max Tech	$28,254	$9,132

Equipment Class	Efficiency Level	Manufacturer Sale Price *2014$*	Incremental Manufacturer Sale Price *2014$*
Oil-Fired Steam Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h	81% TE - Baseline	$7,294	-
	83% TE	$9,016	$1,722
	84% TE	$10,024	$2,730
	86% TE - Max Tech	$12,390	$5,097
Oil-Fired Steam Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h	81% TE - Baseline	$18,702	-
	83% TE	$21,719	$3,017
	85% TE	$25,223	$6,521
	87% TE - Max Tech	$29,292	$10,590

* For the SGHW equipment class, at 84% thermal efficiency and above, it is assumed that customers of natural draft CPB equipment would need to transition to mechanical draft CPB equipment, and the purchase price incurred by these customers would be reflective of MSPs for mechanical draft CPB equipment, as shown in the mechanical draft SGHW equipment pricing.

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 being purchased for a new construction installation or is being 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).

Based on the percentages of the market attributed to each distribution channel,

Table 8.2.2 displays the national weighted-average baseline and incremental markups and their associated components for commercial packaged boilers.

Table 8.2.2 Summary of National Average Markups on Commercial Packaged Boilers

	Replacement			New Construction		
	Baseline Markup	Incremental Markup	National Account: Baseline/Incr. Markup	Baseline Markup	Incremental Markup	National Account: Baseline/Incr. Markup
Manufacturer*	-			-		
Wholesaler/ Manufacturer's Representative	1.39	1.11	1.39/1.11	1.39	1.11	1.39/1.11
Mechanical Contractor	1.52	1.21	-	1.43	1.15	-

	Replacement			New Construction		
	Baseline Markup	**Incremental Markup**	**National Account: Baseline/Incr. Markup**	**Baseline Markup**	**Incremental Markup**	**National Account: Baseline/Incr. Markup**
General Contractor (commercial/ residential)	-	-	-	1.32/1.47	1.21/1.34	-
Sales Tax	1.07			-	-	1.07
Overall Markup (commercial/ residential)	2.27	1.44	1.49/1.19	2.65/2.94	1.53/1.71	1.49/1.19

[*] As discussed in chapter 6, manufacturer sale price, which is used in the LCC, includes all associated manufacturer markups.

Because the relative importance of new construction and replacements in total shipments varies among the equipment classes, the total markup varies as well (Table 8.2.3).

Table 8.2.3 Overall Markup for Commercial Packaged Boilers by Equipment Class

Equipment Class	Baseline Markup	Incremental Markup
Gas-Fired Hot Water Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h	2.21	1.42
Gas-Fired Hot Water Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h	2.23	1.43
Oil-Fired Hot Water Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h	2.29	1.44
Oil-Fired Hot Water Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h	2.13	1.40
Gas-Fired Steam Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h	2.13	1.40
Gas-Fired Steam Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h	2.13	1.40
Oil-Fired Steam Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h	2.13	1.40
Oil-Fired Steam Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h	2.13	1.40

8.2.1.3 Total Commercial Consumer Price

DOE derives the commercial consumer equipment price for the baseline equipment by multiplying the equipment at the baseline manufacturer sale price by the baseline overall markup (including the sales tax). For each efficiency level above the baseline, DOE derives the commercial consumer equipment price by taking baseline equipment commercial consumer price and adding to it the product of the incremental manufacturer selling price and the incremental overall markup (including sales tax). Markups and sales taxes can take on a variety of values, depending on location, so the resulting total installed cost for a particular efficiency level is represented by a distribution of values.

For the LCC analysis, the equipment capacity installed in the considered building sample depends on the sample chosen. While the MSP is based on the representative boiler capacity for each equipment class as established in the engineering analysis, the actual boiler capacity changes for each iteration of the Monte Carlo simulation to reflect that equipment capacity selected for the building sampled. Hence, an MSP adjustment factor is needed to adjust the MSP of the representative boiler. This adjustment factor is based on the supplemental price data collected as part of the engineering analysis. Section 5.5.2 in chapter 5 of the TSD discusses the need for additional price data and the MSP versus boiler capacity regression curve formulation for these equipment classes in detail.

DOE collected price information for gas hot water, oil hot water, gas steam and oil steam boilers of various capacities. For gas hot water boilers, DOE categorized these price data for condensing and non-condensing boilers. DOE then assimilated the price data for small and large boilers and created scatter plots and regression curves for each of these categories. Figures 5.5.1 to 5.5.5 in chapter 5 of the TSD present the scatter plots and the regression curves. The Monte Carlo simulation considers a single curve for each equipment class and does not classify the equipment by condensing or non-condensing. So the condensing and non-condensing gas hot water regression curves were merged together and a single curve was created. Table 8.2.4 presents the regression coefficients for estimating MSP by boiler capacity for each equipment class.

Table 8.2.4 Regression Coefficients to estimate MSP by Boiler Capacity

Boiler Type	**Slope** ***$-h/kBtu***	**Intercept** ***$***
Small and Large Gas Hot Water	10.063	2882.8
Small and Large Oil Hot Water	6.528	4558.7
Small and Large Gas Steam	6.923	3433.3
Small and Large Oil Steam	6.767	3297.2

To calculate the adjusted MSP for the sample under consideration, the ratio of estimated MSPs of the simulation-chosen boiler capacity and the representative boiler capacity is calculated and used as a capacity adjustment factor. This adjustment factor multiplied by the MSP for the boiler type at each efficiency level yields the adjusted MSP for the sample. Table 8.2.5 presents the average commercial consumer equipment price for each boiler equipment class at each efficiency level examined. For the SGHW CPB equipment class, the average commercial consumer equipment price is also provided by draft type.

Table 8.2.5 Average Commercial Consumer Price for Commercial Packaged Boilers (2014$)

Equipment Class	Efficiency Level	Average Consumer Price *2014$*	Incremental Average Consumer Price *2014$*
Gas-Fired Hot Water Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h	80% TE – Baseline	$17,429	-
	81% TE	$18,285	$856
	82% TE	$19,208	$1,779
	84% TE	$21,690	$4,261
	85% TE	$22,961	$5,532
	93% TE	$33,217	$15,788
	95% TE	$33,958	$16,529
	99% TE - Max Tech	$39,465	$22,036
Gas-Fired Hot Water Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h	82% CE - Baseline	$74,483	-
	83% CE	$80,130	$5,647
	84% CE	$86,450	$11,967
	85% CE	$93,524	$19,040
	94% CE	$147,570	$73,087
	97% CE - Max Tech	$156,725	$82,242
Oil-Fired Hot Water Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h	82% TE - Baseline	$19,378	-
	83% TE	$20,268	$890
	84% TE	$21,226	$1,848
	85% TE	$22,255	$2,878
	87% TE	$24,554	$5,176
	88% TE	$25,834	$6,457
	97% TE - Max Tech	$44,234	$24,856
Oil-Fired Hot Water Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h	84% CE - Baseline	$54,327	-
	86% CE	$63,216	$8,889
	88% CE	$74,354	$20,027
	89% CE	$80,938	$26,611
	97% CE - Max Tech	$147,059	$92,732
Gas-Fired Steam Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h	77% TE - Baseline	$14,906	-
	78% TE	$15,696	$790
	79% TE	$16,550	$1,644
	80% TE	$17,473	$2,567
	81% TE	$18,471	$3,565
	83% TE - Max Tech	$20,716	$5,810
Gas-Fired Steam Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h	77% TE - Baseline	$63,124	-
	78% TE	$65,495	$2,371
	79% TE	$68,002	$4,878
	80% TE	$70,653	$7,529
	81% TE	$73,456	$10,332
	82% TE	$76,420	$13,296
	84% TE - Max Tech	$82,867	$19,743
Oil-Fired Steam Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h	81% TE - Baseline	$14,758	-
	83% TE	$17,005	$2,247
	84% TE	$18,320	$3,562

Equipment Class	Efficiency Level	Average Consumer Price *2014$*	Incremental Average Consumer Price *2014$*
	86% TE - Max Tech	$21,408	$6,650
Oil-Fired Steam Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h	81% TE - Baseline	$56,029	-
	83% TE	$61,886	$5,857
	85% TE	$68,689	$12,660
	87% TE - Max Tech	$76,589	$20,560

8.2.1.4 Future Equipment Prices

DOE examines the historical producer price index (PPI) data for cast iron water-heating boilers from 1999-2013 and steel water-heating boilers from 1980 to 2013 (discontinued between 1987 and 1993) from the Bureau of Labor Statistics' (BLS).[a] The PPI data reflect nominal prices, adjusted for equipment quality changes. The inflation-adjusted (deflated) price indexes for cast iron water-heating boilers and steel water-heating boilers are calculated by dividing the PPI series by the Gross Domestic Equipment Chained Price Index (see Figure 8.2.1).

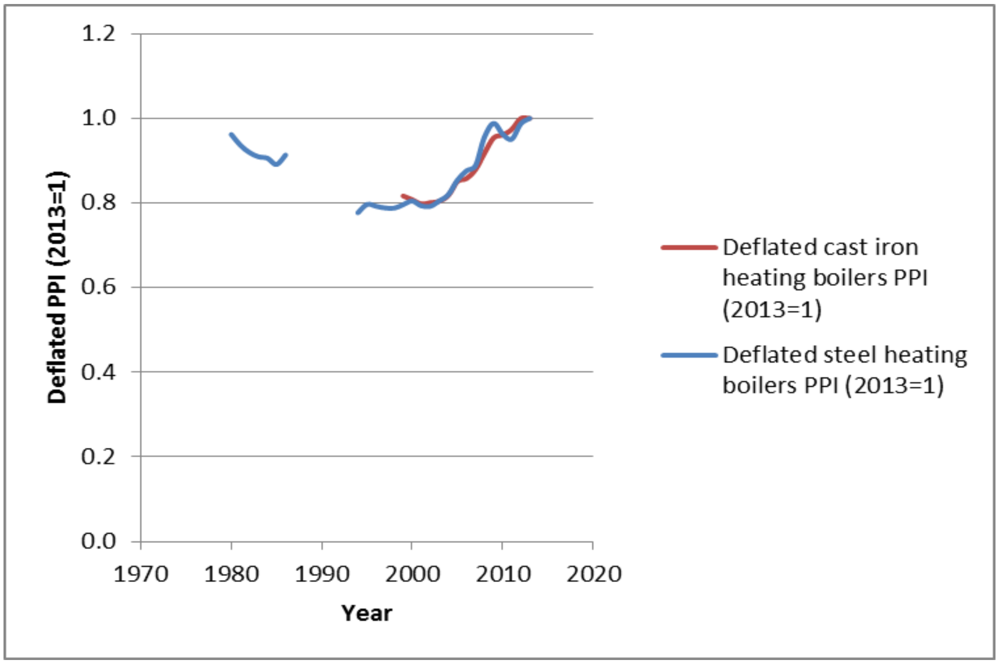

Figure 8.2.1 Historical Deflated Producer Price Indexes for Cast Iron Water-Heating Boilers and Steel Water-Heating Boilers

In Figure 8.2.1, both cast iron water-heating boiler PPI and steel water-heating boiler PPI show strongly rising trends starting from early 2000s—a strong correlation with the historical price index for iron and steel mills (see Figure 8.2.3).[b] The rise in iron and steel PPI between

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[a] Cast iron heating boiler PPI series ID: PCU 3334143334141; Steel heating boiler PPI series ID: PCU 3334143334145; www.bls.gov/ppi/

[b] Iron and steel mills PPI series ID: PCU331110331110; www.bls.gov/ppi/

2003 and 2008 is primarily a result of large demand for such commodities from rapid industrialization in China, India, and other emerging economies. Prior to 2003, the inflation-adjusted PPI for iron and steel mills was in a long downtrend that began in the early 1980s. The limited historical PPI for steel heating boilers also shows that the steel water-heating boilers likely had a downward price trend during the same period of time. The recent trend in iron and steel PPI could be a start of a return to a declining trend, but there is not enough data to be sure.

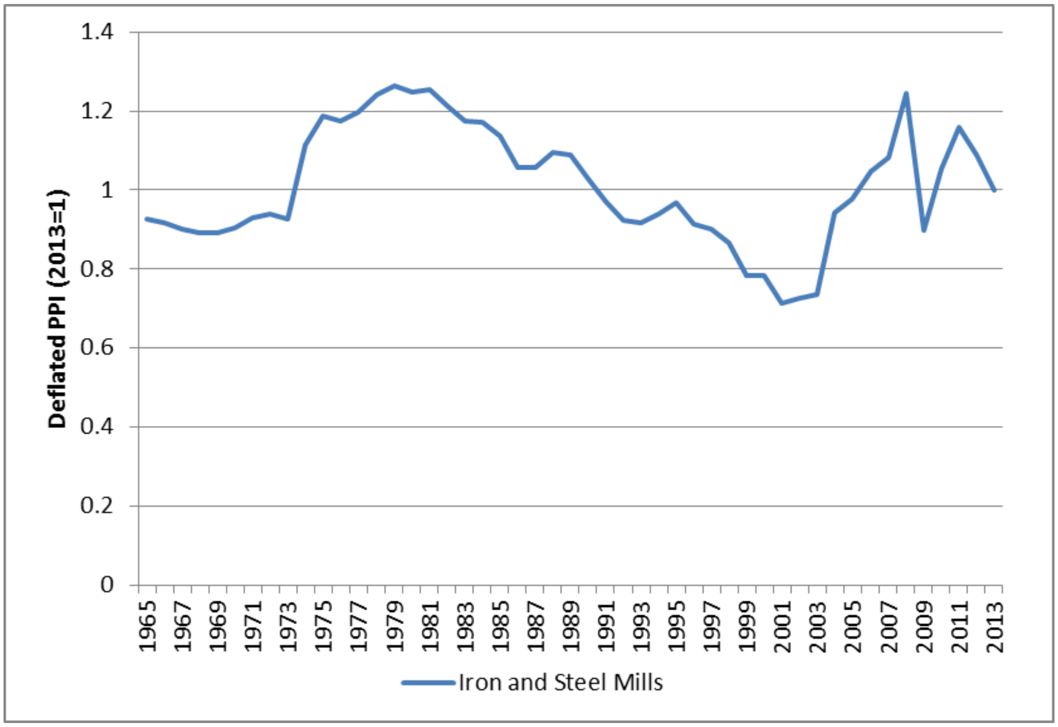

Figure 8.2.2 Deflated Iron and Steel Mills PPI from 1965 to 2013

Given the pattern in iron and steel prices, DOE is not confident that extrapolating the trend in the PPI for cast iron water-heating boilers or steel water-heating boilers would provide a sound projection. Nor is DOE confident that the recent downward trend in iron and steel prices will continue in the future. Given the uncertainty, DOE applies a constant price trend to the manufacturer selling price (in real dollars) of commercial packaged boilers.

8.2.1.5 Installation Cost

DOE's analysis of installation costs accounts for regional differences in labor costs. DOE estimates the installation costs at each considered efficiency level using a variety of sources, including RS Means 2015 Facilities Construction Cost Data, manufacturer literature, and information from expert consultants.[5] For a detailed discussion of the development of installation costs, see appendix 8D.

The installation cost is the cost to the commercial consumer of installing the boiler. The cost of installation covers all labor and material costs associated with the replacement of an existing boiler or the installation of a boiler in a new building, removal of the existing boiler, and any applicable permit fees. Higher-efficiency boilers may require additional installation costs.

DOE's analysis estimates specific installation costs for each sample building based on distributions of some installation parameters (such as vent length) and building characteristics given in CBECS 2003.

DOE gives separate consideration to the cost of installing condensing gas and oil boilers in replacement cases and in new buildings. DOE conducts a detailed analysis of installation costs when a non-condensing boiler is replaced with a condensing boiler, with particular attention to venting and condensate removal issues in replacement applications.

DOE estimates basic installation costs applicable both to replacement and new buildings. These costs, which apply to all boilers, include putting in place and setting up the boiler, gas or oil piping, water piping, permits, and removal or disposal fees.

For *replacement installations*, DOE includes a number of additional costs ("adders") for a fraction of the sample buildings. For natural draft boilers, the additional costs include vent resizing, chimney relining, and a new combustion air venting. For non-condensing mechanical draft boilers, the additional costs include stainless-steel venting when it is not already present and a new combustion air venting. Condensing mechanical-draft boiler cost adders include new stainless steel or plastic venting when stainless steel venting is not already present, new combustion air venting, and condensate removal.

DOE also includes adders for new construction installations. For natural draft boilers, generally a new flue vent (Type B metal) and a combustion air vent for direct-vent installations are the only adders. For non-condensing mechanical draft boilers, the adders generally include a new flue vent (stainless steel) and combustion air venting for direct-vent installations. For condensing boilers the adders include a new flue vent (stainless steel or plastic), a combustion air vent for direct-vent installations, and condensate removal.

8.2.1.6 Total Installed Cost

The total installed cost is the sum of the equipment price and the installation cost. MSPs, markups, and sales taxes all can take on a variety of values, depending on location, so the resulting total installed cost for a particular efficiency level will not be a single-point value, but rather a distribution of values. Table 8.2.6 presents the average total installed cost for each CPB equipment class at each efficiency level examined. The total installed cost presented are aggregates, via the weighted sampling methodology discussed in section 8.1.2 and include the cost of installations and equipment replacements for both natural and mechanical draft CPB equipment.

Table 8.2.6 Average Total Installed Cost for Commercial Packaged Boilers (2014$)

Equipment Class	Efficiency Level	Total Installed Cost *2014$*	Incremental Total Installed Cost *2014$*
Gas-Fired Hot Water Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h	80% TE - Baseline	$25,571	-
	81% TE	$26,427	$856
	82% TE	$27,350	$1,779
	84% TE	$30,302	$4,731
	85% TE	$31,573	$6,002
	93% TE	$40,896	$15,325
	95% TE	$41,637	$16,066
	99% TE - Max Tech	$47,145	$21,574
Gas-Fired Hot Water Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h	82% CE - Baseline	$94,053	-
	83% CE	$99,700	$5,647
	84% CE	$106,020	$11,967
	85% CE	$113,093	$19,040
	94% CE	$169,571	$75,518
	97% CE - Max Tech	$178,725	$84,672
Oil-Fired Hot Water Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h	82% TE - Baseline	$27,566	-
	83% TE	$28,457	$890
	84% TE	$29,414	$1,848
	85% TE	$30,444	$2,878
	87% TE	$32,742	$5,176
	88% TE	$34,666	$7,099
	97% TE - Max Tech	$51,938	$24,371
Oil-Fired Hot Water Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h	84% CE - Baseline	$66,053	-
	86% CE	$74,942	$8,889
	88% CE	$86,080	$20,027
	89% CE	$92,980	$26,927
	97% CE - Max Tech	$159,031	$92,977
Gas-Fired Steam Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h	77% TE - Baseline	$22,540	-
	78% TE	$23,330	$790
	79% TE	$24,183	$1,644
	80% TE	$25,107	$2,567
	81% TE	$26,105	$3,565
	83% TE - Max Tech	$28,350	$5,810
Gas-Fired Steam Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h	77% TE - Baseline	$82,527	-
	78% TE	$84,898	$2,371
	79% TE	$87,405	$4,878
	80% TE	$90,056	$7,529
	81% TE	$92,859	$10,332
	82% TE	$96,563	$14,036
	84% TE - Max Tech	$103,011	$20,484
Oil-Fired Steam Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h	81% TE - Baseline	$21,965	-
	83% TE	$24,212	$2,247
	84% TE	$25,527	$3,562
	86% TE - Max Tech	$28,615	$6,650
Oil-Fired Steam Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h	81% TE - Baseline	$67,991	-
	83% TE	$73,849	$5,857
	85% TE	$80,651	$12,660
	87% TE - Max Tech	$88,551	$20,560

8.2.2 Operating Cost Inputs

DOE defines the operating cost by the following equation:

$$OC = EC + RC + MC$$

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 commercial packaged boilers. 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 key equipment class, DOE calculates the annual energy use savings for each sample building at each efficiency level as described in chapter 7. A rebound effect occurs when an increase in equipment efficiency leads to increased demand for the equipment's service. For example, when a commercial consumer realizes that a more-efficient heating device will lower the energy bill, that person may opt to increase his or her amenity level, for example, by setting the thermostat at a higher temperature.

DOE conducted a literature review on the direct rebound effect in commercial buildings, and found very few studies, especially with regard to space heating and cooling. In a paper from 1993, Nadel describes several studies on takeback in the wake of utility lighting efficiency programs in the commercial and industrial sectors.[c] The findings suggest that in general the rebound associated with lighting efficiency programs in the commercial and industrial sectors is very small. In a 1995 paper, Eto et al.[d] state that changes in energy service levels after efficiency programs have not been studied systematically for the commercial sector. They state that while pre-/post-billing analyses can implicitly pick up the energy use impacts of amenity changes resulting from program participation, the effect is usually impossible to isolate. A number of programs attempted to identify changes in energy service levels through customer surveys. Five concluded that there was no evidence of takeback, while two estimated small amounts of

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[c] S. Nadel (1993). The Takeback Effect: Fact or Fiction? Conference paper: American Council for an Energy-Efficient Economy.

[d] Eto et al. (1995). Where Did the Money Go? The Cost and Performance of the Largest Commercial Sector DSM Programs. LBL–3820. Lawrence Berkeley National Laboratory, Berkeley, CA.

takeback for specific end uses, usually less than 10-percent. A recent paper by Qiu,[e] which describes a model of technology adoption and subsequent energy demand in the commercial building sector, does not present specific rebound percentages, but the author notes that compared with the residential sector, rebound effects are smaller in the commercial building sector. An important reason for this is that in contrast to residential heating and cooling, HVAC operation adjustment in commercial buildings is driven primarily by building managers or owners. The comfort conditions are already established in order to satisfy the occupants, and they are unlikely to change due to installation of higher-efficiency equipment. While it is possible that a small degree of rebound could occur for higher-efficiency CPBs, e.g., building managers may choose to increase the operation time of these heating units, there is no basis to select a specific value. Because the available information suggests that any rebound would be small to negligible, DOE did not include a rebound effect for this rule.

EIA includes a rebound effect for several end-uses in the commercial sector, including heating and cooling, as well as improvements in building shell efficiency in its AEO reports.[f] The DOE analysis presented here does not include either the rebound effect for building shell efficiency or the rebound effect for equipment efficiency as is included in the AEO, and therefore cannot definitively assess what the impact of including the rebound effect would have on this analysis. For example, if the building shell efficiency improvements included in the AEO reduced heating and cooling load by 10 percent and the rebound effect on building shell efficiency was assumed to be 10 percent, the total impact would be to reduce heating and cooling loads by 9 percent. The DOE analysis presented here includes only the building shell improvements from the AEO but not the rebound effect on the building shell efficiency improvements. For illustrative purposes, DOE estimates that a rebound effect of 10 percent on CPB efficiency for heating improvements could reduce the energy savings by 0.04 quads (10 percent) over the analysis period.

8.2.2.2 Energy Prices

DOE derives average monthly energy prices for a number of geographic areas in the United States using the latest data from EIA and monthly energy price factors that it develops. The process then assigns an appropriate energy prices to each commercial building and household 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 data.[6] The EIA Form 826 data include energy prices by state. 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.

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[e] Qui, Y. (2014). Energy Efficiency and Rebound Effects: An Econometric Analysis of Energy Demand in the Commercial Building Sector. Environmental and Resource Economics, 59(2): 295 – 335.

[f] Energy Information Administration, Commercial Demand Module of the National Energy Modeling System: Model Documentation 2013, Washington, DC, November 2013, page 57. The building shell efficiency improvement index in the AEO accounts for reductions in heating and cooling load due to building code enhancements and other improvements that could reduce the buildings need for heating and cooling.

Table 8.2.7 and Table 8.2.8 show the electricity prices by region for commercial and residential sectors, respectively. (See appendix 8C for more details.)

Table 8.2.7 Average Commercial Electricity Prices in 2014

Region Code	Census Division	Commercial Electricity Prices *2014$/kWh*
1	New England	$0.15
2	Middle Atlantic	$0.13
3	East North Central	$0.10
4	West North Central	$0.09
5	South Atlantic	$0.09
6	East South Central	$0.10
7	West South Central	$0.08
8	Mountain	$0.09
9	Pacific	$0.14

Table 8.2.8 Average Residential Electricity Prices in 2014

Region Code	Geographic Area	Residential Electricity Prices *2014$/kWh*
1	Connecticut, Maine, New Hampshire, Rhode Island, Vermont	$0.15
2	Massachusetts	$0.15
3	New York	$0.16
4	New Jersey	$0.13
5	Pennsylvania	$0.10
6	Illinois	$0.09
7	Indiana, Ohio	$0.10
8	Michigan	$0.11
9	Wisconsin	$0.11
10	Iowa, Minnesota, North Dakota, South Dakota	$0.09
11	Kansas, Nebraska	$0.10
12	Missouri	$0.09
13	Virginia	$0.08
14	Delaware, District of Columbia, Maryland	$0.11
15	Georgia	$0.10
16	North Carolina, South Carolina	$0.09
17	Florida	$0.10
18	Alabama, Kentucky, Mississippi	$0.06
19	Tennessee	$0.10
20	Arkansas, Louisiana, Oklahoma	$0.08
21	Texas	$0.08
22	Colorado	$0.10
23	Idaho, Montana, Utah, Wyoming	$0.09
24	Arizona	$0.10
25	Nevada, New Mexico	$0.10
26	California	$0.16

Region Code	Geographic Area	Residential Electricity Prices *2014$/kWh*
27	Oregon, Washington	$0.25
28	Alaska	$0.04
29	Hawaii	$0.34
30	West Virginia	$0.08

DOE obtains the data for natural gas prices from EIA's Natural Gas Navigator, which includes monthly natural gas prices by state for residential, commercial, and industrial commercial consumers.[7] For areas with more than one state, DOE weights each state's average price by its population. Table 8.2.9 and Table 8.2.10 show the natural gas prices by region for commercial and residential sectors, respectively. (See appendix 8C for more details.)

Table 8.2.9 Average Commercial Natural Gas Prices in 2014

Region Code	Census Division	Commercial Gas Prices *2013$/MMBtu*
1	New England	$12.12
2	Middle Atlantic	$9.32
3	East North Central	$8.47
4	West North Central	$8.45
5	South Atlantic	$10.19
6	East South Central	$9.80
7	West South Central	$8.23
8	Mountain	$8.70
9	Pacific	$9.96

Table 8.2.10 Average Residential Natural Gas Prices in 2014

Region Code	Geographic Area	Residential Gas Prices *2014$/MMBtu*
1	Connecticut, Maine, New Hampshire, Rhode Island, Vermont	$15.08
2	Massachusetts	$14.47
3	New York	$12.54
4	New Jersey	$10.20
5	Pennsylvania	$11.68
6	Illinois	$9.68
7	Indiana, Ohio	$9.74
8	Michigan	$9.29
9	Wisconsin	$10.60
10	Iowa, Minnesota, North Dakota, South Dakota	$9.40
11	Kansas, Nebraska	$10.07
12	Missouri	$10.56
13	Virginia	$12.26
14	Delaware, District of Columbia, Maryland	$12.55
15	Georgia	$14.69
16	North Carolina, South Carolina	$12.09

Region Code	Geographic Area	Residential Gas Prices *2014$/MMBtu*
17	Florida	$18.97
18	Alabama, Kentucky, Mississippi	$6.13
19	Tennessee	$10.22
20	Arkansas, Louisiana, Oklahoma	$10.49
21	Texas	$11.02
22	Colorado	$8.72
23	Idaho, Montana, Utah, Wyoming	$9.20
24	Arizona	$17.31
25	Nevada, New Mexico	$10.88
26	California	$11.53
27	Oregon, Washington	$20.47
28	Alaska	$5.74
29	Hawaii	$47.51
30	West Virginia	$10.17

DOE collects 2013 average commercial fuel oil prices from EIA's State Energy Consumption, Price, and Expenditure Estimates (SEDS).[8] SEDS includes annual fuel oil prices for residential, commercial, industrial, and transportation consumers by state. For areas with more than one state, DOE weights each state's average price, adjusted to 2014$, by its population. Table 8.2.11 and Table 8.2.12 show the fuel oil prices by region for commercial and residential sectors, respectively. Appendix 8C includes more details.

Table 8.2.11 Average Commercial Fuel Oil Prices in 2013

Region Code	Census Division	Commercial Oil Prices *2014$/MMBtu*
1	New England	$25.42
2	Middle Atlantic	$25.00
3	East North Central	$24.65
4	West North Central	$24.49
5	South Atlantic	$24.31
6	East South Central	$24.40
7	West South Central	$24.14
8	Mountain	$24.65
9	Pacific	$25.22

Table 8.2.12 Average Residential Fuel Oil Prices in 2013

Region Code	Geographic Area	Residential Oil Prices *2014$/MMBtu*
1	Connecticut, Maine, New Hampshire, Rhode Island, Vermont	$27.94
2	Massachusetts	$28.24
3	New York	$28.34
4	New Jersey	$29.16
5	Pennsylvania	$28.89

Region Code	Geographic Area	Residential Oil Prices *2014$/MMBtu*
6	Illinois	$28.42
7	Indiana, Ohio	$28.36
8	Michigan	$28.35
9	Wisconsin	$28.09
10	Iowa, Minnesota, North Dakota, South Dakota	$28.41
11	Kansas, Nebraska	$28.33
12	Missouri	$27.87
13	Virginia	$28.09
14	Delaware, District of Columbia, Maryland	$28.68
15	Georgia	$27.81
16	North Carolina, South Carolina	$28.12
17	Florida	$28.35
18	Alabama, Kentucky, Mississippi	$16.70
19	Tennessee	$28.62
20	Arkansas, Louisiana, Oklahoma	$26.68
21	Texas	$26.40
22	Colorado	$25.19
23	Idaho, Montana, Utah, Wyoming	$25.66
24	Arizona	$29.22
25	Nevada, New Mexico	$28.02
26	California	$29.63
27	Oregon, Washington	$56.29
28	Alaska	$10.22
29	Hawaii	$28.67
30	West Virginia	$28.35

Monthly Prices

To determine monthly prices for use in the analysis, DOE develops monthly energy price for each fuel. See appendix 8C for a description of the monthly prices for each fuel.

Electricity and Natural Gas Marginal Prices

Monthly electricity and natural gas prices are adjusted using seasonal marginal price factors to determine monthly marginal electricity and natural gas prices. These marginal energy prices are used to determine the cost to the commercial consumer of the change in energy consumed. For a discussion of the seasonal marginal energy price factors, see appendix 8C.

Building Energy Price Adjustment Factor

CBECS 2003 and RECS 2009 report the total annual consumption and expenditure of each energy use type. To take into account that building energy prices vary inside a geographical area, DOE develops an adjustment factor based on the reported average energy price in CBECS 2003 and RECS 2009 for each building divided by the average energy price in the geographical region in CBECS 2003 and RECS 2009. This factor is then multiplied times the monthly price developed above to determine the building energy price. Appendix 8C includes more details.

8.2.2.3 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*.[2] Figure 8.2.3 and Figure 8.2.4 show the national commercial and residential energy price trends. To estimate the trend after 2040, DOE uses the average rate of change during 2030–2040.

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.

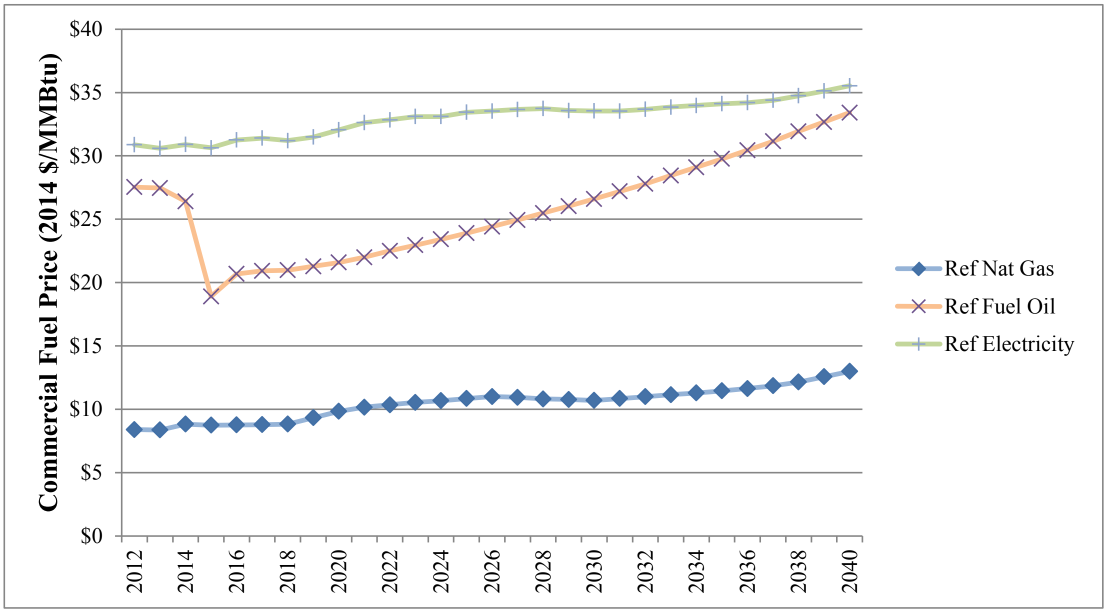

Figure 8.2.3 Projected National Commercial Energy Prices

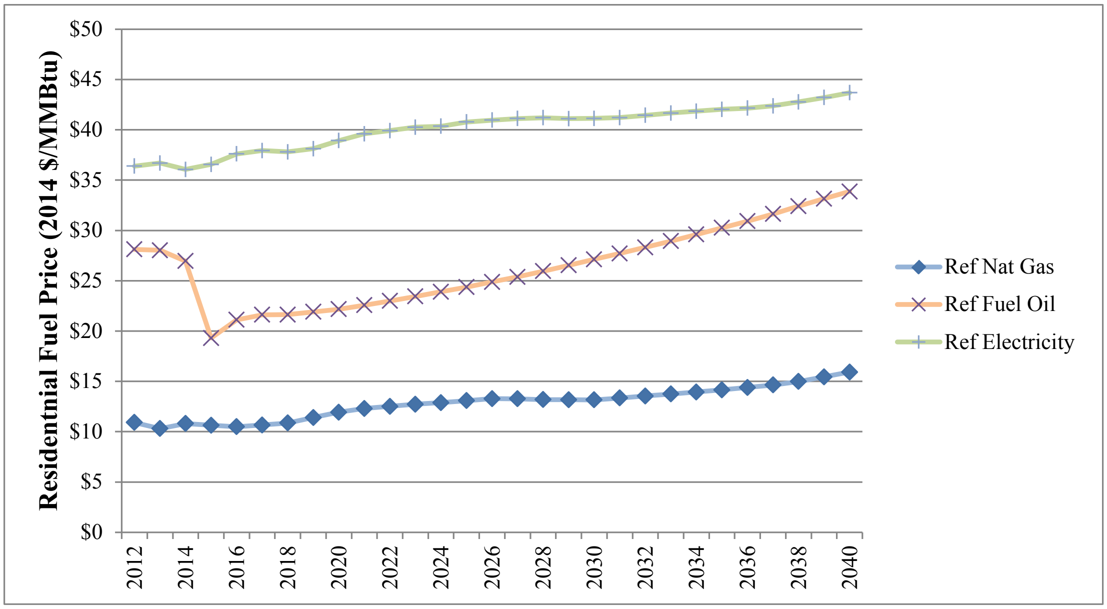

Figure 8.2.4 Projected National Residential Energy Prices

8.2.2.4 Repair Cost

The repair cost is the cost to the commercial consumer for replacing or repairing components in the commercial packaged boiler that have failed (such as the ignition, controls, heat exchanger, mechanical vent damper, or power vent blower). The repair costs at each considered efficiency level are based on *2015 RS Means Facilities Maintenance and Repair Data*.[9] DOE accounts for regional differences in labor costs. The failure year distribution was assumed to be a Weibull function for each component. The mean failure year for each component is based on RS Means and a report by the Gas Research Institute (GRI).[10] DOE assumes that all boilers have a 1 year warranty for parts and labor and a 10-year warranty on the heat exchanger. For a detailed discussion of the development of repair costs, see appendix 8E.

Table 8.2.13 shows the annualized repair cost estimates for each equipment class.

Table 8.2.13 Annualized Repair Cost for Commercial Packaged Boilers (2014$)

Equipment Class	Efficiency Level	Annualized Repair Cost *2014$*	Incremental Annualized Repair Cost *2014$*
Gas-Fired Hot Water Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h	80% TE - Baseline	$84.67	-
	81% TE	$85.42	$0.75
	82% TE	$86.23	$1.57
	84% TE	$88.37	$3.71
	85% TE	$89.48	$4.82
	93% TE	$147.02	$62.35
	95% TE	$148.62	$63.95
	99% TE - Max Tech	$160.51	$75.84

Equipment Class	Efficiency Level	Annualized Repair Cost *2014$*	Incremental Annualized Repair Cost *2014$*
Gas-Fired Hot Water Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h	82% CE - Baseline	$226.59	-
	83% CE	$231.53	$4.94
	84% CE	$237.05	$10.46
	85% CE	$243.24	$16.65
	94% CE	$541.62	$315.03
	97% CE - Max Tech	$563.61	$337.03
Oil-Fired Hot Water Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h	82% TE - Baseline	$49.45	-
	83% TE	$50.22	$0.77
	84% TE	$51.05	$1.59
	85% TE	$51.93	$2.48
	87% TE	$53.92	$4.46
	88% TE	$55.02	$5.57
	97% TE - Max Tech	$174.63	$125.18
Oil-Fired Hot Water Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h	84% CE - Baseline	$83.28	-
	86% CE	$90.79	$7.51
	88% CE	$100.19	$16.91
	89% CE	$105.75	$22.47
	97% CE - Max Tech	$188.65	$105.37
Gas-Fired Steam Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h	77% TE - Baseline	$84.07	-
	78% TE	$84.76	$0.70
	79% TE	$85.52	$1.45
	80% TE	$86.33	$2.27
	81% TE	$87.22	$3.15
	83% TE - Max Tech	$89.20	$5.13
Gas-Fired Steam Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h	77% TE - Baseline	$220.35	-
	78% TE	$222.35	$2.00
	79% TE	$224.46	$4.12
	80% TE	$226.70	$6.35
	81% TE	$229.07	$8.72
	82% TE	$231.57	$11.22
	84% TE - Max Tech	$237.01	$16.66
Oil-Fired Steam Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h	81% TE - Baseline	$43.68	-
	83% TE	$45.58	$1.90
	84% TE	$46.69	$3.01
	86% TE - Max Tech	$49.30	$5.62
Oil-Fired Steam Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h	81% TE - Baseline	$87.05	-
	83% TE	$92.09	$5.04
	85% TE	$97.95	$10.90
	87% TE - Max Tech	$104.75	$17.70

8.2.2.5 Maintenance Cost

The maintenance cost is the routine cost to the commercial consumer of maintaining equipment operation. The maintenance cost depends on boiler capacity and heating medium (hot water or steam). Within an equipment class, DOE assumes that the maintenance cost is the same at all non-condensing efficiency levels, and that the maintenance cost at condensing efficiency levels is slightly higher. Annualized maintenance costs for commercial packaged boilers are presented in Table 8.2.14.

Labor hours and costs for annual maintenance are estimated using RS Means data. The frequency with which the maintenance occurs is derived from *RS Means 2015 Facilities Maintenance and Repair Data* on the frequency with which owners of different types of boilers perform maintenance. For a detailed discussion of the development of maintenance costs, see appendix 8E.

Table 8.2.14 Annualized Maintenance Cost for Commercial Packaged Boilers (2014$)

Equipment Class	**Efficiency Level**	**Annualized Maintenance Cost** ***2014$***	**Incremental Annualized Maintenance Cost** ***2014$***
Gas-Fired Hot Water Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h	80% TE - Baseline	$1,488	-
	81% TE	$1,488	$0
	82% TE	$1,488	$0
	84% TE	$1,488	$0
	85% TE	$1,488	$0
	93% TE	$1,517	$29
	95% TE	$1,517	$29
	99% TE - Max Tech	$1,517	$29
Gas-Fired Hot Water Commercial Packaged Boiler >2,500,000 Btu/h	82% CE - Baseline	$2,617	-
	83% CE	$2,617	$0
	84% CE	$2,617	$0
	85% CE	$2,617	$0
	94% CE	$2,649	$33
	97% CE - Max Tech	$2,649	$33
Oil-Fired Hot Water Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h	82% TE - Baseline	$2,141	-
	83% TE	$2,141	$0
	84% TE	$2,141	$0
	85% TE	$2,141	$0
	87% TE	$2,141	$0
	88% TE	$2,141	$0
	97% TE - Max Tech	$2,177	$37
Oil-Fired Hot Water Commercial Packaged Boiler >2,500,000 Btu/h	84% CE - Baseline	$3,260	-
	86% CE	$3,260	$0
	88% CE	$3,260	$0
	89% CE	$3,260	$0
	97% CE - Max Tech	$3,298	$38
Gas-Fired Steam Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h	77% TE - Baseline	$2,234	-
	78% TE	$2,234	$0
	79% TE	$2,234	$0
	80% TE	$2,234	$0
	81% TE	$2,234	$0
	83% TE - Max Tech	$2,234	$0
Gas-Fired Steam Commercial Packaged Boiler >2,500,000 Btu/h	77% TE - Baseline	$3,061	-
	78% TE	$3,061	$0
	79% TE	$3,061	$0
	80% TE	$3,061	$0
	81% TE	$3,061	$0

Equipment Class	Efficiency Level	Annualized Maintenance Cost *2014$*	Incremental Annualized Maintenance Cost *2014$*
	82% TE	$3,061	$0
	84% TE - Max Tech	$3,061	$0
Oil-Fired Steam Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h	81% TE - Baseline	$2,352	-
	83% TE	$2,352	$0
	84% TE	$2,352	$0
	86% TE - Max Tech	$2,352	$0
Oil-Fired Steam Commercial Packaged Boiler >2,500,000 Btu/h	81% TE - Baseline	$3,663	-
	83% TE	$3,663	$0
	85% TE	$3,663	$0
	87% TE - Max Tech	$3,663	$0

8.2.2.6 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 commercial packaged boiler lifetimes.[g] For a detailed discussion of the development of boiler lifetime, see appendix 8F.

Table 8.2.15 shows the Weibull distribution parameters alpha, beta, and the location. DOE assumes that the lifetime of a commercial packaged boiler is the same across the different equipment classes and efficiency levels.

Table 8.2.15 Lifetime Parameters for Commercial Packaged Boilers

Equipment Class	Weibull Parameters		
	Alpha (scale)	Beta (shape)	Location (delay)
Commercial Packaged Boilers	26.91	2.34	1.00

8.2.2.7 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 to

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[g] See appendix 8F for a list of the studies used.

future year energy costs and non-energy operations and maintenance costs to calculate the estimated net LCC of products of various efficiency levels and LCC savings as compared to the baseline for a representative sample of commercial end users.

DOE's method views the purchase of a higher efficiency appliance as an investment that yields a stream of energy cost savings. DOE derives the discount rates for the LCC analysis by estimating the cost of capital for companies that purchase commercial packaged boilers. 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 boilers.[11]

Damodaran Online is a widely used source of information about company debt and equity financing for most types of firms, and was the primary source of data for this analysis.[12] Detailed sectors included in the Damondaran Online 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.[13] 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."[14]

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 8.2.16).[15] 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.[16]

Table 8.2.16 Risk-free rate and equity risk premium, 2004 – 2013

Year	Risk-Free Rate %	ERP %
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 as follows:

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

Eq. 8.5

Where:

k_d = 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 CPB analysis.

Table 8.2.17 shows the average WACC values for the major sectors that purchase commercial packaged boilers. 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 8.2.17 Weighted Average Cost of Capital for Sectors that Purchase Boilers

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%
Education, State/Local Government	3.51%	1.15%
Federal Government	3.55%	1.41%
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 (SCF)) to estimate a consumer's opportunity cost of funds related to appliance energy cost savings and maintenance costs. The discount rate value is applied in the LCC to future year energy cost savings and non-energy operations and maintenance costs in order to present the estimated net LCC and LCC savings. DOE notes that the discount rate used in the LCC analysis is distinct from an implicit discount rate, as it is not used to model consumer purchase decisions. The opportunity cost of funds in this case may include interest payments on debt and interest returns on assets.

DOE estimates separate discount rate distributions for six income groups, which are divided based on income percentile as reported in the Federal Reserve Board's SCF (see Table 8.2.18).[17] This disaggregation reflects the fact that low and high income consumers tend to have substantially different shares of debt and asset types, as well as facing different rates on debts and assets. Summaries of shares and rates presented in this chapter are averages across the entire population.

Table 8.2.18 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, consumers are likely to draw from or add to their collection of debt and asset holdings approximately in proportion to their current holdings when future expenditures are required or future savings accumulate. DOE has included several previously excluded debt types (*i.e.,* vehicle and education loans, mortgages, all forms of home equity loan) in order to better account for all of the options available to consumers.

The average share of total debt plus equity and the associated rate of each asset and debt type are used to calculate a weighted average discount rate for each Federal Reserve Board's SCF household (Table 8.2.19). The household-level discount rates are then aggregated to form discount rate distributions for each of the six income groups. Note that previously DOE performed aggregation of asset and debt types over households by summing the dollar value across all households and then calculating shares. Weighting by dollar value gave disproportionate influence to the asset and debt shares and rates of higher income consumers. DOE has shifted to a household-level weighting to more accurately reflect the average consumer in each income group.

DOE 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.[h] DOE derives the household-weighted mean percentages of each source of financing throughout the 5 years surveyed. DOE posits that these long-term averages are most appropriate to use in its analysis.

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[h] Note that two older versions of the SCF are also available (1989 and 1992); these surveys are not used in this analysis because they do not provide all of the necessary types of data (*e.g.*, credit card interest rates, etc.). DOE feels that the 15-year span covered by the six surveys included is sufficiently representative of recent debt and equity shares and interest rates.

Table 8.2.19 Types of Household Debt and Equity by Percentage Shares (%)

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

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

Rates for Types of Debt

DOE 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 8.2.20). 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).[i] For example, a 6% nominal mortgage rate has an effective nominal rate of 5.5% for a household at the 25% marginal tax rate. When adjusted for an inflation rate of 2%, the effective real rate becomes 2.45%.

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

Table 8.2.20 Data Used to Calculate Real Effective Mortgage Rates

Year	Mortgage Interest Rates in Selected Years (%)			
	Average Nominal Interest Rate	Inflation Rate*	Applicable Marginal Tax Rate**	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

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

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

Table 8.2.21 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 8.2.21 Average Real Effective Interest Rates for Household Debt

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

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

Rates for Types of Assets

No similar rate data are available from the SCF for classes of assets, so DOE 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)[18,19,20] have been collected from Federal Reserve Board time-series data. Rates on money market accounts are from Cost of Savings Index data.[21] 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.[16] 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 8.2.22. 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 8F.

Table 8.2.22 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 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 consumer i,
$Share_{i,j}$ = share of asset or debt type j for consumer i, and
$Rate_{i,j}$ = real interest rate or rate of return of asset or debt type j for consumer i.

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

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

Table 8.2.23 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 8F presents the full probability distributions for each income group that DOE uses in the LCC and PBP analysis.

Table 8.2.23 Average Real Effective Discount

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

8.2.2.8 Compliance Date of Standard

Pursuant to 42 U.S.C. 6313(a)(6)(C), the compliance date of any new energy efficiency standard for commercial packaged boilers is generally 3 years after the final rule is published. Consistent with its published regulatory agenda, DOE assumes that the final rule would be issued in 2016 and that, therefore, the new standards would require compliance beginning in 2019. DOE calculates the LCC and PBP for all commercial consumers as if they each would purchase a new boiler in 2019.

8.2.2.9 No-New-Standards-Case Distribution of Efficiency Levels

To estimate the market shares of the different efficiency levels in each CPB equipment class beginning in 2019, DOE develops data on the share of models in each equipment class, separated by draft type, based on the AHRI certification directory (see Table 8.2.24).[22] DOE analyzes the equipment directories from 2007 to 2015 and identifies efficiency trends that are then projected forward to 2019. For a detailed discussion of the development of no-new-standards case distributions, see appendix 8H.

Table 8.2.24 Base-Case Market Shares in 2019 by Efficiency Level for Commercial Packaged Boilers

Equipment Class	Efficiency Level	Design Option	Fraction of Models	
			Mechanical Draft	Natural Draft
Gas-Fired Hot Water Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h	0	80% TE - Baseline	4.8%	19.6%
	1	81% TE	6.0%	21.0%
	2	82% TE	4.9%	59.3%
	3	84% TE	10.8%	-
	4	85% TE	22.9%	-
	5	93% TE	22.6%	-
	6	95% TE	24.8%	-
	7	99% TE - Max Tech	3.3%	-
Gas-Fired Hot Water Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h	0	82% CE - Baseline	4.2%	72.5%
	1	83% CE	25.5%	19.0%
	2	84% CE	7.4%	7.1%
	3	85% CE	23.2%	1.4%
	4	94% CE	36.6%	-
	5	97% CE - Max Tech	3.0%	-
Oil-Fired Hot Water Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h	0	82% TE - Baseline	27.7%	52.7%
	1	83% TE	28.0%	12.7%
	2	84% TE	7.7%	13.6%
	3	85% TE	18.2%	10.2%
	4	87% TE	11.4%	8.4%
	5	88% TE	3.5%	2.3%
	6	97% TE - Max Tech	3.7%	-
Oil-Fired Hot Water Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h	0	84% CE - Baseline	31.4%	65.1%
	1	86% CE	48.0%	33.7%
	2	88% CE	13.4%	1.2%
	3	89% CE	1.2%	-
	4	97% CE - Max Tech	6.0%	-
Gas-Fired Steam Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h	0	77% TE - Baseline	-	72.9%
	1	78% TE	-	7.3%
	2	79% TE	13.6%	17.9%
	3	80% TE	44.6%	1.8%
	4	81% TE	29.1%	-
	5	83% TE - Max Tech	12.7%	-
Gas-Fired Steam Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h	0	77% TE - Baseline	-	23.3%
	1	78% TE	-	47.3%
	2	79% TE	15.5%	12.5%
	3	80% TE	36.5%	11.6%
	4	81% TE	5.8%	5.3%
	5	82% TE	25.8%	-
	6	84% TE - Max Tech	16.4%	-
Oil-Fired Steam Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h	0	81% TE - Baseline	26.5%	56.2%
	1	83% TE	55.3%	37.6%
	2	84% TE	12.9%	3.1%
	3	86% TE - Max Tech	5.3%	3.1%
Oil-Fired Steam Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h	0	81% TE - Baseline	38.6%	45.3%
	1	83% TE	32.5%	49.5%
	2	85% TE	28.2%	5.3%
	3	87% TE - Max Tech	0.7%	-

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:

$$PBP = \Delta IC / \Delta OC$$

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.

Payback periods are expressed in years. Payback periods 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 in 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 as calculated from the DOE test procedure. The calculation excludes repair costs and maintenance costs.

The data inputs to PBP are the total installed cost of the equipment to the commercial consumer for each efficiency level and the annual (first year) operating costs for each efficiency 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 each commercial packaged boiler. Each LCC and PBP calculation is performed on a single building that is selected from the sample of the commercial users. The selection of a building is based on its sample weight (*i.e.*, how representative a particular building is of other building in the distribution—either regionally or nationally), as described in 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 commercial packaged boilers, DOE conducts LCC and PBP analyses for each trial standard level (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 below.

8.4.1 Gas-Fired Hot Water Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h

Table 8.4.1 shows the LCC and PBP results for all efficiency levels considered for gas-fired hot water commercial packaged boilers ≥300,000 Btu/h and ≤2,500,000 Btu/h. 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 Gas-Fired Hot Water Commercial Packaged Boilers ≥300,000 Btu/h and ≤2,500,000 Btu/h

Efficiency Level*	**TE**	**Average Costs *2014$***				**Simple Payback *years***	**Average Lifetime *years***
		Installed Cost	**First Year's Operating Cost**	**Lifetime Operating Cost**	**LCC**		
0	80%	$25,571	$12,551	$218,155	$243,727	NA	24.8
1	81%	$26,427	$12,420	$215,863	$242,290	6.5	24.8
2	82%	$27,350	$12,292	$213,627	$240,977	6.9	24.8
3	84%	$30,302	$12,046	$209,326	$239,627	9.4	24.8
4	85%	$31,573	$11,927	$207,252	$238,826	9.6	24.8
5	93%	$40,896	$11,587	$202,027	$242,924	15.9	24.8
6	95%	$41,637	$11,371	$198,263	$239,901	13.6	24.8
7	99%	$47,145	$10,969	$191,355	$238,500	13.6	24.8

* 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.

Table 8.4.2 LCC Savings Relative to the No-New-Standards Case Efficiency Distribution for Gas-Fired Hot Water Commercial Packaged Boilers ≥300,000 Btu/h and ≤2,500,000 Btu/h

Efficiency Level	TE	Life-Cycle Cost Savings	
		% of Consumers that Experience Net Cost	Average Savings* *2014$*
0	80%	0%	NA
1	81%	2%	$106
2	82%	4%	$318
3	84%	20%	$223
4	85%	23%	$521
5	93%	46%	-$2,031
6	95%	42%	$302
7	99%	56%	$1,656

* The calculation includes buildings with zero LCC savings (no impact).

Figure 8.4.1 shows the range of LCC savings for the efficiency levels considered for gas-fired hot water commercial packaged boilers ≥300,000 Btu/h and ≤2,500,000 Btu/h. For each efficiency level, the top and the bottom of the box indicate the 75th and 25th percentiles, respectively. The bar at the middle of the box indicates the median; 50% of the buildings have LCC savings above this value. The "whiskers" at the bottom and the top of the box indicate the 5th and 95th percentiles. The small box shows the average LCC savings for each efficiency level.

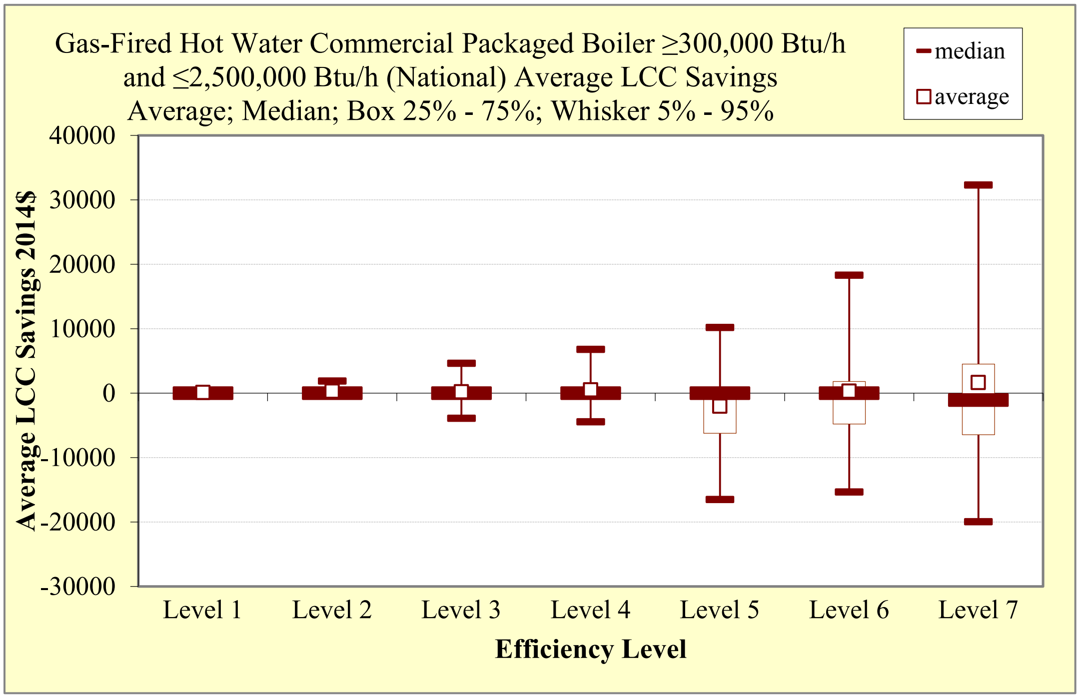

Figure 8.4.1 Distribution of LCC Savings for Gas-Fired Hot Water Commercial Packaged Boilers ≥300,000 Btu/h and ≤2,500,000 Btu/h

8.4.2 Gas-Fired Hot Water Commercial Packaged Boilers >2,500,000 Btu/h and ≤10,000,000 Btu/h

Table 8.4.3 shows the LCC and PBP results for all efficiency levels considered for gas-fired hot water commercial packaged boilers >2,500,000 Btu/h and ≤10,000,000 Btu/h. 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 Gas-Fired Hot Water Commercial Packaged Boilers >2,500,000 Btu/h and ≤10,000,000 Btu/h

Efficiency Level*	CE	Average Costs *2014$*				Simple Payback *years*	Average Lifetime *years*
		Installed Cost	First Year's Operating Cost	Lifetime Operating Cost	LCC		
0	82%	$94,053	$49,620	$842,932	$936,985	NA	24.8
1	83%	$99,700	$49,025	$832,857	$932,556	9.5	24.8
2	84%	$106,020	$48,445	$823,055	$929,074	10.2	24.8
3	85%	$113,093	$47,881	$813,516	$926,609	11.0	24.8
4	94%	$169,571	$45,655	$779,745	$949,315	19.0	24.8
5	97%	$178,725	$44,197	$755,202	$933,927	15.6	24.8

* 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.

Table 8.4.4 LCC Savings Relative to the No-New-Standards Case Efficiency Distribution for Gas-Fired Hot Water Commercial Packaged Boilers >2,500,000 Btu/h and ≤10,000,000 Btu/h

Efficiency Level	CE	Life-Cycle Cost Savings	
		% of Consumers that Experience Net Cost	Average Savings* *2014$*
0	82%	0%	NA
1	83%	10%	$924
2	84%	21%	$2,419
3	85%	27%	$3,647
4	94%	57%	-$13,074
5	97%	56%	$2,062

* The calculation includes buildings with zero LCC savings (no impact).

Figure 8.4.2 shows the range of LCC savings for the efficiency levels considered for gas-fired hot water commercial packaged boilers >2,500,000 Btu/h and ≤10,000,000 Btu/h. For each efficiency level, the top and the bottom of the box indicate the 75th and 25th percentiles, respectively. The bar at the middle of the box indicates the median; 50% of the buildings have LCC savings above this value. The "whiskers" at the bottom and the top of the box indicate the 5th and 95th percentiles. The small box shows the average LCC savings for each efficiency level.

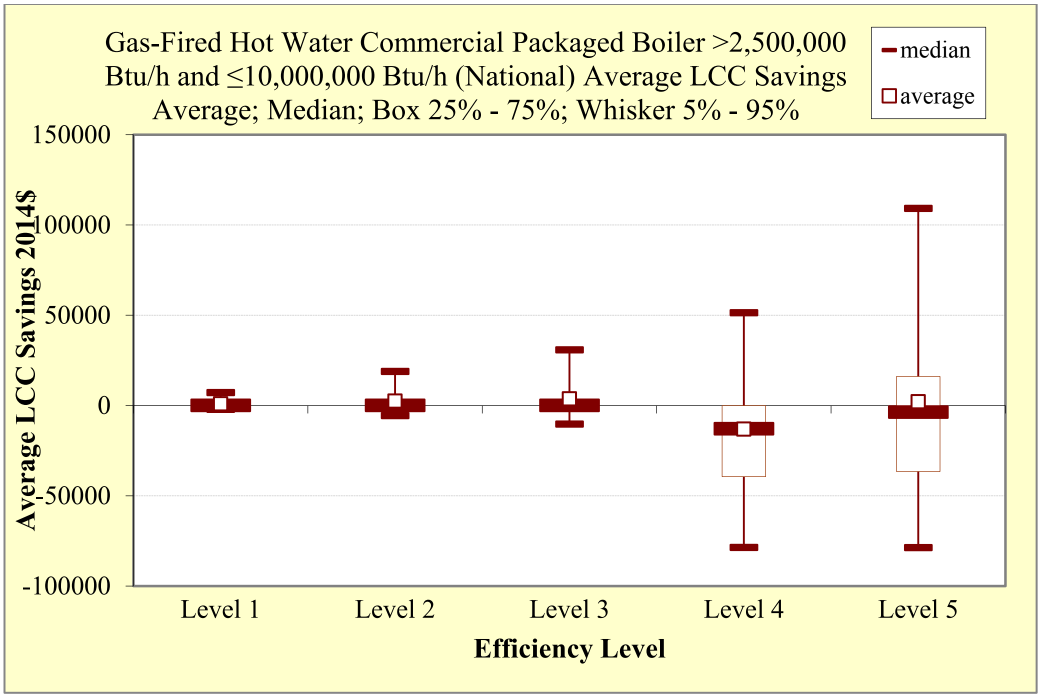

Figure 8.4.2 Distribution of LCC Savings for Gas-Fired Hot Water Commercial Packaged Boilers >2,500,000 Btu/h and ≤10,000,000 Btu/h

8.4.3 Oil-Fired Hot Water Commercial Packaged Boilers ≥300,000 Btu/h and ≤2,500,000 Btu/h

Table 8.4.5 shows the LCC and PBP results for all efficiency levels considered for oil-fired hot water commercial packaged boilers ≥300,000 Btu/h and ≤2,500,000 Btu/h. 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 Oil-Fired Hot Water Commercial Packaged Boilers ≥300,000 Btu/h and ≤2,500,000 Btu/h

Efficiency Level*	TE	Average Costs *2014$*				Simple Payback *years*	Average Lifetime *years*
		Installed Cost	First Year's Operating Cost	Lifetime Operating Cost	LCC		
0	82%	$27,566	$17,797	$323,016	$350,583	NA	24.8
1	83%	$28,457	$17,607	$319,481	$347,938	4.7	24.8
2	84%	$29,414	$17,422	$316,032	$345,447	4.9	24.8
3	85%	$30,444	$17,242	$312,666	$343,110	5.2	24.8
4	87%	$32,742	$16,893	$306,170	$338,912	5.7	24.8
5	88%	$34,666	$16,724	$303,036	$337,701	6.6	24.8
6	97%	$51,938	$16,087	$292,517	$344,455	14.3	24.8

* 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.

Table 8.4.6 LCC Savings Relative to the Base Case Efficiency Distribution for Oil-Fired Hot Water Commercial Packaged Boilers ≥300,000 Btu/h and ≤2,500,000 Btu/h

Efficiency Level	TE	Life-Cycle Cost Savings	
		% of Consumers that Experience Net Cost	Average Savings* *2014$*
0	82%	0%	NA
1	83%	8%	$1,040
2	84%	13%	$2,544
3	85%	16%	$4,208
4	87%	20%	$7,799
5	88%	26%	$8,939
6	97%	56%	$2,333

* The calculation includes buildings with zero LCC savings (no impact).

Figure 8.4.3 shows the range of LCC savings for the efficiency levels considered for oil-fired hot water commercial packaged boilers ≥300,000 Btu/h and ≤2,500,000 Btu/h. For each efficiency level, the top and the bottom of the box indicate the 75th and 25th percentiles, respectively. The bar at the middle of the box indicates the median; 50% of the buildings have LCC savings above this value. The "whiskers" at the bottom and the top of the box indicate the 5th and 95th percentiles. The small box shows the average LCC savings for each efficiency level.

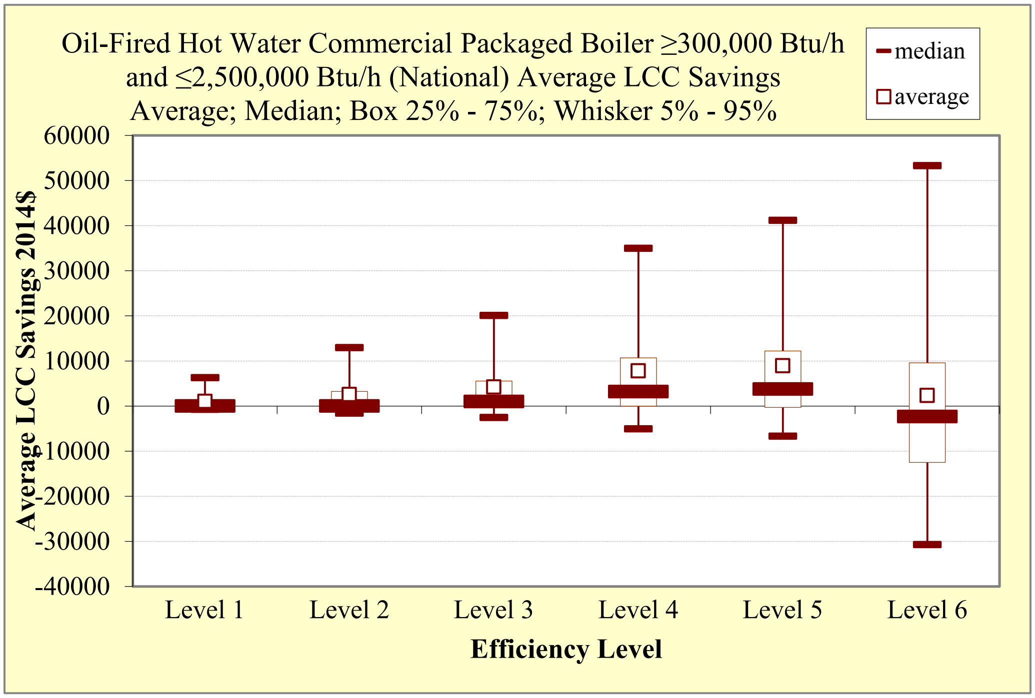

Figure 8.4.3 Distribution of LCC Savings for Oil-Fired Hot Water Commercial Packaged Boilers ≥300,000 Btu/h and ≤2,500,000 Btu/h

8.4.4 Oil-Fired Hot Water Commercial Packaged Boilers >2,500,000 Btu/h and ≤10,000,000 Btu/h

Table 8.4.7 shows the LCC and PBP results for all efficiency levels considered for oil-fired hot water commercial packaged boilers >2,500,000 Btu/h and ≤10,000,000 Btu/h. In Table 8.4.7, the simple payback is measured relative to the baseline equipment. 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 Oil-Fired Hot Water Commercial Packaged Boilers >2,500,000 Btu/h and ≤10,000,000 Btu/h

Efficiency Level*	CE	Average Costs *2014$*				Simple Payback *years*	Average Lifetime *years*
		Installed Cost	First Year's Operating Cost	Lifetime Operating Cost	LCC		
0	84%	$66,053	$101,507	$1,804,595	$1,870,649	NA	24.8
1	86%	$74,942	$99,348	$1,766,049	$1,840,992	4.1	24.8
2	88%	$86,080	$97,281	$1,729,192	$1,815,272	4.7	24.8
3	89%	$92,980	$96,281	$1,711,365	$1,804,345	5.2	24.8
4	97%	$159,031	$93,901	$1,670,295	$1,829,325	12.2	24.8

* 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.

Table 8.4.8 LCC Savings Relative to the No-New-Standards Case Efficiency Distribution for Oil-Fired Hot Water Commercial Packaged Boilers >2,500,000 Btu/h and ≤10,000,000 Btu/h

Efficiency Level	CE	Life-Cycle Cost Savings	
		% of Consumers that Experience Net Cost	Average Savings* *2014$*
0	84%	0%	NA
1	86%	1%	$10,108
2	88%	5%	$30,834
3	89%	7%	$40,983
4	97%	46%	$17,076

* The calculation includes buildings with zero LCC savings (no impact).

Figure 8.4.4 shows the range of LCC savings for the efficiency levels considered for oil-fired hot water commercial packaged boilers >2,500,000 Btu/h and ≤10,000,000 Btu/h. For each efficiency level, the top and the bottom of the box indicate the 75th and 25th percentiles, respectively. The bar at the middle of the box indicates the median; 50% of the buildings have LCC savings above this value. The "whiskers" at the bottom and the top of the box indicate the 5th and 95th percentiles. The small box shows the average LCC savings for each efficiency level.

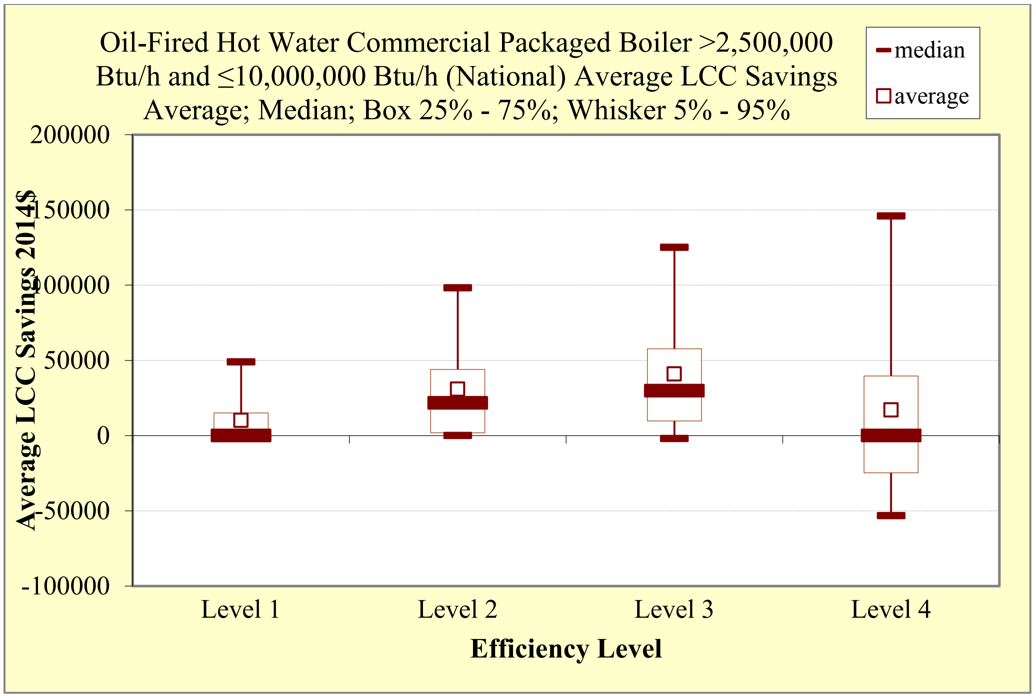

Figure 8.4.4 Distribution of LCC Savings for Oil-Fired Hot Water Commercial Packaged Boilers >2,500,000 Btu/h and ≤10,000,000 Btu/h

8.4.5 Gas-Fired Steam Commercial Packaged Boilers ≥300,000 Btu/h and ≤2,500,000 Btu/h

Table 8.4.9 shows the LCC and PBP results for all efficiency levels considered for gas-fired steam commercial packaged boilers ≥300,000 Btu/h and ≤2,500,000 Btu/h. In Table 8.4.9, the simple payback is measured relative to the baseline equipment. 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 Gas-Fired Steam Commercial Packaged Boilers ≥300,000 Btu/h and ≤2,500,000 Btu/h

Efficiency Level*	**TE**	**Average Costs** *2014$*				**Simple Payback** *years*	**Average Lifetime** *years*
		Installed Cost	**First Year's Operating Cost**	**Lifetime Operating Cost**	**LCC**		
0	77%	$22,540	$12,354	$212,456	$234,996	NA	24.8
1	78%	$23,330	$12,228	$210,244	$233,574	6.3	24.8
2	79%	$24,183	$12,106	$208,090	$232,274	6.6	24.8
3	80%	$25,107	$11,987	$205,992	$231,098	7.0	24.8
4	81%	$26,105	$11,871	$203,946	$230,051	7.4	24.8
5	83%	$28,350	$11,647	$200,010	$228,360	8.2	24.8

* 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.

Table 8.4.10 LCC Savings Relative to the No-New-Standards Case Efficiency Distribution for Gas-Fired Steam Commercial Packaged Boilers ≥300,000 Btu/h and ≤2,500,000 Btu/h

Efficiency Level	TE	Life-Cycle Cost Savings	
		% of Consumers that Experience Net Cost	Average Savings* *2014$*
0	77%	0%	NA
1	78%	10%	$600
2	79%	12%	$1,205
3	80%	18%	$1,933
4	81%	26%	$2,782
5	83%	34%	$4,383

* The calculation includes buildings with zero LCC savings (no impact).

Figure 8.4.5 shows the range of LCC savings for the efficiency levels considered for gas-fired steam commercial packaged boilers ≥300,000 Btu/h and ≤2,500,000 Btu/h. For each efficiency level, the top and the bottom of the box indicate the 75th and 25th percentiles, respectively. The bar at the middle of the box indicates the median; 50% of the buildings have LCC savings above this value. The "whiskers" at the bottom and the top of the box indicate the 5th and 95th percentiles. The small box shows the average LCC savings for each efficiency level.

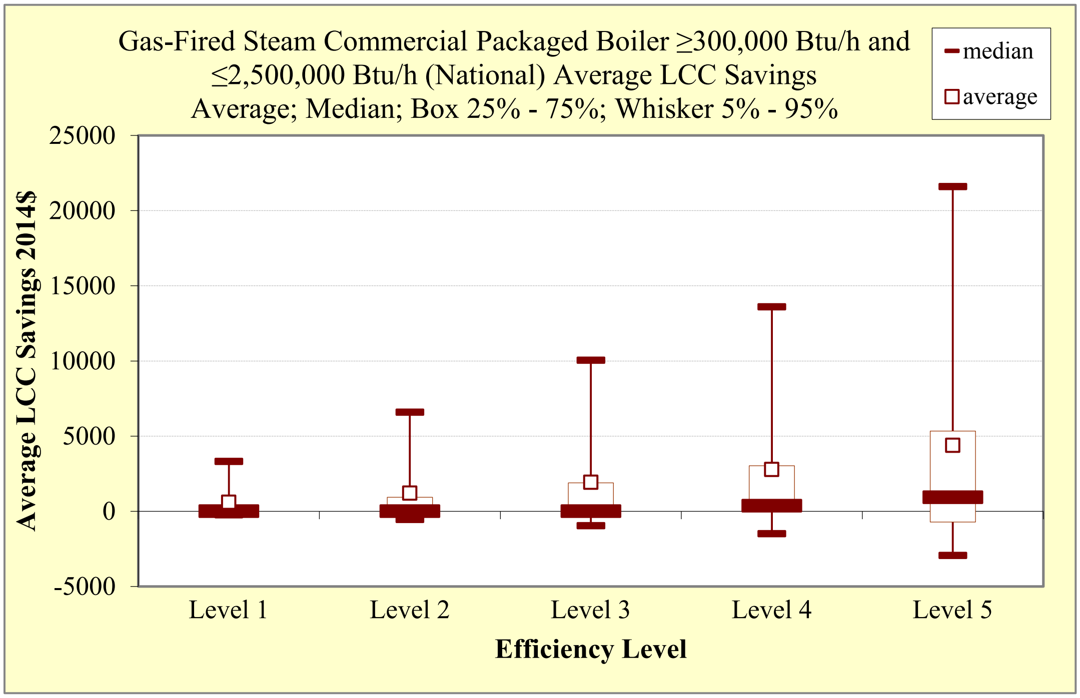

Figure 8.4.5 Distribution of LCC Savings for Gas-Fired Steam Commercial Packaged Boilers ≥300,000 Btu/h and ≤2,500,000 Btu/h

8.4.6 Gas-Fired Steam Commercial Packaged Boilers >2,500,000 Btu/h and ≤10,000,000 Btu/h

Table 8.4.11 shows the LCC and PBP results for all efficiency levels considered for gas-fired steam commercial packaged boilers >2,500,000 Btu/h and ≤10,000,000 Btu/h. In

Table 8.4.11, the simple payback is measured relative to the baseline equipment. 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 Gas-Fired Steam Commercial Packaged Boilers >2,500,000 Btu/h and ≤10,000,000 Btu/h

Efficiency Level*	**TE**	**Average Costs** *2014$*				**Simple Payback** *years*	**Average Lifetime** *years*
		Installed Cost	**First Year's Operating Cost**	**Lifetime Operating Cost**	**LCC**		
0	77%	$82,527	$53,362	$926,128	$1,008,655	NA	24.8
1	78%	$84,898	$52,735	$915,193	$1,000,091	3.8	24.8
2	79%	$87,405	$52,125	$904,540	$991,946	3.9	24.8
3	80%	$90,056	$51,529	$894,159	$984,215	4.1	24.8
4	81%	$92,859	$50,949	$884,039	$976,898	4.3	24.8
5	82%	$96,563	$50,383	$874,171	$970,734	4.7	24.8
6	84%	$103,011	$49,292	$855,155	$958,165	5.0	24.8

* 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.

Table 8.4.12 LCC Savings Relative to the No-New-Standards Case Efficiency Distribution for Gas-Fired Steam Commercial Packaged Boilers >2,500,000 Btu/h and ≤10,000,000 Btu/h

Efficiency Level	**TE**	**Life-Cycle Cost Savings**	
		% of Consumers that Experience Net Cost	**Average Savings*** *2014$*
0	77%	0%	NA
1	78%	1%	$880
2	79%	5%	$3,528
3	80%	7%	$7,059
4	81%	12%	$12,255
5	82%	15%	$16,802
6	84%	19%	$28,295

* The calculation includes buildings with zero LCC savings (no impact).

Figure 8.4.6 shows the range of LCC savings for the efficiency levels considered for gas-fired steam commercial packaged boilers >2,500,000 Btu/h and ≤10,000,000 Btu/h. For each efficiency level, the top and the bottom of the box indicate the 75th and 25th percentiles, respectively. The bar at the middle of the box indicates the median; 50% of the buildings have LCC savings above this value. The "whiskers" at the bottom and the top of the box indicate the 5th and 95th percentiles. The small box shows the average LCC savings for each efficiency level.

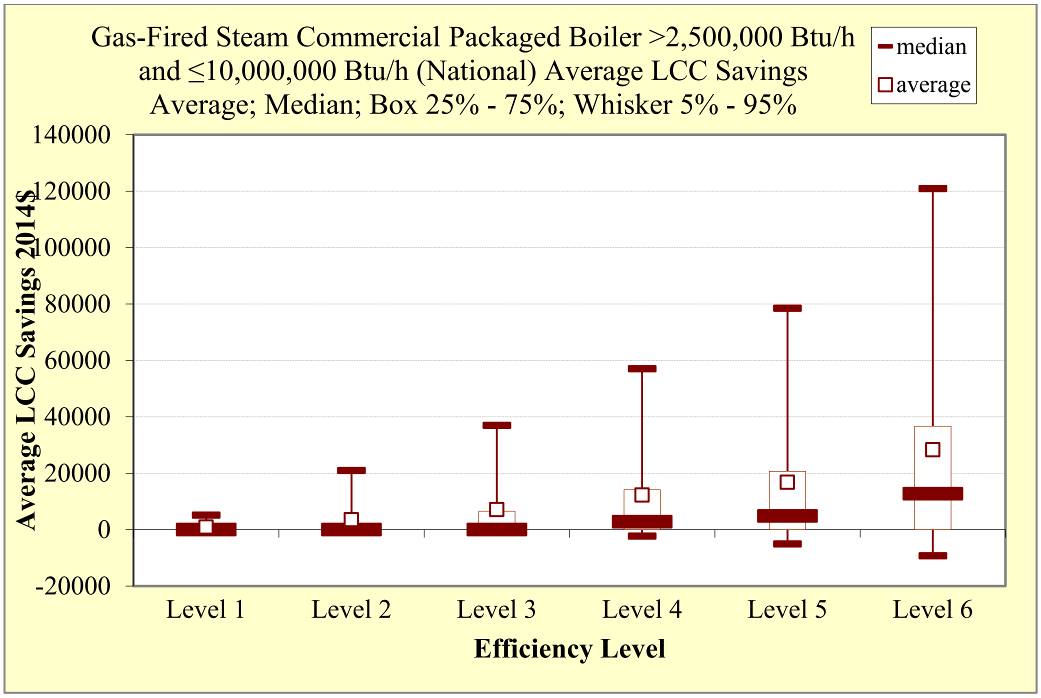

Figure 8.4.6 Distribution of LCC Savings for Oil-Fired Steam Commercial Packaged Boilers >2,500,000 Btu/h and ≤10,000,000 Btu/h

8.4.7 Oil-Fired Steam Commercial Packaged Boilers ≥300,000 Btu/h and ≤2,500,000 Btu/h

Table 8.4.13 shows the LCC and PBP results for all efficiency levels considered for oil-fired steam commercial packaged boilers ≥300,000 Btu/h and ≤2,500,000 Btu/h. In Table 8.4.13, the simple payback is measured relative to the baseline equipment. In Table 8.4.14, the LCC savings are measured relative to the no-new-standards-case efficiency distribution in the compliance year (2019).

Table 8.4.13 Average LCC and PBP Results by Efficiency Level for Oil-Fired Steam Commercial Packaged Boilers ≥300,000 Btu/h and ≤2,500,000 Btu/h

Efficiency Level*	TE	Average Costs *2014$*				Simple Payback *years*	Average Lifetime *years*
		Installed Cost	First Year's Operating Cost	Lifetime Operating Cost	LCC		
0	81%	$21,965	$20,964	$375,253	$397,218	NA	24.8
1	83%	$24,212	$20,513	$366,987	$391,199	5.0	24.8
2	84%	$25,527	$20,296	$363,005	$388,532	5.3	24.8
3	86%	$28,615	$19,876	$355,328	$383,942	6.1	24.8

* 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.

Table 8.4.14 LCC Savings Relative to the No-New-Standards Case Efficiency Distribution for Oil-Fired Steam Commercial Packaged Boilers ≥300,000 Btu/h and ≤2,500,000 Btu/h

Efficiency Level	TE	Life-Cycle Cost Savings	
		% of Consumers that Experience Net Cost	Average Savings* *2014$*
0	81%	0%	NA
1	83%	4%	$1,985
2	84%	12%	$4,256
3	86%	16%	$8,637

* The calculation includes buildings with zero LCC savings (no impact).

Figure 8.4.7 shows the range of LCC savings for the efficiency levels considered for oil-fired steam commercial packaged boilers ≥300,000 Btu/h and ≤2,500,000 Btu/h. For each efficiency level, the top and the bottom of the box indicate the 75th and 25th percentiles, respectively. The bar at the middle of the box indicates the median; 50% of the buildings have LCC savings above this value. The "whiskers" at the bottom and the top of the box indicate the 5th and 95th percentiles. The small box shows the average LCC savings for each efficiency level.

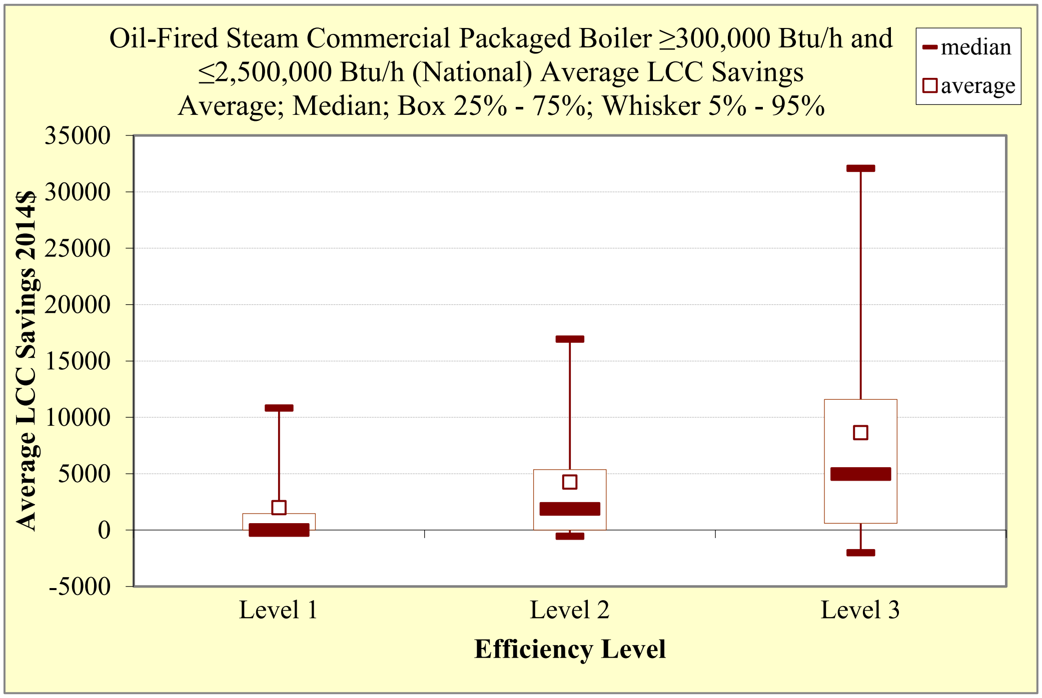

Figure 8.4.7 Distribution of LCC Savings for Oil-Fired Steam Commercial Packaged Boilers ≥300,000 Btu/h and ≤2,500,000 Btu/h

8.4.8 Oil-Fired Steam Commercial Packaged Boilers >2,500,000 Btu/h and ≤10,000,000 Btu/h

Table 8.4.15 shows the LCC and PBP results for all efficiency levels considered for oil-fired steam commercial packaged boilers >2,500,000 Btu/h and ≤10,000,000 Btu/h. In Table 8.4.15, the simple payback is measured relative to the baseline equipment. In Table 8.4.16, the LCC savings are measured relative to the no-new-standards-case efficiency distribution in the compliance year (2019).

Table 8.4.15 Average LCC and PBP Results by Efficiency Level for Oil-Fired Steam Commercial Packaged Boilers >2,500,000 Btu/h and ≤10,000,000 Btu/h

Efficiency Level*	**TE**	**Average Costs** *2014$*				**Simple Payback** *years*	**Average Lifetime** *years*
		Installed Cost	**First Year's Operating Cost**	**Lifetime Operating Cost**	**LCC**		
0	81%	$67,991	$99,776	$1,738,018	$1,806,009	NA	24.8
1	83%	$73,849	$97,444	$1,697,166	$1,771,014	2.5	24.8
2	85%	$80,651	$95,223	$1,658,263	$1,738,914	2.8	24.8
3	87%	$88,551	$93,105	$1,621,176	$1,709,727	3.1	24.8

* The results for each TSL are calculated assuming that all consumers use equipment with that efficiency level. The PBP is measured relative to the baseline equipment.

Table 8.4.16 LCC Savings Relative to the No-New-Standards Case Efficiency Distribution for Oil-Fired Steam Commercial Packaged Boilers >2,500,000 Btu/h and ≤10,000,000 Btu/h

Efficiency Level	**TE**	**Life-Cycle Cost Savings**	
		% of Consumers that Experience Net Cost	**Average Savings*** *2014$*
0	81%	0%	NA
1	83%	0%	$13,243
2	85%	1%	$36,128
3	87%	1%	$65,128

* The calculation includes buildings with zero LCC savings (no impact).

Figure 8.4.8 shows the range of LCC savings for the efficiency levels considered for oil-fired steam commercial packaged boilers >2,500,000 Btu/h and ≤10,000,000 Btu/h. For each standard level, the top and the bottom of the box indicate the 75th and 25th percentiles, respectively. The bar at the middle of the box indicates the median; 50% of the buildings have LCC savings above this value. The "whiskers" at the bottom and the top of the box indicate the 5th and 95th percentiles. The small box shows the average LCC savings for each standard level.

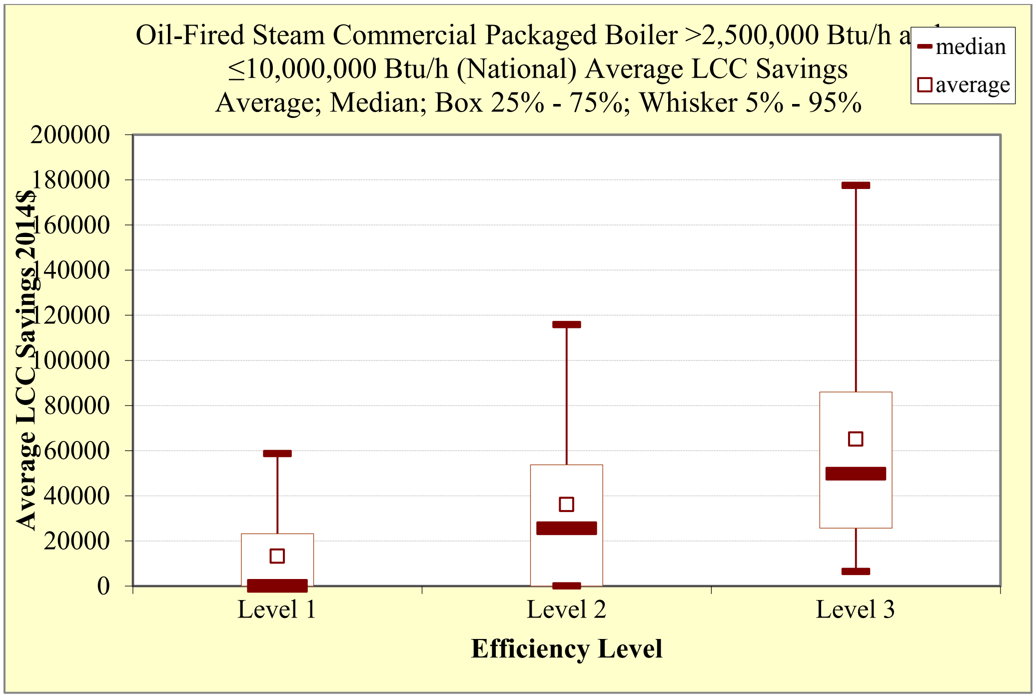

Figure 8.4.8 Distribution of LCC Savings for Oil-Fired Steam Commercial Packaged Boilers >2,500,000 Btu/h and ≤10,000,000 Btu/h

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 the use of building samples and probability distributions, and it is based not on 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 each standard level relative to the distribution of equipment energy efficiencies estimated for the no-new-standards-case. Table 8.5.1 through Table 8.5.8 present the rebuttable PBPs for commercial packaged boilers.

Table 8.5.1 Rebuttable Payback Period for Gas-Fired Hot Water Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h

Efficiency Level	Description	Rebuttable Payback Period *years*
1	81% TE	5.6
2	82% TE	5.9
3	84% TE	8.0
4	85% TE	8.2
5	93% TE	13.3
6	95% TE	11.4
7	99% TE - Max Tech	11.5

Table 8.5.2 Rebuttable Payback Period for Gas-Fired Hot Water Commercial Packaged Boilers >2,500,000 Btu/h and ≤10,000,000 Btu/h

Efficiency Level	Technology Option	Rebuttable Payback Period *years*
1	83% CE	7.8
2	84% CE	8.3
3	85% CE	9.0
4	94% CE	15.5
5	97% CE - Max Tech	12.7

Table 8.5.3 Rebuttable Payback Period for Oil-Fired Hot Water Commercial Packaged Boilers ≥300,000 Btu/h and ≤2,500,000 Btu/h

Efficiency Level	Technology Option	Rebuttable Payback Period *years*
1	83% TE	9.2
2	84% TE	9.6
3	85% TE	10.1
4	87% TE	11.2
5	88% TE	12.9
6	97% TE - Max Tech	27.4

Table 8.5.4 Rebuttable Payback Period for Oil-Fired Hot Water Commercial Packaged Boilers >2,500,000 Btu/h and ≤10,000,000 Btu/h

Efficiency Level	Technology Option	Rebuttable Payback Period *years*
1	86% CE	7.6
2	88% CE	8.8
3	89% CE	9.5
4	97% CE - Max Tech	22.7

Table 8.5.5 Rebuttable Payback Period for Gas-Fired Steam Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h

Efficiency Level	Technology Option	Rebuttable Payback Period *years*
1	78% TE	5.4
2	79% TE	5.7
3	80% TE	6.0
4	81% TE	6.3
5	83% TE - Max Tech	7.1

Table 8.5.6 Rebuttable Payback Period for Gas-Fired Steam Commercial Packaged Boilers >2,500,000 Btu/h and ≤10,000,000 Btu/h

Efficiency Level	Technology Option	Rebuttable Payback Period *years*
1	78% TE	3.2
2	79% TE	3.3
3	80% TE	3.4
4	81% TE	3.6
5	82% TE	3.9
6	84% TE - Max Tech	4.2

Table 8.5.7 Rebuttable Payback Period for Oil-Fired Steam Commercial Packaged Boilers ≥300,000 Btu/h and ≤2,500,000 Btu/h

Efficiency Level	Technology Option	Rebuttable Payback Period *years*
1	83% TE	9.2
2	84% TE	9.8
3	86% TE - Max Tech	11.3

Table 8.5.8 Rebuttable Payback Period for Oil-Fired Steam Commercial Packaged Boilers >2,500,000 Btu/h and ≤10,000,000 Btu/h

Efficiency Level	Technology Option	Rebuttable Payback Period *years*
1	83% TE	4.6
2	85% TE	5.1
3	87% TE - Max Tech	5.6

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APPENDIX 8A. USER INSTRUCTIONS FOR THE LIFE-CYCLE COST ANALYSIS SPREADSHEET FOR COMMERCIAL PACKAGED BOILERS

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APPENDIX 8A. USER INSTRUCTIONS FOR THE LIFE-CYCLE COST ANALYSIS SPREADSHEET FOR COMMERCIAL PACKAGED BOILERS

8A.1 USER INSTRUCTIONS

The results obtained in this analysis can be examined and reproduced using Microsoft Excel spreadsheets available on the U.S. Department of Energy's (DOE's) commercial packaged boiler (CPB) rulemaking website: https://www1.eere.energy.gov/buildings/appliance_standards/rulemaking.aspx/ruleid/79. From that page, follow the links to the notice of proposed rulemaking phase and then to *Analytical Tools*.

8A.2 STARTUP

DOE's spreadsheets enable users to perform life-cycle cost (LCC) and payback period (PBP) analyses for each equipment class. Two spreadsheets exist for eight commercial packaged boiler equipment classes: a spreadsheet labeled LCC and another labeled Model Input. The Model Input contains the raw data used for the analysis as well the formulas that led to the processed data that, in turn, are used in the LCC. The purpose of the LCC is (1) to input raw data for the analysis and (2) inform the public about how DOE processes the data and derives the LCC.[a]

The two spreadsheets are independent. The main LCC spreadsheet can be downloaded and run separately. To change the input of the main LCC, based on updated data from the Model Input, manually copy/paste the data that was modified in the Model Input into the main LCC spreadsheet.

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.[b]

8A.3 DESCRIPTION OF LIFE-CYCLE COST SPREADSHEETS

8A.3.1 Main LCC Spreadsheet

For the CPB equipment classes considered for amended standards, DOE creates a single LCC spreadsheet containing a collection of worksheets. Each worksheet represents a conceptual component within the LCC calculation. To facilitate navigability and identify how worksheets

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[a] While amended standards are proposed for only eight CPB equipment classes in the notice of proposed rulemaking (NOPR), the Model Input and LCC spreadsheets retain a separation by draft type to separately and adequately consider the installation costs and trends particular to these commercial packaged boilers. A sampling methodology is then used to combine the results into the eight CPB equipment classes for which amended standards are proposed.

[b] Oracle Crystal Ball: www.oracle.com/us/products/applications/crystalball/overview/index.html. Last accessed on 09/02/2015.

are related, each worksheet clearly identifies variables imported to and exported from the current worksheet. The LCC spreadsheet contains the following worksheets. Note that an asterisk (*) after the worksheet title denotes that results displayed for that worksheet are for only one building and not the entire population.

Introduction	The *Introduction* worksheet contains an overview of each worksheet and a flow chart of the inputs and outputs of the spreadsheet.
Statistics	The *Statistics* worksheet contains the statistics of key parameters from the outcome of the Monte Carlo simulations for the sample of buildings.
Summary	The *Summary* worksheet contains a user interface to manipulate energy price trends and start-year inputs, and to run the Crystal Ball simulation. LCC and PBP simulation results for each efficiency level are also displayed here.
LCC&PB Calcs[*]	The *LCC&PB Calcs* worksheet shows LCC calculation results for different efficiency levels for a single Commercial Building Energy Consumption Survey (CBECS) 2003 building or Residential Energy Consumption Survey (RECS) 2009 household.[1,2] During a Crystal Ball simulation, the spreadsheet records the LCC and PBP values for every sampled building.
LCC&PB by Category[*]	The *LCC&PB by Category* worksheet shows LCC calculation results from *LCC&PB Calcs* disaggregated by different markets (commercial replacement, commercial new construction, residential replacement, and residential new construction).
Rebuttable PBP	The *Rebuttable PBP* worksheet contains the total and incremental manufacturer costs, retail prices, installation costs, repair and maintenance costs, energy use calculations, and the simple PBP calculations for each efficiency level.
Equip Price[*]	The *Equip Price* worksheet calculates retail price values used as inputs in the LCC calculations in the *Summary* worksheet.
Markups[*]	The *Markups* worksheet calculates markup values used as inputs in the *Equip Price* worksheet. DOE applied baseline and incremental markups to calculate final retail prices. DOE calculated the markups differently for replacement units and new units.
Eqp Price Trend	The *Equipment Price Trend* worksheet calculates projected equipment price trend scenarios used to adjust the manufacturer's cost over the entire analysis period in the *Equip Price* worksheet.
Bldg. Sample	This intermediate engine's primary purpose is to gather relevant data for "each" n-th simulation run based on the CBECS/RECS sample selected.
Venting Costs	The *VentingCosts* worksheet provides information on costs associated with venting for each equipment class.

LaborCosts	The *LaborCosts* worksheet provides information on costs associated with the labor component of venting.
CostDB	The *CostDB* worksheet provides information on the material costs associated with venting.
VentingLabels	The *VentingLabels* worksheet provides information on the selection process for each design option within an equipment class (related to venting).
Installation Cost[*]	The *Installation Cost* worksheet provides the weighted average installation cost for each design option. These results are used to calculate the total installed prices of the design options.
Install., Mnt., and Repair Data	The *Installation, Maintenance, and Repair Data* worksheet provides the data sources for inputs to the installation, maintenance, and repair cost calculations.
Maint and Repair Cost[*]	The *Maintenance and Repair Cost* worksheet provides the maintenance and repair costs for each design option. These results are used to determine operating costs for the design options.
Labor Cost[*]	The *Labor Cost* worksheet provides the labor cost by region as used to determine the installation and repair/maintenance costs.
No-New-Standards-Case Efficiency[*]	The *No-New-Stds-Case Efficiency* worksheet includes the boiler efficiency distribution for 2019.
Efficiency (Existing)[*]	The *Efficiency (Existing)* worksheet includes the CPB efficiency for all years during the period 1973–2009.
Energy Use[*]	The *Energy Use* worksheet calculates annual energy use by fuel type, depending on equipment class. The annual energy use calculations for each design option are inputs to the *LCC&PB Calcs* worksheet to calculate the annual operating cost of the LCC.
Energy Use (Calcs)[*]	The *Energy Use (Calcs)* worksheet displays intermediate energy use calculations. The intermediate energy use calculations for each design option are inputs to the *Energy Use* worksheet to calculate the annual energy use by fuel type, depending on equipment class.
Energy Price[*]	The *Energy Price* worksheet shows the estimated monthly natural gas, oil, and electricity prices.
Energy Price Trends[*]	The *Energy Price Trends* worksheet shows the future price trends of the different heating fuels. DOE used energy price data and forecasts from the Energy Information Administration's (EIA's) *Annual Energy Outlook 2015* for the period until 2040 and extrapolated beyond 2040.[3]
Discount Rate[*]	The *Discount Rate* worksheet contains the distributions of discount rates for commercial and residential applications.
Lifetime[*]	The *Lifetime* worksheet contains the distribution of lifetimes for equipment by equipment class.

Energy Use Adj Factors*	The *Energy Use Adj Factors* worksheet contains adjustment factors for normal heating degree days and cooling degree days, as well as building shell efficiency index.
Weather Data*	The *Weather Data* worksheet contains heating degree days, cooling degree days, heating and cooling outdoor design temperature, and annual mean temperature by weather station.
LCC Output	The *LCC Output* worksheet contains the LCC results for each completed simulation run
Forecast Cells	The *Forecast Cells* worksheet contains information relevant to tracking the different summary statistics for each forecast cell.
Labels	The *Labels* worksheet contains labels and definitions used throughout the spreadsheet and is the worksheet where the efficiency levels (ELs) used in the analysis are defined.

Figure 8A.3.1 depicts how these various inputs are used in order to generate the LCC and PBP outputs.

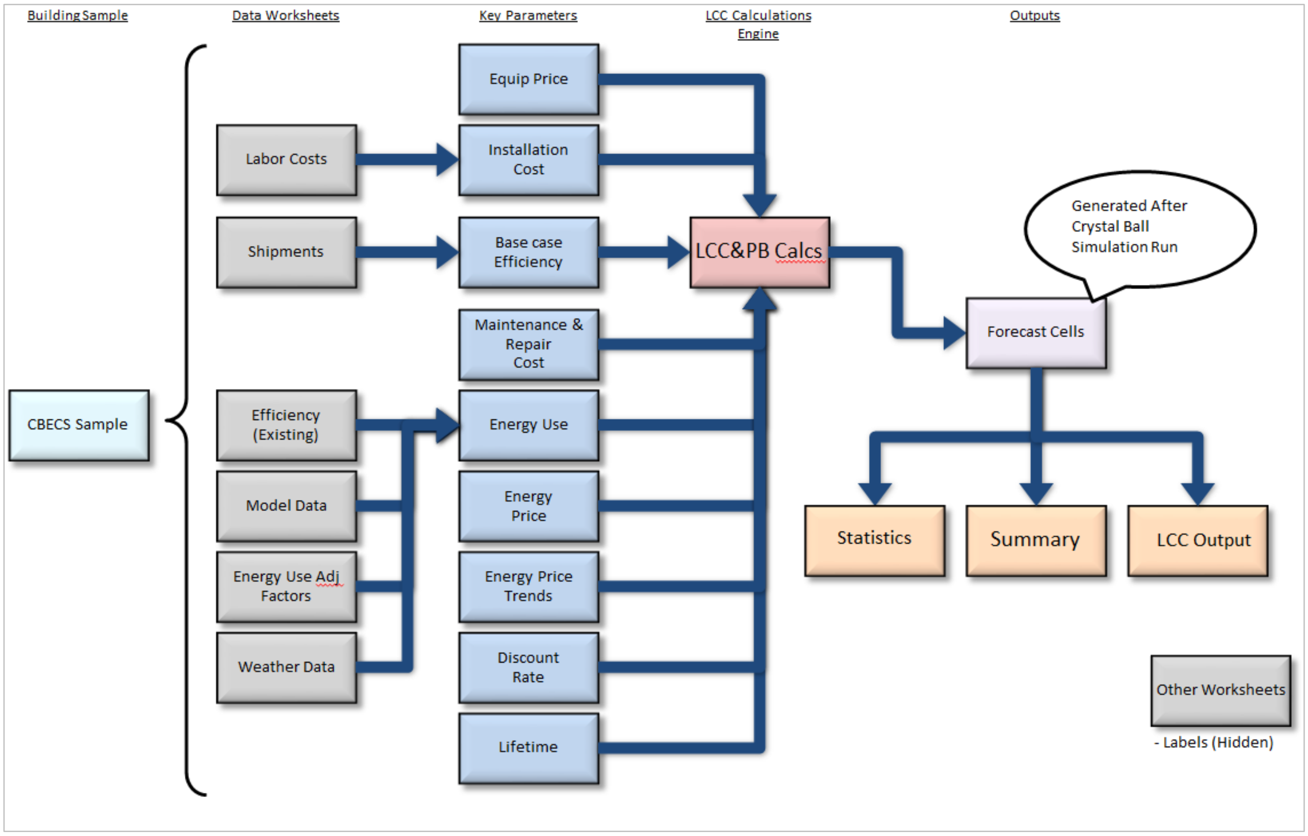

Figure 8A.3.1 LCC and Payback Calculation Process

8A.3.2 Model Input Worksheet

The Model Input spreadsheet contains the following worksheets:

- Markup Input
- Eqp Price Trend
- Labor Cost Data
- RECS Sample
- Input_Recs_Export
- RECS_Export
- RECS Codebook
- RECS_Expt_Tmplate
- CBECS Sample
- CBECS to LCC Bldg Sample
- Bldg Sple Assumpt.
- CE & TE Relationship
- Condensing Models Trend
- No-New-Stds-Case Eff Dist
- Efficiency (Existing)
- Energy Price Trends (to LCC)
- Energy Price Trends (to NIA)
- Energy Use Adj Input
- Energy Use Adj Factors
- Efficiency Adj Factors
- Energy Use Trend (for NIA)
- Weighting
- Weather Data
- Discount Rate
- Lifetime (Ref)
- Definitions

Each of these worksheets is designed to calculate inputs that are used in the main LCC or National Impact Analysis (NIA) models.

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 "Enable Macro" when prompted and then click on the tab for the *Summary* worksheet.

2) Use Excel's View/Zoom commands at the top menu bar to change the size of the display to fit your monitor.

3) As needed, change the parameters listed under USER OPTIONS on the *Summary* worksheet. There are five drop-down boxes and one command button. The default parameters are as follows:

   a) Energy Price Trend: Defaults to “AEO 2015 - Reference Case.” To change the input, use the drop-down menu and select the desired trend (Reference Economic Case, Low Economic Case, or High Economic Case).

   b) Start Year: Defaults to “2019.” To change the value, use the drop-down menu and select the desired year.

   c) # of Trials: Defaults to “10,000.” To change the value, use the drop-down menu and select the desired number of Crystal Ball trials (100, 200, 500, 1,000, 5,000, 10,000)

   d) Subgroup: Defaults to “National.” To change the input, use the drop-down menu and select the desired subgroup (National, Residential – Low Income, Commercial – Small Business).

   e) Eqp. Price Trend: Defaults to “Constant.” To change the input, use the drop-down menu and select the desired trend (Constant, Increasing, Decreasing).

4) To run the Crystal Ball simulation, click the “Run” button (otherwise, re-run after changing any parameters). 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 named *Summary* will reappear with the results.

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APPENDIX 8B. UNCERTAINTY AND VARIABILITY IN LIFE-CYCLE COST ANALYSIS FOR COMMERCIAL PACKAGED BOILERS

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APPENDIX 8B. UNCERTAINTY AND VARIABILITY IN LIFE-CYCLE COST ANALYSIS FOR COMMERCIAL PACKAGED BOILERS

8B.1 INTRODUCTION

Analysis of energy conservation standards involves calculations of impacts, for example, the impact of a standard on commercial customer 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, direct heating equipment, or pool heater) is not directly recorded but rather estimated based upon available information. Even direct laboratory measurements have some margin of error. When estimating numerical values expected for quantities at some future date, the exact outcome is rarely known in advance.

8B.3 VARIABILITY

Variability 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, water heater energy consumption depends upon the specific circumstances and behaviors of the occupants (*e.g.*, number of persons, length and temperature of showers, *etc.*). Variability makes specifying an appropriate population value more difficult 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
- 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. The crossover point is the energy rate at which the commercial customer achieves savings in operating expense that more than compensate for the increased purchase expense. The disadvantage of scenario analysis is that there is no information about the likelihood of each scenario.

Probability analysis considers the probabilities within a range of values. For quantities with variability (*e.g.*, electricity rates in different households), surveys can be used to generate a frequency distribution of numerical values (*e.g.*, the number of households with electricity rates at particular levels) to estimate the probability of each value. For quantities with uncertainty, statistical or subjective measures can be used to provide probabilities (*e.g.*, manufacturing cost to improve energy efficiency to some level may be estimated to be $10 ± $3).

The major disadvantage of the probability approach is that it requires more information, namely information about the shapes and magnitudes of the variability and uncertainty of each quantity. The advantage of the probability approach is that it provides greater information about the outcome of the calculations; that is, it provides the probability that the outcome will be in a particular range.

Scenario and probability analysis provide some indication of the robustness of the policy given the uncertainties and variability. A policy is robust when the impacts are acceptable over a wide range of possible conditions.

8B.5 PROBABILITY ANALYSIS AND THE USE OF 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 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 after 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 include those depicted as probability curves in Figure 8B.5.1.

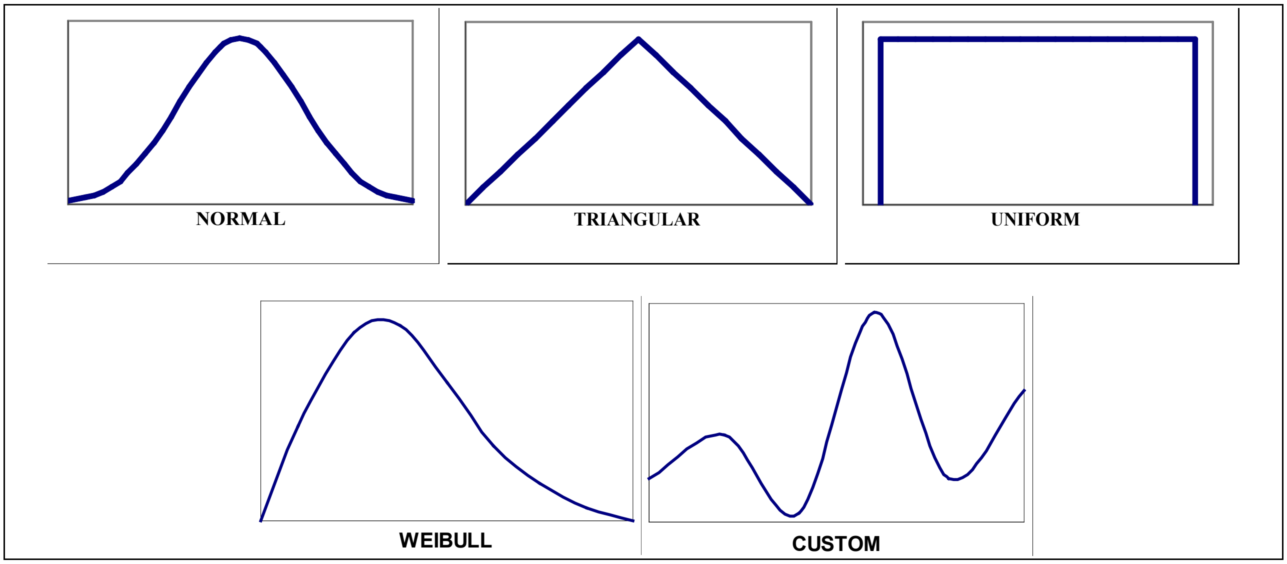

Figure 8B.5.1 Normal, Triangular, Uniform, Weibull, and Custom Probability Distributions

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 (or scenarios) 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 FOR COMMERCIAL PACKAGED BOILERS

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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.

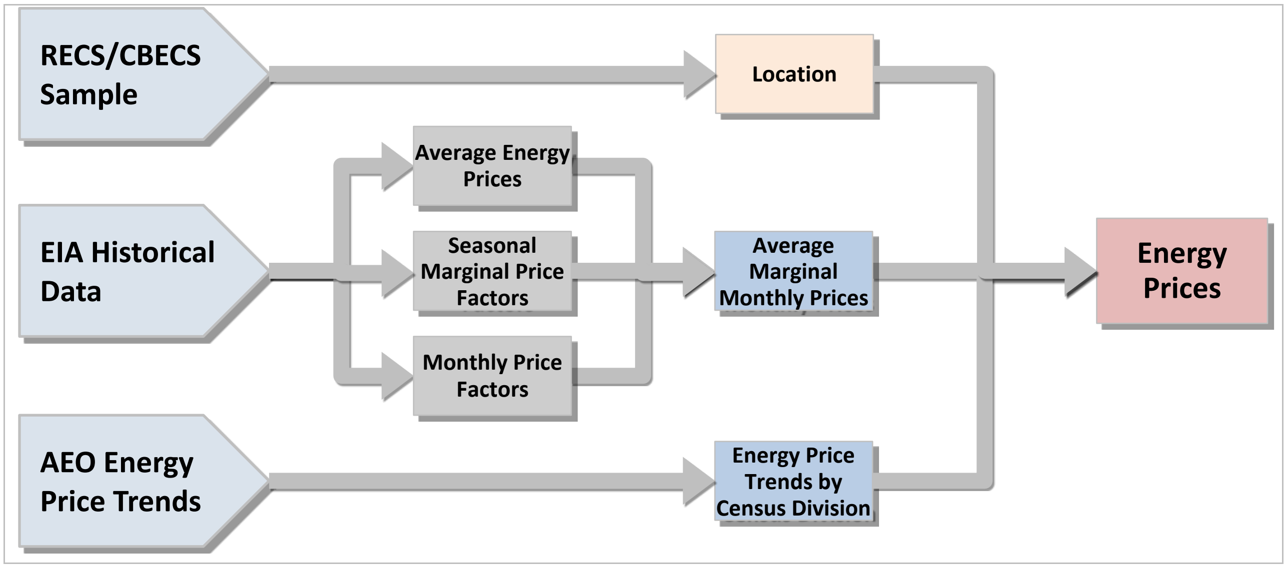

Figure 8C.1.1 Energy Price Calculation Process

8C.2 COMMERCIAL BUILDING ENERGY CONSUMPTION SURVEY/RESIDENTIAL ENERGY CONSUMPTION SURVEY SAMPLE MAPPING PROCESS

To match the state data from the Energy Information Administration (EIA) to the Commercial Building Energy Consumption Survey (CBECS) building and Residential Energy Consumption Survey (RECS) household samples, the U.S. Department of Energy (DOE) uses 2007–2014 commercial packaged boiler (CPB) models data from the Air-Conditioning, Heating, and Refrigeration Institute (AHRI) Directory of Certified Product Performance. See appendix 7A for more details. CBECS 2003 provides 9 census divisions and RECS 2009 utilizes 27 regions, also called reportable domains. The 27th region originally included Oregon, Washington, Alaska, and Hawaii. Alaska and Hawaii were subdivided into regions 28 and 29, respectively, based on cooling and heating degree days. In addition, region 14 originally included West Virginia, which has been disaggregated into region 30 based on cooling and heating degree days.

8C.2.1 Average Annual and Marginal Prices Determination

8C.2.1.1 Annual Electrical Prices

DOE derives 2014 annual electricity prices from 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.

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

State	**2014 Monthly Residential Electrical Prices** ***2014¢/kWh***											
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
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
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
ME	14.3	14.3	14.0	12.4	12.0	12.2	11.8	NM[*]	NM[*]	NM[*]	NM[*]	NM[*]
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

State	2014 Monthly Commercial Electrical Prices *2014¢/kWh*											
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
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
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

* NM = not meaningful

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, DC, Maryland	13.0	13.3	13.3	13.9	14.2	13.7	13.6	13.7	13.5	14.0	13.3	13.3
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	5.9	6.0	6.4	6.8	6.7	6.6	6.6	6.5	6.4	6.6	6.5	6.3
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	Oregon, Washington	27.3	27.9	27.9	28.4	29.4	29.8	30.2	30.0	29.2	29.4	28.8	27.4
28	Alaska	4.2	4.4	4.6	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.4	4.4

Reportable Domain Number	Locations	2014 Monthly Residential Electricity Prices *2014¢/kWh*											
		Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
29	Hawaii	37.4	37.1	38.5	38.1	38.0	38.7	38.4	37.8	38.1	36.4	35.1	34.6
30	West Virginia	9.0	9.1	9.2	9.6	9.7	9.6	9.4	9.5	9.5	9.7	9.3	9.1

8C.2.1.2 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 natural gas prices aggregated to census divisions (for commercial applications) and reportable domains (for residential applications), respectively.

Table 8C.2.5 2014 Monthly Commercial Natural Gas Prices by State

State	2014 Monthly Commercial Natural Gas Prices *2014$/mcf*											
	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
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

State	**2014 Monthly Commercial Natural Gas Prices** *2014$/mcf*											
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
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$/mcf*											
	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
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

State	**2014 Monthly Residential Natural Gas Prices** *2014$/mcf*											
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
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$/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 8C.2.8 2014 Monthly Residential Natural Gas Prices by Reportable Domain

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, DC, Maryland	10.8	11.6	12.3	13.3	15.2	18.3	20.2	20.1	18.7	16.3	11.8	11.8
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	5.1	5.2	5.5	6.5	8.8	11.0	12.1	11.9	11.8	9.3	6.0	5.8
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	Oregon, Washington	20.3	20.0	19.8	19.9	19.6	22.4	24.4	25.5	23.2	20.8	19.9	20.1

Reportable Domain Number	Locations	2014 Monthly Residential Natural Gas Prices *2014$/mcf*											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
28	Alaska	5.2	5.2	5.4	6.1	7.3	8.2	8.5	8.6	8.6	8.1	5.7	5.3
29	Hawaii	45.7	44.7	49.2	49.3	51.0	52.4	49.3	51.4	49.6	44.8	44.9	38.7
30	West Virginia	9.2	9.3	9.4	10.4	12.4	15.5	17.7	18.0	14.9	11.5	10.3	9.9

8C.2.1.3 Annual Fuel Oil Prices

DOE obtains data for fuel oil prices from EIA's State Energy Consumption, Price, and Expenditures Estimates (SEDS)[3] for 2013, which includes annual fuel oil prices by state for residential, commercial, and industrial customers. DOE adjusted these for 2014$ and uses them as an estimate of 2014 averaged prices at the state level. Table 8C.2.9 shows the annual commercial fuel oil prices for each state. Table 8C.2.10 shows the annual residential fuel oil prices for each state. Table 8C.2.11 and Table 8C.2.12 present fuel oil prices aggregated to census divisions (for commercial applications) and reportable domains (for residential applications) respectively and provided as monthly price estimates. For areas with more than one state, DOE weights each state's average price by its population to the respective geographic regions. In order to estimate monthly energy price variation in 2014, DOE developed long-term average monthly oil price factors from examination of EIA's Short-Term Energy Outlook[4] monthly oil price data for 1995-2009. DOE first calculated monthly energy price factors by dividing the monthly prices by the average price for each year and averaged over the years examined. These long-term price factors are applied to the 2014 annual average price estimates to provide monthly oil price estimates for 2014 for the residential and commercial sector as shown in Table 8C.2.11 and Table 8C.2.12.

Table 8C.2.9 2014 Commercial Average Fuel Oil Prices by State

State	2014 Commercial Average Fuel Oil Prices *2014$/MMBtu*	State	2014 Commercial Average Fuel Oil Prices *2014$/MMBtu*
AL	23.7	MT	23.2
AK	27.4	NE	24.5
AZ	25.1	NV	25.3
AR	24.1	NH	25.7
CA	25.4	NJ	24.9
CO	23.9	NM	23.9
CT	25.7	NY	25.1
DE	23.6	NC	24.1
DC	25.0	ND	24.3
FL	24.3	OH	24.6
GA	23.9	OK	24.2
HI	24.6	OR	23.3
ID	26.3	PA	24.9
IL	24.7	RI	25.6
IN	24.8	SC	24.3
IA	24.6	SD	24.1
KS	24.6	TN	24.8
KY	24.6	TX	24.2
LA	23.7	UT	24.6
ME	25.1	VT	26.5
MD	25.8	VA	23.9
MA	25.2	WA	25.0
MI	24.7	WV	24.5
MN	24.8	WI	24.5
MS	24.4	WY	24.1

Table 8C.2.10 2014 Residential Average Fuel Oil Prices by State

State	2014 Residential Average Fuel Oil Prices *2014$/MMBtu*	State	2014 Residential Average Fuel Oil Prices *2014$/MMBtu*
AL	25.8	MT	24.5
AK	27.6	NE	28.2
AZ	29.2	NV	29.5
AR	26.3	NH	26.6
CA	29.6	NJ	29.2
CO	25.2	NM	26.1
CT	28.3	NY	28.3
DE	27.3	NC	28.0
DC	28.9	ND	28.1
FL	28.3	OH	28.2
GA	27.8	OK	27.9
HI	28.7	OR	27.6
ID	26.0	PA	28.9
IL	28.4	RI	28.4
IN	28.6	SC	28.3
IA	28.3	SD	27.8
KS	28.4	TN	28.6
KY	28.3	TX	26.4
LA	25.8	UT	25.9
ME	27.9	VT	28.2
MD	28.9	VA	28.1
MA	28.2	WA	29.4
MI	28.3	WV	28.3
MN	28.6	WI	28.1
MS	26.6	WY	25.5

Table 8C.2.11 2014 Monthly Commercial Fuel Oil Prices by Census Division

Census Division	Division Number	2014 Monthly Commercial Fuel Oil Prices *2014$/MMBtu*											
		Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
New England	1	25.3	25.7	25.5	25.3	25.1	24.9	24.5	24.5	25.3	25.9	26.4	26.7
Middle Atlantic	2	24.9	25.2	25.1	24.8	24.7	24.5	24.1	24.1	24.9	25.5	25.9	26.2
East North Central	3	23.5	23.8	24.1	24.3	24.3	24.2	24.0	24.6	25.4	26.0	26.0	25.5
West North Central	4	23.4	23.7	24.0	24.1	24.1	24.0	23.9	24.4	25.3	25.8	25.8	25.4
South Atlantic	5	24.4	24.7	24.6	24.3	23.5	23.2	23.2	23.5	24.3	25.0	25.4	25.7
East South Central	6	24.5	24.8	24.7	24.3	23.6	23.3	23.3	23.5	24.4	25.1	25.5	25.8
West South Central	7	24.2	24.5	24.4	24.1	23.3	23.0	23.1	23.3	24.1	24.8	25.2	25.5
Mountain	8	23.0	23.4	24.5	24.9	24.8	24.8	24.4	24.4	25.2	25.7	25.6	25.1
Pacific	9	23.6	24.0	25.0	25.5	25.4	25.3	24.9	25.0	25.8	26.2	26.2	25.6

Table 8C.2.12 2014 Monthly Residential Oil Prices by Reportable Domain

Reportable Domain Number	Locations	2014 Monthly Residential Fuel Oil Prices *2014$/MMBtu*											
		Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1	Connecticut, Maine, New Hampshire, Rhode Island, Vermont	27.8	28.2	28.0	27.8	27.6	27.4	27.0	26.9	27.8	28.5	29.0	29.3
2	Massachusetts	28.1	28.5	28.3	28.1	27.9	27.7	27.3	27.2	28.1	28.8	29.3	29.6
3	New York	28.2	28.6	28.4	28.2	28.0	27.8	27.4	27.3	28.2	28.9	29.4	29.7
4	New Jersey	29.0	29.4	29.2	29.0	28.8	28.6	28.2	28.1	29.0	29.8	30.2	30.6
5	Pennsylvania	28.7	29.2	29.0	28.7	28.5	28.3	27.9	27.9	28.7	29.5	30.0	30.3
6	Illinois	27.1	27.5	27.8	28.0	28.0	27.9	27.7	28.3	29.3	30.0	29.9	29.5
7	Indiana, Ohio	27.1	27.4	27.8	27.9	27.9	27.8	27.7	28.3	29.3	29.9	29.9	29.4
8	Michigan	27.1	27.4	27.8	27.9	27.9	27.8	27.6	28.3	29.3	29.9	29.8	29.4
9	Wisconsin	26.8	27.1	27.5	27.7	27.6	27.6	27.4	28.0	29.0	29.6	29.6	29.1
10	Iowa, Minnesota, North Dakota, South Dakota	27.1	27.4	27.8	28.0	28.0	27.9	27.7	28.3	29.3	30.0	29.9	29.4
11	Kansas, Nebraska	27.1	27.4	27.7	27.9	27.9	27.8	27.6	28.2	29.2	29.9	29.8	29.4
12	Missouri	26.6	26.9	27.3	27.5	27.4	27.4	27.2	27.8	28.8	29.4	29.4	28.9
13	Virginia	28.2	28.5	28.4	28.0	27.2	26.8	26.8	27.1	28.1	28.8	29.4	29.7
14	Delaware, DC, Maryland	28.8	29.1	29.0	28.6	27.7	27.4	27.4	27.7	28.7	29.5	30.0	30.3
15	Georgia	27.9	28.2	28.1	27.7	26.9	26.5	26.6	26.8	27.8	28.6	29.1	29.4
16	North Carolina, South Carolina	28.2	28.6	28.4	28.1	27.2	26.8	26.9	27.1	28.1	28.9	29.4	29.7
17	Florida	28.5	28.8	28.7	28.3	27.4	27.1	27.1	27.3	28.4	29.1	29.6	30.0
18	Alabama, Kentucky, Mississippi	16.8	17.0	16.9	16.7	16.2	15.9	16.0	16.1	16.7	17.2	17.5	17.7
19	Tennessee	28.7	29.1	28.9	28.5	27.7	27.3	27.3	27.6	28.6	29.4	29.9	30.2
20	Arkansas, Louisiana, Oklahoma	26.8	27.1	27.0	26.6	25.8	25.5	25.5	25.7	26.7	27.4	27.9	28.2
21	Texas	26.5	26.8	26.7	26.3	25.5	25.2	25.2	25.5	26.4	27.1	27.6	27.9
22	Colorado	23.5	23.9	25.0	25.4	25.4	25.3	24.9	25.0	25.8	26.2	26.2	25.6
23	Idaho, Montana, Utah, Wyoming	24.0	24.4	25.5	25.9	25.9	25.8	25.4	25.4	26.3	26.7	26.7	26.1
24	Arizona	27.3	27.8	29.0	29.5	29.5	29.3	28.9	28.9	29.9	30.4	30.4	29.7
25	Nevada, New Mexico	26.2	26.6	27.8	28.3	28.3	28.1	27.7	27.8	28.7	29.2	29.2	28.5
26	California	27.7	28.2	29.4	29.9	29.9	29.8	29.3	29.4	30.4	30.8	30.8	30.1
27	Oregon, Washington	52.6	53.5	55.9	56.8	56.7	56.5	55.7	55.8	57.7	58.6	58.5	57.2
28	Alaska	9.5	9.7	10.1	10.3	10.3	10.3	10.1	10.1	10.5	10.6	10.6	10.4

Reportable Domain Number	Locations	2014 Monthly Residential Fuel Oil Prices *2014$/MMBtu*											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
29	Hawaii	26.8	27.2	28.4	28.9	28.9	28.8	28.3	28.4	29.4	29.8	29.8	29.1
30	West Virginia	28.5	28.8	28.7	28.3	27.4	27.1	27.1	27.3	28.4	29.1	29.6	30.0

8C.2.1.4 Household Energy Price Adjustment Factor

RECS 2009 reports the total annual consumption and expenditure of each energy use type. From these data DOE determines average energy prices per geographical area. To take into account that residential building energy prices vary inside a geographical area, DOE develops an adjustment factor based on the reported average energy price in RECS 2009 divided by the average energy price of the geographical region. This factor is then multiplied times the monthly marginal energy prices (for natural gas and electricity) or the monthly price developed above to come up with the household energy price.

8C.2.1.5 Seasonal Marginal Price Factor Determination

Marginal energy prices are the prices commercial customers pay for the last unit of energy used. DOE used the marginal energy prices for each building for the cost of saved energy associated with the use of higher-efficiency equipment. Because marginal prices reflect a change in a commercial customer’s bill associated with a change in energy consumed, such prices are appropriate for determining energy cost savings associated with possible changes to efficiency standards.

EIA provides historical monthly consumption and expenditures by state. These data were used to determine 10 year average marginal price factors for the RECS 2009 geographical areas and CBECS census divisions, which are then used to convert average monthly energy prices into marginal monthly energy prices, which are applied to differential energy savings due to standards in the calculation of life-cycle cost. Because a boiler may operate during both the heating and cooling seasons, DOE determined summer and winter marginal price factors. A heating season marginal price factor is used for the months of November-March. A cooling season marginal price factor is used for the months of April-October

For oil-fired boilers, DOE used the geographic area average oil prices for both no-new-standards case equipment and higher-efficiency equipment, as the data necessary for estimating marginal prices were not available. DOE used the same method for liquid-petroleum-gas-fired boilers.

8C.2.1.6 Marginal Electrical Prices Factors

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 energy expenditures due to actual energy consumption to total expenditures (which includes for example, fixed costs, connection fee and surcharges, in addition to usage related expenditures).

Table 8C.2.13 and Table 8C.2.14 present the marginal factors for gas and electricity, at the different geographic regions used for residential and commercial applications.

8C.2.1.7 Marginal Natural Gas Price Factors

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.2.13 and Table 8C.2.14 present the marginal factors for gas and electricity, at the different geographic regions used for residential and commercial applications.

8C.2.1.8 Marginal Fuel Oil Price Factors

For oil-fired boilers, DOE uses only average oil prices for its estimates of energy cost because the data necessary for estimating marginal prices are not available.

Table 8C.2.13 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	0.70	0.92	1.16	0.91
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

Marginal Price Factors	Natural Gas	Natural Gas	Electricity	Electricity
REPORTABLE_DOMAIN	Non-Winter	Winter	Non-Winter	Winter
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	0.84	0.94	0.88	0.95
28	0.86	0.96	0.85	0.91
29	0.77	0.91	1.46	0.89
30	0.80	0.95	0.92	0.84

Table 8C.2.14 **Commercial 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 forecasted fuel price indices developed use the forecast of annual average price changes in EIA's *Annual Energy Outlook 2015 with Projections to 2040 (AEO2015).*[5] Figure 8C.3.1, Figure 8C.3.2, and Figure 8C.3.3 show the commercial electricity, natural gas, and fuel oil 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, natural gas, and fuel oil.

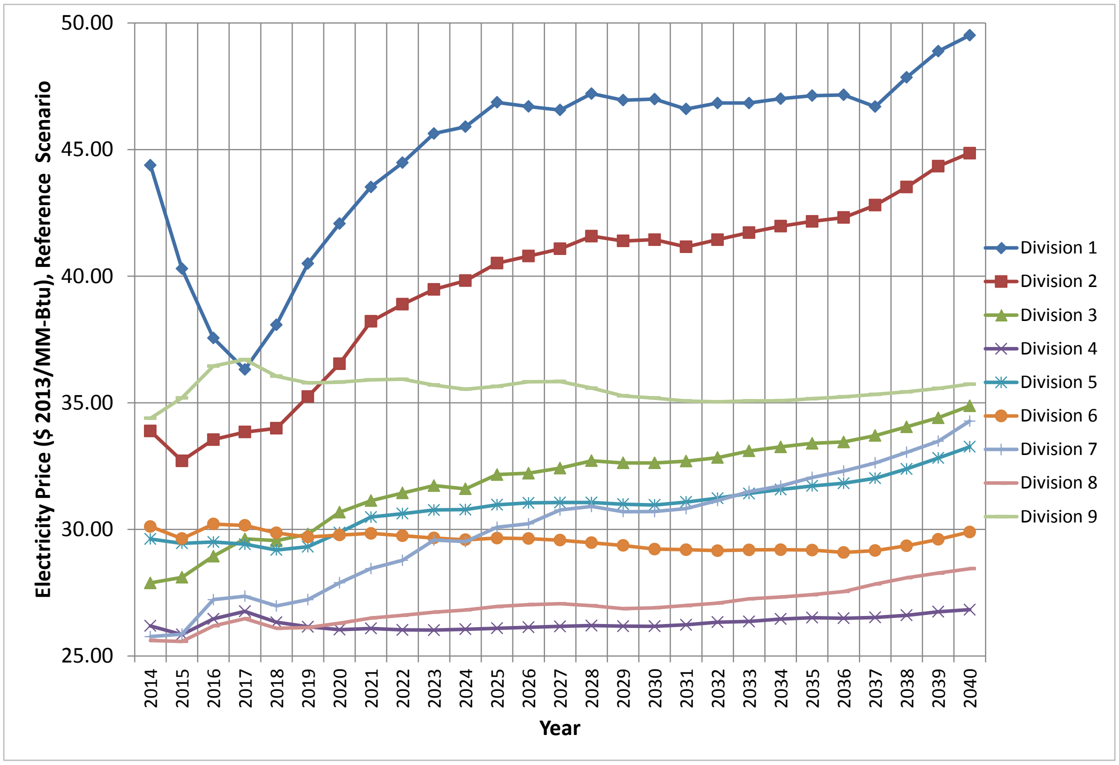

Figure 8C.3.1 Projected Commercial Electricity Prices (based on Census Divisions)

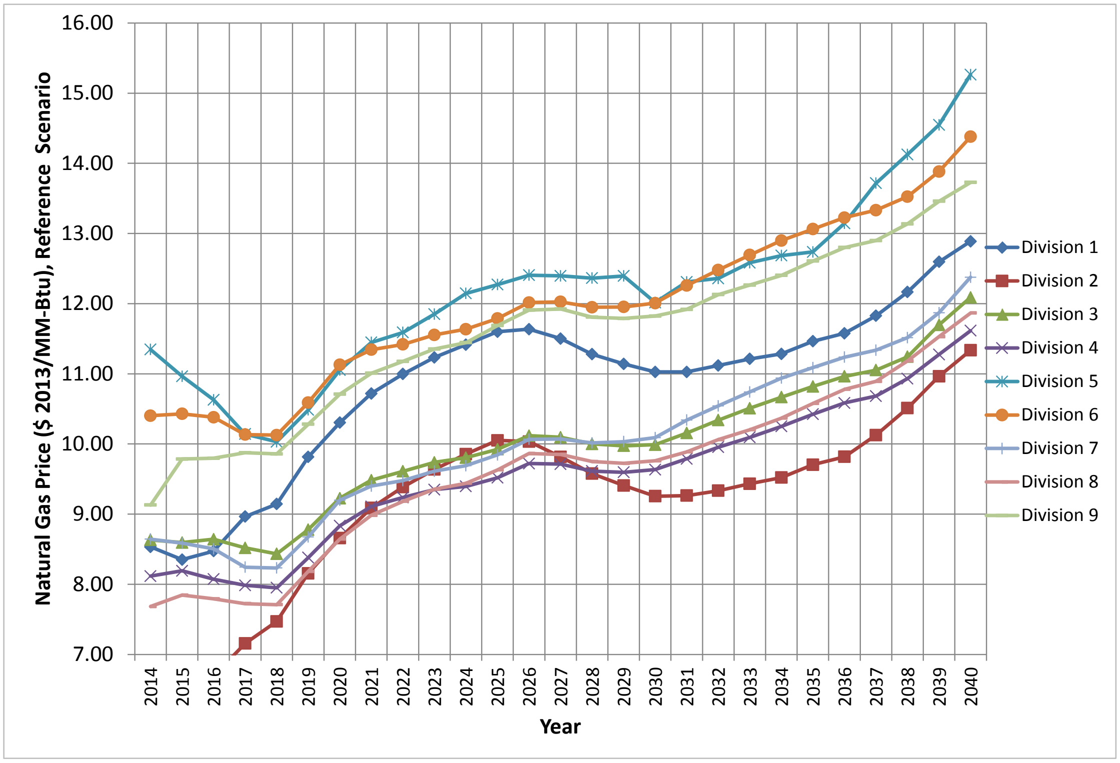

Figure 8C.3.2 Projected Commercial Natural Gas Prices (based on Census Divisions)

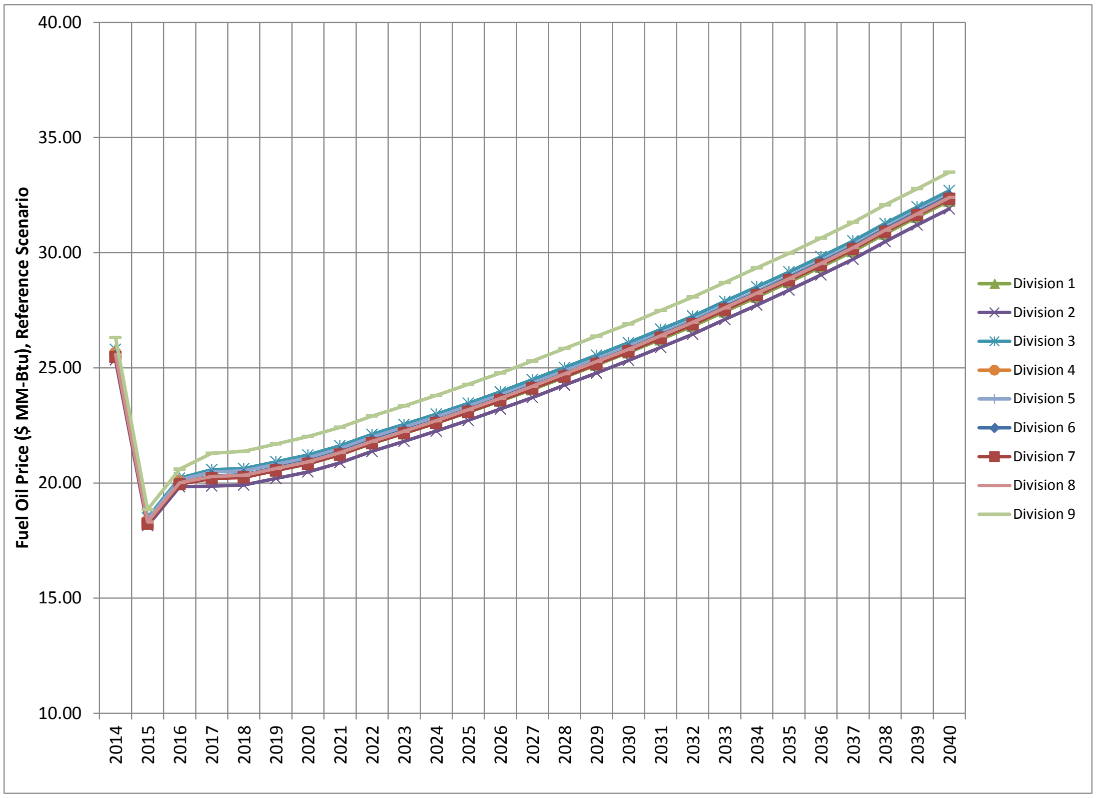

Figure 8C.3.3 Projected Commercial Fuel Oil Prices (based on Census Divisions)

8C.3.2 Residential Energy Price Trends

DOE applies the projected energy price for each of the census division to each residential building sample based on the household's location. To arrive at prices in future years, DOE multiplies the prices described in the preceding section by forecasted fuel price indices developed using the annual average price changes in EIA's *AEO2015*. Figure 8C.3.4, Figure 8C.3.5, and Figure 8C.3.6 show the residential sector electricity, natural gas, and fuel oil price trends at the census division level. To estimate the trend after 2040, DOE follows past guidelines provided to FEMP by EIA and uses the average rate of change during 2030–2040 for electricity, natural gas, and fuel oil.

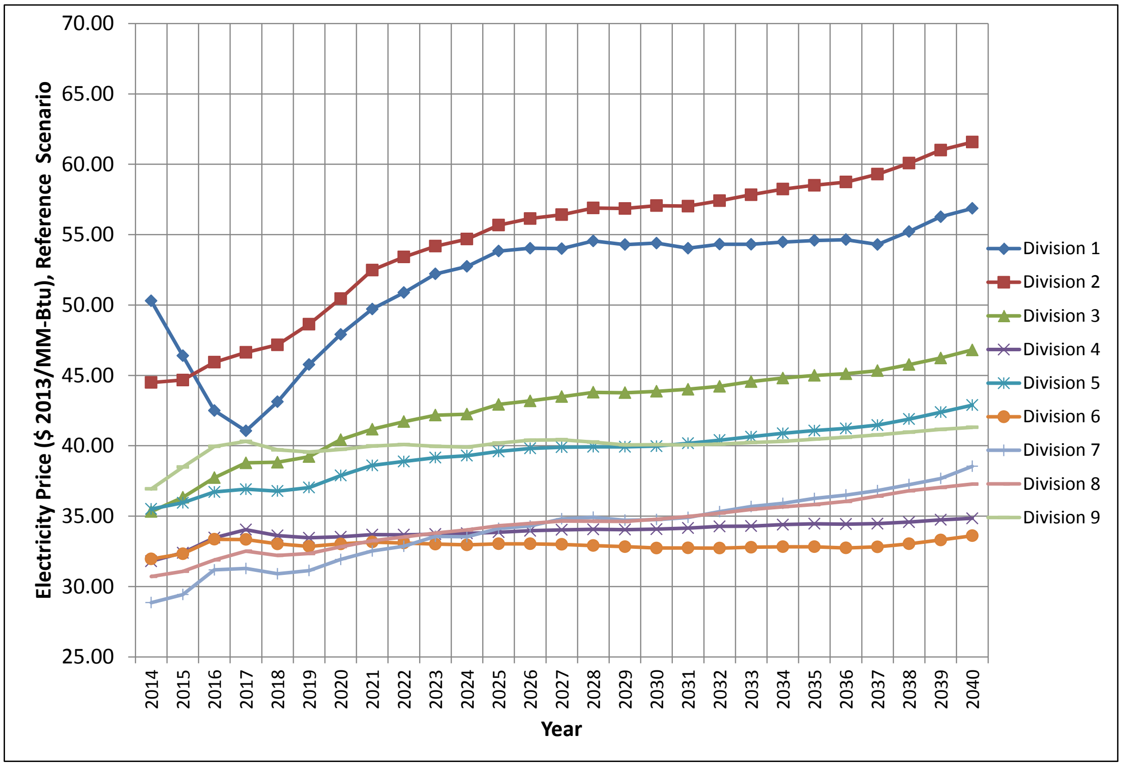

Figure 8C.3.4 Projected Residential Electricity Prices (based on Census Divisions)

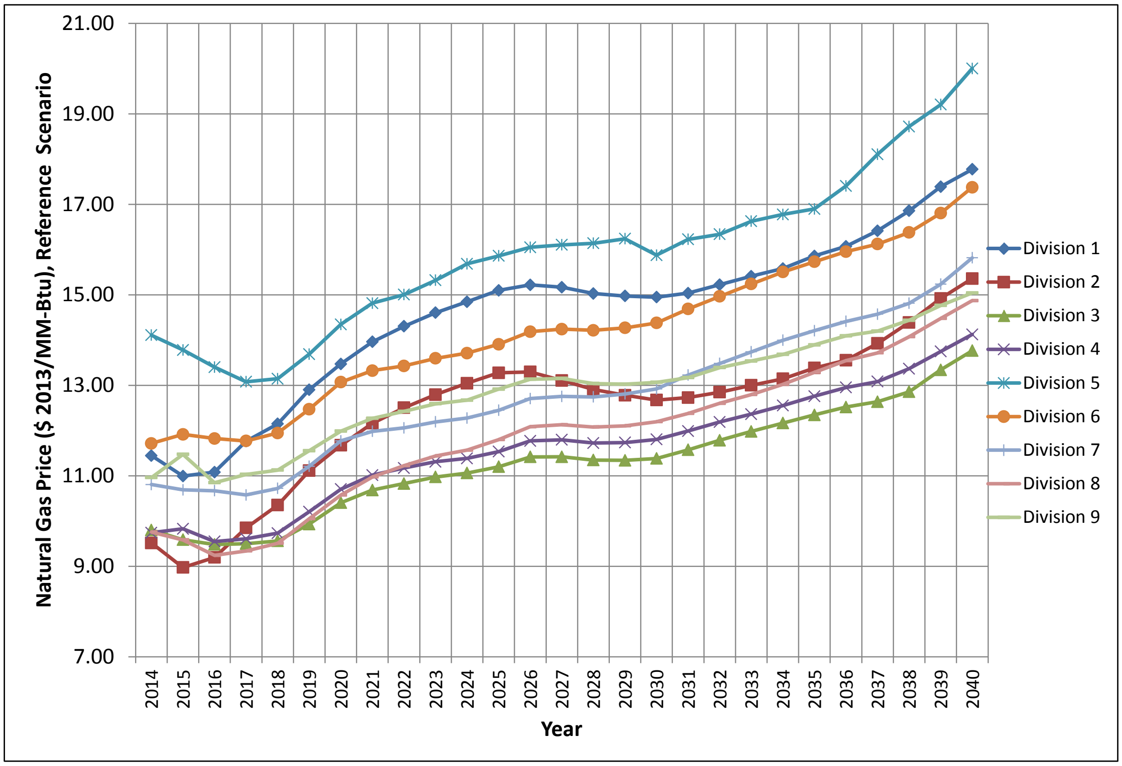

Figure 8C.3.5 Projected Residential Natural Gas Prices (based on Census Divisions)

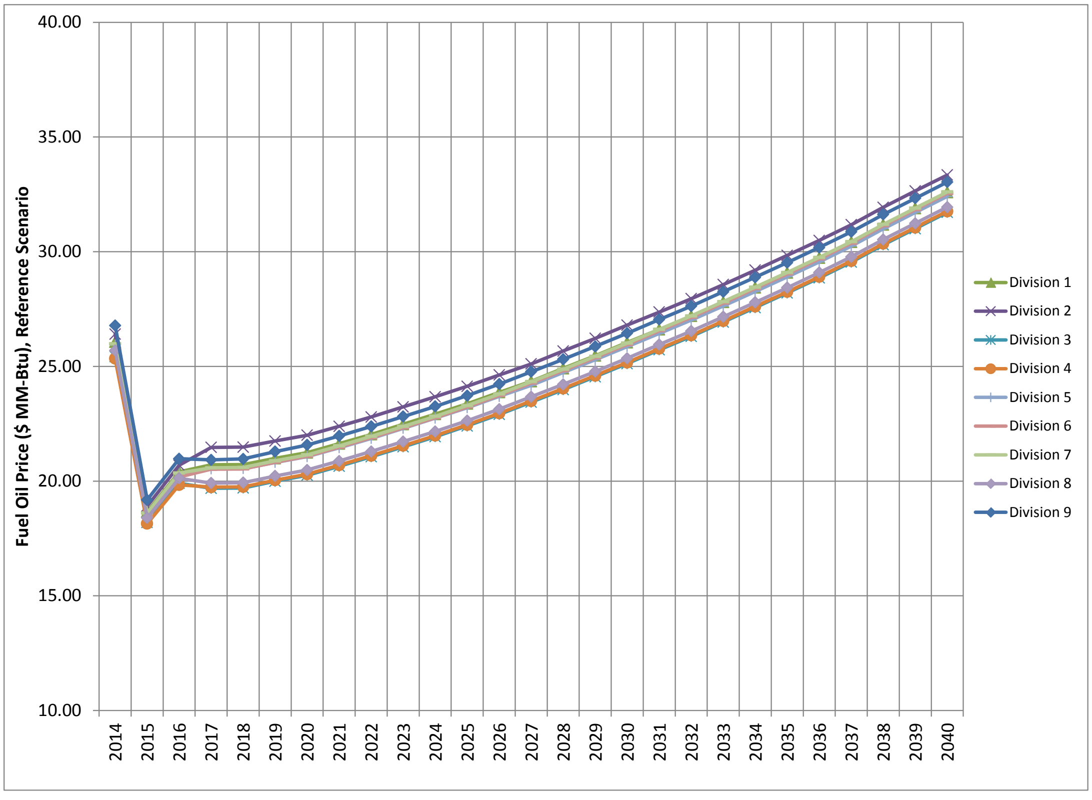

Figure 8C.3.6 Projected Residential Fuel Oil Prices (based on Census Divisions)

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APPENDIX 8D. INSTALLATION COST DETERMINATION FOR COMMERCIAL PACKAGED BOILERS

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APPENDIX 8D. INSTALLATION COST DETERMINATION FOR COMMERCIAL PACKAGED BOILERS

8D.1 INTRODUCTION

This appendix provides the details of the derivation of installation costs for all categories of commercial packaged boilers (CPBs) under consideration. The installation cost is the price to the commercial consumer of labor and materials (other than the cost of the actual equipment) needed to install boiler equipment.

The installation cost calculations for boilers vary by characteristics of the boiler being installed, geographic region, choices made by the installing contractor and owner, and characteristics of the building in which the boiler is being installed. The analysis accounted for different installation costs for the following considerations:

- gas-fired boilers and oil-fired boilers;
- natural draft and mechanical draft equipment types;
- condensing and non-condensing boilers;
- new boiler installation and replacement boiler installation;
- commercial and residential buildings;
- venting systems requirements: Category I (non-condensing), Category II (condensing), Category III (stainless vents), and Category IV (condensing);
- vent materials: masonry chimneys, Type B metal vents, stainless steel vents, AL29-4C metal vents, and plastic (polyvinylchloride (PVC), chlorinated polyvinylchloride (CPVC), or polypropylene (PP)); and
- special situations, such as the need to reline a chimney or replace specific components.

The U.S. Department of Energy (DOE) estimates installation costs for boilers based on review of component vendors' online catalogues, RS Means[1,2,3,4,5,6] (a well-known and respected construction cost estimation method), and manufacturer literature and communication with expert consultants. Applying the RS Means methodology to a boiler installation requires knowledge of its details, including the vent length, venting material, vent type, diameter, and number of elbows. DOE has reviewed relevant published literature and installation manuals to estimate these quantities as a distribution of values derived from available data. 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. The curve fitting capabilities found in Microsoft Excel®, and known as "TrendLine", were used to obtain the linear regressions used in this analysis. The results of the TrendLine regression were found to be equally representative of the data as the more complex regression routines found in MiniTab, a software program used for statistical analyses. Therefore, the simple regression equations from TrendLine were ultimately used for the analysis. A Crystal Ball® Monte Carlo simulation was used to model the resultant costs for each individual building.[a]

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[a] See chapter 8 of this technical support document (TSD) for a description of the Monte Carlo simulation methodology.

8D.1.1 New Construction and Replacement Market Shares

As determined in the shipment analysis portion of the national impact analysis (NIA) (see chapter 9 of this technical support document (TSD)), approximately 22 percent of the market will be new construction and 78 percent will be replacements in 2019. The installation cost determination methodology is structured upon the market share distribution between boilers intended for new construction installation and those utilized as a replacement for a prior existing installation.

8D.1.2 Boiler Technologies

There are two main boiler designs: non-condensing and condensing. Non-condensing boilers have a thermal efficiency (TE) between 77 percent and 89 percent. Condensing boilers have a TE of 90 percent or greater, and are only available as mechanical draft equipment in the hot water equipment class. In this model, natural draft boilers utilize the Category I venting system, which relies on negative pressure and uses either a masonry chimney or a Type B metal vent. Mechanical draft boilers employ a Category IV vent, which has a positive internal pressure and can be made of either plastic (PVC[b], CPVC[c], or PP[d]) or stainless steel. For a detailed discussion on venting categories and material selection, see section 8D.3.1.

8D.1.3 Installation Location

Based on information from consultants, DOE assumes that all commercial packaged boilers were located in a mechanical room.

8D.1.4 Basic Installation Costs

DOE estimates basic installation costs that are applicable to both replacement and new building installations. These costs include putting in place and setting up the boiler, as well as connecting fuel and water piping to the boiler. Additional costs that only apply to retrofits include removal of the old boiler, obtaining the permit, and removal or disposal fees. Table 8D.1.1 presents the average basic installation cost applied to all efficiency levels for all equipment classes.

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[b] Polyvinyl chloride is abbreviated as "PVC" when discussing venting materials.

[c] Chlorinated polyvinyl chloride is abbreviated as "CPVC" when discussing venting materials.

[d] Polypropylene is abbreviated as "PP" when discussing venting materials.

Table 8D.1.1 Basic Installation Cost (2014$)

Equipment Class	Basic Installation Cost
Small Gas-Fired Hot Water	$5,354
Large Gas-Fired Hot Water	$13,579
Small Oil-Fired Hot Water	$5,007
Large Oil-Fired Hot Water	$7,270
Small Gas-Fired Steam	$5,724
Large Gas-Fired Steam	$14,894
Small Oil-Fired Steam	$4,744
Large Oil-Fired Steam	$7,588

8D.2 LABOR COSTS

The labor costs shown in the tables in this appendix are the national average values. In its analysis, 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.2.1 Definition of Crew

DOE used the definitions of "crew" provided in the RS Means data books 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; this cost is presented in dollars equated to the national average. Noting that the costs per hour are different between residential and commercial crews, the context of the analysis is used to differentiate which labor rate is used as shown in Table 8D.2.1; installations of small, gas-fired, and natural draft hot water boilers in a residential building use residential "crews" and commercial 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	$63.99
Q1	1 Plumber, 1 Plumber Apprentice	2	$67.83
Q2	1 Plumber, 2 Plumber Apprentice	3	$70.33
Q9	1 Sheet Metal Worker, 1 Sheet Metal Worker Apprentice	2	$65.34

Crew Definitions from RS Means for Classifying Labor Costs	Crew Description	Number of Laborers within the Specified Crew	Cost/Labor Hour (Including O&P)
Commercial Crews			
1 Plumb	1 Plumber	1	$88.65
Q1	1 Plumber, 1 Plumber Apprentice	2	$79.78
Q2	1 Plumber, 2 Plumber Apprentice	3	$82.73
Q9	1 Sheet Metal Worker, 1 Sheet Metal Worker Apprentice	2	$76.95

8D.2.2 RS Means 2015 Regional Labor Costs

DOE used regional material and labor costs to more accurately estimate installation, maintenance, and repair costs by region. RS Means provides average national labor costs for different trade groups as shown in Table 8D.2.2. Bare costs are given in RS Means, while labor costs including overhead and profit (O&P) are the bare costs multiplied by the RS Means markups by trade shown in Table 8D.2.3.

Table 8D.2.2 RS Means 2015 National Average Labor Costs by Crew

Crew Type	Crew Description	Laborers per Crew	Cost per Labor Hour	
			Bare Costs	Incl. O&P*
Residential Labors Costs				
Q1	1 Plumber, 1 Plumber Apprentice	2	$41.09	$67.83
Q2	1 Plumber, 2 Plumber Apprentice	3	$42.61	$70.33
Q7	1 Steamfitter Foreman, 2 Steamfitters, 1 Steamfitter Apprentice	4	$44.25	$73.03
Q9	1 sheet metal worker, 1 sheet metal worker apprentice	2	$39.16	$65.34
Q10	2 sheet metal worker, 1 sheet metal worker apprentice	3	$38.19	$63.72
1 Plum	1 Plumbers	1	$38.77	$63.99
1 Plum Apprentice	1 Plumber Apprentice	1	$46.95	$77.49
1 Elec	1 Electrician	1	$35.10	$57.42
1 Sheet	1 Sheet metal worker	1	$36.95	$61.65
1 Sheet Apprentice	1 Sheet metal worker apprentice	1	$44.75	$46.87
1 Carp	1 Carpenter	1	$31.45	$52.84

Crew Type	Crew Description	Laborers per Crew	Cost per Labor Hour	
			Bare Costs	Incl. O&P*
Commercial Labors Costs (Standard Union)				
Q1	1 Plumber, 1 Plumber Apprentice	2	$52.83	$79.78
Q2	1 Plumber, 2 Plumber Apprentice	3	$54.78	$82.73
Q7	1 Steamfitter Foreman, 2 Steamfitters, 1 Steamfitter Apprentice	4	$56.89	$85.90
Q9	1 sheet metal worker, 1 sheet metal worker apprentice	2	$50.35	$76.95
Q10	2 sheet metal worker, 1 sheet metal worker apprentice	3	$52.22	$79.80
1 Plum	1 Plumbers	1	$58.70	$88.65
1 Plum Apprentice	1 Plumber Apprentice	1	$46.95	$70.90
1 Elec	1 Electrician	1	$52.40	$78.39
1 Sheet	1 Sheet metal worker	1	$55.95	$85.50
1 Sheet Apprentice	1 Sheet metal worker apprentice	1	$44.75	$68.40
1 Carp	1 Carpenter	1	$44.90	$69.15

* O&P includes markups in Table 8D.2.3.

Table 8D.2.3 RS Means Labor Costs Markups by Trade (Commercial)

Trade	Total
Plumber	55.6%
Electrician	54.6%
Sheet Metal	56.5%
Carpenter	64.0%

RS Means also provides material and labor cost factors for 295 cities and towns in the United States. To derive average labor cost values by state, DOE weights the price factors by 2008–2012 boiler shipments by state. DOE uses the material and labor cost factors for cost associated with fire suppression, plumbing, and heating, ventilating, and air conditioning (HVAC). Table 8D.2.4 shows the final regional material and labor price factors used in the analysis by geographical area and Table 8D.2.5 shows the same by census division.

Table 8D.2.4 Material and Labor Cost Factors by Geographical Area (for RECS 2009 Sample)

Geographical Area	Plumbing, HVAC		Electrical		Weighted Average	
	Material	Labor	Material	Labor	Material	Labor
Connecticut, Maine, New Hampshire, Rhode Island, Vermont	0.99	0.90	1.01	0.90	1.00	0.95
Massachusetts	1.00	1.19	1.02	1.16	1.01	1.27
New York	1.00	1.61	1.02	1.68	1.03	1.60
New Jersey	1.00	1.25	1.02	1.37	1.00	1.24
Pennsylvania	0.98	1.14	0.96	1.25	0.98	1.16
Illinois	0.99	1.28	0.95	1.27	0.99	1.32
Indiana, Ohio	0.99	0.89	0.98	0.90	0.98	0.90
Michigan	1.00	1.01	0.97	0.99	0.96	1.01
Wisconsin	0.99	0.95	1.02	0.95	1.00	1.01
Iowa, Minnesota, North Dakota, South Dakota	0.99	0.97	1.01	0.94	1.00	1.00
Kansas, Nebraska	0.99	0.74	0.99	0.77	0.99	0.74
Missouri	0.99	0.96	1.01	0.95	0.99	0.98
Virginia	0.99	0.66	0.97	0.71	1.01	0.69
Delaware, District of Columbia, Maryland	0.98	0.84	0.98	0.95	0.99	0.84
Georgia	0.99	0.66	0.99	0.69	0.97	0.67
North Carolina, South Carolina	1.00	0.36	0.97	0.44	0.99	0.48
Florida	1.00	0.69	0.99	0.68	1.00	0.73
Alabama, Kentucky, Mississippi	0.99	0.75	0.99	0.78	0.97	0.80
Tennessee	1.00	0.71	1.00	0.63	0.98	0.68
Arkansas, Louisiana, Oklahoma	1.00	0.59	1.02	0.65	0.99	0.62
Texas	0.99	0.56	0.95	0.61	0.98	0.61
Colorado	0.99	0.79	1.01	0.84	1.01	0.82
Idaho, Montana, Utah, Wyoming	1.00	0.70	0.98	0.70	1.01	0.71
Arizona	1.00	0.80	0.98	0.66	0.97	0.74
Nevada, New Mexico	1.00	0.76	0.91	0.80	0.99	0.80
California	0.99	1.21	1.00	1.21	1.01	1.19
Oregon, Washington	1.00	1.04	1.02	0.97	1.02	0.98
Alaska	1.00	1.05	1.34	1.17	1.24	1.14
Hawaii	1.00	1.10	1.06	1.27	1.12	1.21
West Virginia	0.98	0.85	0.96	0.90	0.99	0.88

Table 8D.2.5 Material and Labor Cost Factors by Census Division (for CBECS 2012 Sample)

Census Division	Plumbing, HVAC		Electrical		Weighted Average	
	Material	Labor	Material	Labor	Material	Labor
New England	0.99	1.02	1.01	1.01	1.00	1.08
Middle Atlantic	0.99	1.43	1.01	1.51	1.01	1.42
East North Central	0.99	1.06	0.98	1.05	0.98	1.09
West North Central	0.99	0.96	1.01	0.93	1.00	0.99
South Atlantic	0.98	0.79	0.97	0.88	0.99	0.80
East South Central	1.00	0.73	0.99	0.70	0.97	0.74
West South Central	1.00	0.58	0.99	0.63	0.99	0.62
Mountain	1.00	0.76	0.99	0.79	1.01	0.79

8D.3 VENTING SYSTEM EQUIPMENT COST

Estimating venting costs is complex because a large variety of installation scenarios are possible. DOE calculates venting costs for each building in the Commercial Building Energy Consumption Survey (CBECS) and Residential Energy Consumption Survey (RECS) boiler samples. To determine venting costs for both new construction and replacement installations, DOE uses a number of parameters that have an impact on the venting installation cost, including installation type (replacement or new construction), assumed existing venting material in replacement boiler installations (chimney vent, Type B metal vent, or stainless steel), and new vent material (Type B metal, stainless steel, or plastic).

Non-condensing boilers exhaust high-temperature flue gas, which heats the inside of the vent above the dew point and therefore prevents water vapor in the flue gas from condensing; if flue gas does condense and does not re-evaporate quickly during the boiler firing cycle, it corrodes the vent, the boiler heat exchanger, or both, thus reducing the lifetime of the vent system or the boiler itself. Typically, a small amount of condensate at cold startup is acceptable as long as the wall of the venting dries out quickly.

More efficient low-temperature condensing boilers are designed to condense the water vapor in the flue gas inside the primary heat exchanger or a secondary heat exchanger, thus increasing boiler efficiency by reducing latent heat loss. It is noted that flue gas condensing inside the venting does not change the efficiency of the boiler and that the condensate collected inside the boiler is allowed to flow out of a specially designed drain.

The flue must be made of a material that will not corrode, such as stainless steel or certain types of plastic. DOE recognizes that plastic venting is not applicable to use for venting of non-condensing boilers because the flue gas temperature is higher than the plastic can safely withstand. However, plastic piping can be used to vent condensing boilers in which the flue gas temperature is relatively low. Based upon industry research and stakeholder feedback, DOE understands that plastic piping is primarily used when the vent diameter is 6 inches or less because it is generally cheaper. Above 6 inches, the fittings for plastic piping are significantly more expensive and additional components are required to support the venting system.

Therefore, at these larger sizes, stainless steel becomes more common. (AHRI, No. 37, at p. 5; Raypak, No. 35, at p. 5; Lochinvar, No. 34, at p. 5)

8D.3.1 Venting Categories & Material Selection

The National Fuel Gas Code (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.3.1. The fourth column in Table 8D.3.1 lists the commercially recognized materials used to construct the venting systems for each category.

Although the NFGC does not specifically describe categories II and IV as venting systems used for condensing products,[e] 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. Therefore, DOE's investigation has revealed that the selection of venting[f] is based upon two criteria: (1) type of draft—natural draft or mechanical draft, and (2) the temperature of flue gases vented by the equipment—condensing exhaust or non-condensing exhaust.

Table 8D.3.1 National Fuel Gas Code (NFGC) Venting Categories Applied to CPB 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).

In the context of draft, 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 exit from the boiler 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. This is the most common design for natural draft equipment, but DOE recognizes that in certain cases the installation configuration may be dictated by building configuration or other physical parameters that warrant the use of 300 series stainless steel venting for natural draft boilers as well, such as horizontal venting of atmospheric draft boilers. Therefore, DOE assumed a small percentage of

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[e] The NFGC includes a phrase in the definition of Category II and IV venting that states 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.

[f] 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.

all installations (5 percent) use stainless steel venting or venting systems for natural draft equipment.

Mechanical draft venting refers to equipment relying upon a mechanical source (blower or inducer[g]) to expel flue gases. This equipment operates at pressures above atmospheric pressure; therefore, it requires sealed venting or vent systems. These venting systems are smaller in diameter and can tolerate longer pipe-run distances, including horizontal venting.

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. Usage of non-condensing venting components with condensing equipment is prohibited by the NFGC and is therefore not included in the analysis.

The plastics listed in the table (which include CPVC, PVC, and PP) are only suitable in condensing applications due to the lower vent temperatures experienced during operation of condensing equipment requiring greater corrosion resistance to the highly corrosive condensate.

Masonry chimneys are uncommon in new construction, but may be used for venting in existing buildings. See section 8D.3.5 for a complete discussion of modeling of costs associated with chimneys.

8D.3.2 Vent Size, Number of Elbows, and Length of Run

DOE observed that the diameter of the venting was a primary factor in determining the cost of the venting system (*i.e.*, higher input equipment requires larger diameter venting, which results in higher costs). The NFGC includes a series of tables to establish the maximum and minimum input for venting combustion flue gas based upon vented 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. For the representative models in each subcategory, DOE developed trendlines and regression models to establish the suitable size for the venting system as a function of equipment input capacity. The logarithmic curve fit is shown in the following equation, and the corresponding coefficients are shown in Table 8D.3.2.

$$Vent\ Diameter = a \times ln(Input\ Cap) + b$$

Eq. 8D.1

Where:

a = constant, as identified in Table 8D.3.2,
Input Cap = input capacity of the boiler, kBtu/h, and

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[g] DOE recognizes that the venting on the suction side of an draft inducer will by definition operate at a negative pressure and that the venting on the discharge side will operate as positive pressure venting. For this analysis, all mechanical venting systems were modeled as blowers.

b = constant, as identified in Table 8D.3.2.

The values of the parameters *a* and *b* are determined separately for natural draft boilers and mechanical draft boilers, and are given in Table 8D.3.2. For this analysis, the calculated vent size is rounded to the nearest commonly available vent size, where the commonly available vent sizes are assumed to be 3, 4, 6, 8, 10, 16, 20, 22, and 24 inches in diameter. For example, a representative 800 kBtu/h natural draft gas boiler uses a 10-inch Type B vent, while a representative 3000 kBtu/h natural draft gas boiler uses a 16-inch Type B vent.

Table 8D.3.2 Values for Constants in Vent Diameter Calculation

	Forced Draft	Natural Draft
a	4.9079	4.7913
b	-24.513	-20.54

In this analysis, the number of elbows modeled in the venting system are determined by draft type. Natural draft boilers require that the venting system be vertical because the effectiveness of the exhaust system is determined by two parameters: (1) the temperature difference between the outside air and the flue gases and (2) the pneumatic resistance (head) of the venting system. Assuming sufficient temperature difference, these systems are modeled with an equal probability of either a vertical run or a venting configuration that uses two 45 degree elbows to direct the flow of flue gases upwards to ensure acceptable head for effective operation. For boilers that are mechanically vented, the flow of exhaust air is independent of temperature difference induced buoyancy. Therefore, horizontal runs are acceptable and the model included equal probability for 0, 1, 2 and 3 elbow configuration for both 45 degree and 90 degree elbows.

Direct vent equipment is defined as CPB 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 CPB equipment travels through the appropriate venting depending upon the input and category of the CPB 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. DOE assumed that for non-condensing boilers, 12.5 percent of installations with vent runs shorter than 31.5 feet were direct vented. The percentage of condensing boilers utilizing direct venting was modeled as 25 percent, as DOE interpreted stakeholders' comments to indicate that condensing equipment is more likely to be direct vented, but that stakeholders do not have exact approximations of the venting method used for equipment in the field. (Lochinvar, No. 34, at p. 5; Raypak, No. 35, at p. 5)

As noted previously, DOE investigated literature available from manufacturer's websites 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[7] (CBECS 2003) and EIA's 2009 Residential Energy Consumption Survey[8] (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 CPB equipment to vent at the manufacturer's identified vent diameter.[h] This terminology is intended to simplify 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, often referred to as the "run" of the vent. Therefore, the vent length distributions used in the Monte Carlo analysis, as shown in Table 8D.3.3, represent linear feet and are somewhat less than the maximum allowable vent lengths identified in the manufacturer's literature.

Table 8D.3.3 Vent Length Distributions Used in the Monte Carlo Analysis

Vent Type	**Distribution**	**Minimum Vent Length** *linear ft*	**Average Vent Length** *linear ft*	**Maximum Vent Length** *linear ft*
Non-Direct Vent	Triangular	8	42	75
Direct Vent	Triangular	8	21	40

8D.3.3 Chimney Relining and Chimney Resizing

DOE assumes that 25 percent of buildings built before 1980 with a natural draft boiler utilize a chimney for boiler venting. DOE assumes that if a building has chimney venting then the chimney will need to be relined if the boiler is replaced. See average chimney relining costs by chimney diameter and material in Table 8D.3.4.

Table 8D.3.4 Chimney Relining Cost used in Analysis

Chimney Diameter *inches*	**Material**	**Relining Cost per foot** *$/ft*
3"	Galvanized	$6.53
4"	Galvanized	$7.06
3"	Double Wall Galvanized	$11.28
4"	Double Wall Galvanized	$14.00
3"	Stainless Steel	$9.10
4"	Stainless Steel	$11.93
5"	Stainless Steel	$16.19
6"	Stainless Steel	$20.45
7"	Stainless Steel	$22.33
8"	Stainless Steel	$24.21

Chimney resizing occurs when the existing chimney diameter is too large for the new boiler. DOE assumes that chimney resizing occurs any time an existing boiler with an efficiency of less than or equal to 75 percent is being replaced. DOE assumes that chimney resizing also occurs in 5 percent of all other natural draft replacement installations where chimney relining does not occur.

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[h] 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).

8D.3.4 Condensate Removal for Condensing Boilers

Condensate removal is required for all condensing boiler installations. DOE considered the following when assessing the cost of condensate removal:

- *Condensate Pipe:* For condensing boilers, the condensate must be disposed of in an appropriate drain. Therefore, for all installations, DOE applies the cost of adding condensate pipe from the equipment to an adequate drainage location. DOE assumes a length of 15 feet in replacement installations and 5 feet in new construction installations.
- *Condensate Pump:* If a drain is not near, then the condensate must be pumped to a remote drain. DOE assumes that a condensate pump is required for 25 percent of the installations.
- *Condensate Neutralizer:* DOE assumes that 12.5 percent of all installations would require a condensate neutralizer to adjust the pH of the condensate from a pH similar to that of orange juice to a neutral pH.

Table 8D.3.5 summarizes the condensate removal adders associated with condensing boilers.

Table 8D.3.5 Installation Fractions for Condensate Removal

Installation Cost Description	Criteria	Frequency of Applying Criteria
Condensate Pipe	All Installations	100%
Condensate Pump	All Installations	25%
Condensate Neutralizer	All Installations	12.5%

In addition to the installation costs, the electricity use of the condensate pump is taken into account in the energy use calculations (see chapter 7 of this TSD). The pump is assumed to be 250 watts for small boilers and 500 watts for large boilers.

Table 8D.3.6 presents the average costs for condensate removal components for new construction and new owner installations. These costs are only included when applicable.

Table 8D.3.6 Installation Cost Components for Condensate Removal (2014$)

Installation Component	Cost
Condensate Pipe	$65
Condensate Pump	$285
Condensate Neutralizer	$130

8D.3.5 Cost of Venting System 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,[9] Fleetfarm.com,[10] Houseneeds.com,[11] VentingPipe.com,[12] and Cinnabar Equipment Company.[13]

The following tables (Table 8D.3.7 through Table 8D.3.13) provide the material costs of specific components used in the "CostDB" worksheet within the life-cycle cost (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.3.7 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 x 100 ft	Q9	0.035/ft	Linear Feet	$19.80 ($1.32 x 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 x 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.1.1.

** 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.1,2,3,4,5,6

Table 8D.3.8 CPVC Socket Jointed 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	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
Extrapolated			7.0	Q1	0.399	LF	$67.70
Extrapolated			8.0	Q1	0.427	LF	$77.91
Extrapolated			10.0	Q1	0.477	LF	$99.62
Extrapolated			16.0	Q1	0.629	LF	$164.77
Extrapolated			20.0	Q1	0.730	LF	$208.20
Extrapolated			22.0	Q1	0.781	LF	$229.91
Extrapolated			24.0	Q1	0.831	LF	$251.63

* Crew is defined in Table 8D.1.1.

** Labor hours are presented in decimal places of hours where 1.0 = 1 hour.

† LF = Linear feet

Table 8D.3.9 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
Extrapolated			10.0	Q1	2.804	ea	$180.02
Extrapolated			16.0	Q1	4.618	ea	$323.52
Extrapolated			20.0	Q1	5.828	ea	$419.19
Extrapolated			22.0	Q1	6.433	ea	$467.03
Extrapolated			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.3.10 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
Extrapolated			20.0	Q2	1.200	LF	$242.16
Extrapolated			22.0	Q2	1.310	LF	$271.76
Extrapolated			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.3.11 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
Extrapolated			5.0	R-31	3.030	ea	$0.77
Extrapolated			6.0	R-31	3.636	ea	$0.88
Extrapolated			7.0	R-31	4.242	ea	$0.99
Extrapolated			8.0	R-31	4.848	ea	$1.10
Extrapolated			10.0	R-31	6.060	ea	$1.32
Extrapolated			16.0	R-31	9.696	ea	$1.98
Extrapolated			20.0	R-31	12.120	ea	$2.42
Extrapolated			22.0	R-31	13.332	ea	$2.64
Extrapolated			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.3.12 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
Extrapolated			5.0	R-31	2.255	ea
Extrapolated			6.0	R-31	2.511	ea
Extrapolated			7.0	R-31	2.817	ea
Extrapolated			8.0	R-31	3.124	ea
Extrapolated			10.0	R-31	3.737	ea
Extrapolated			16.0	R-31	5.576	ea
Extrapolated			20.0	R-31	6.802	ea
Extrapolated			22.0	R-31	7.415	ea
Extrapolated			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.3.13 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	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	1 Elec	0.500	ea
2015 Mech	2605 33.95 4050	426	4	1 Elec	0.727	ea
Extrapolated			5	1 Elec	0.941	ea
Extrapolated			6	1 Elec	1.154	ea
Extrapolated			7	1 Elec	1.370	ea
Extrapolated			8	1 Elec	1.585	ea
Extrapolated			10	1 Elec	2.016	ea
Extrapolated			16	1 Elec	3.309	ea
Extrapolated			20	1 Elec	4.171	ea
Extrapolated			22	1 Elec	4.602	ea
Extrapolated			24	1 Elec	5.033	ea

* Crew is defined in Table 8D.1.1.

** Labor hours are presented in decimal places of hours where 1.0 = 1 hour.

† ea = each

8D.3.6 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 a non-condensing replacement product 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.3.1 for retrofit installations and Figure 8D.3.2 for new installations.

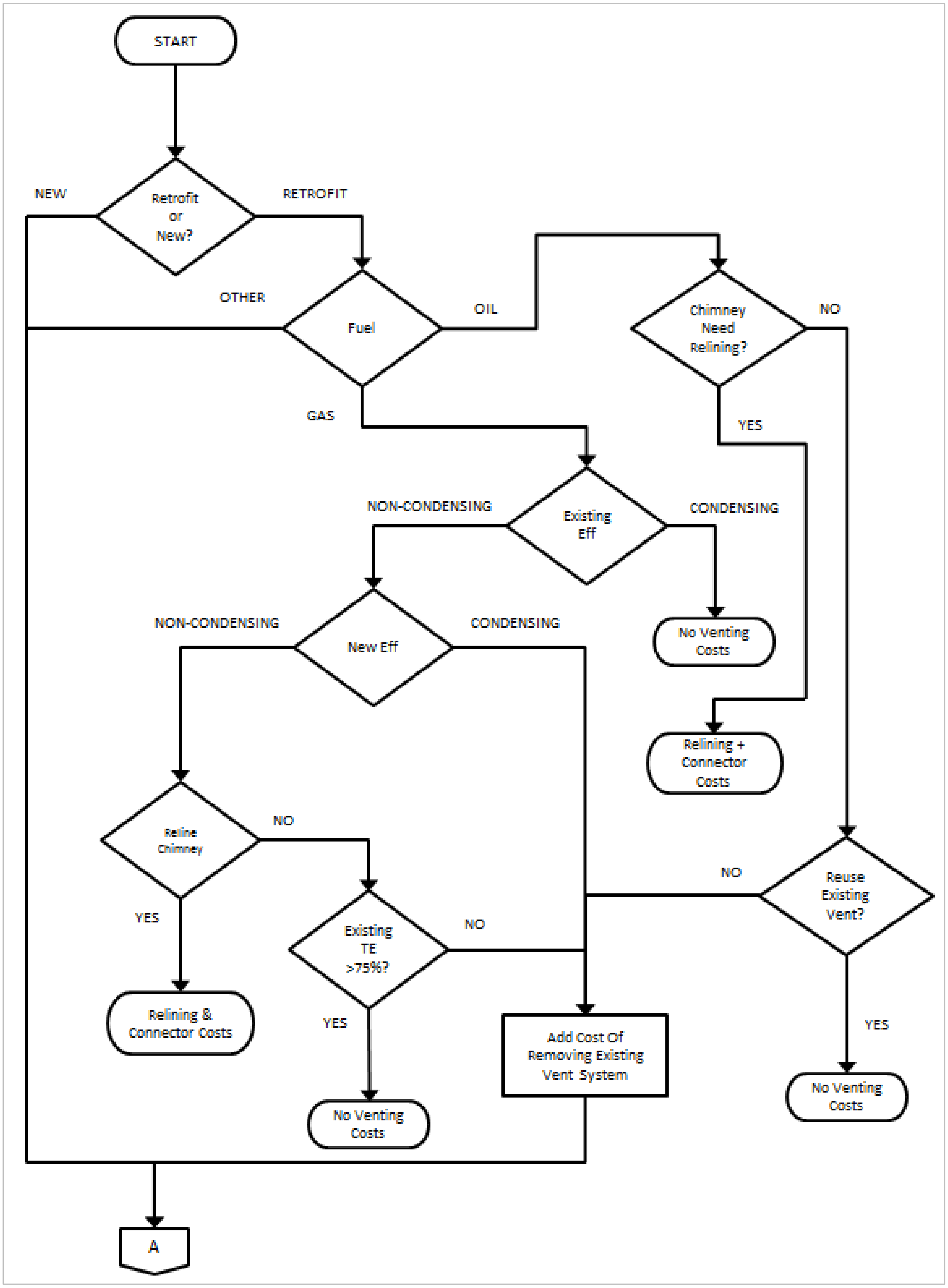

Figure 8D.3.1 Venting Logic Process Used for Replacement Installations in the Life-Cycle Analysis

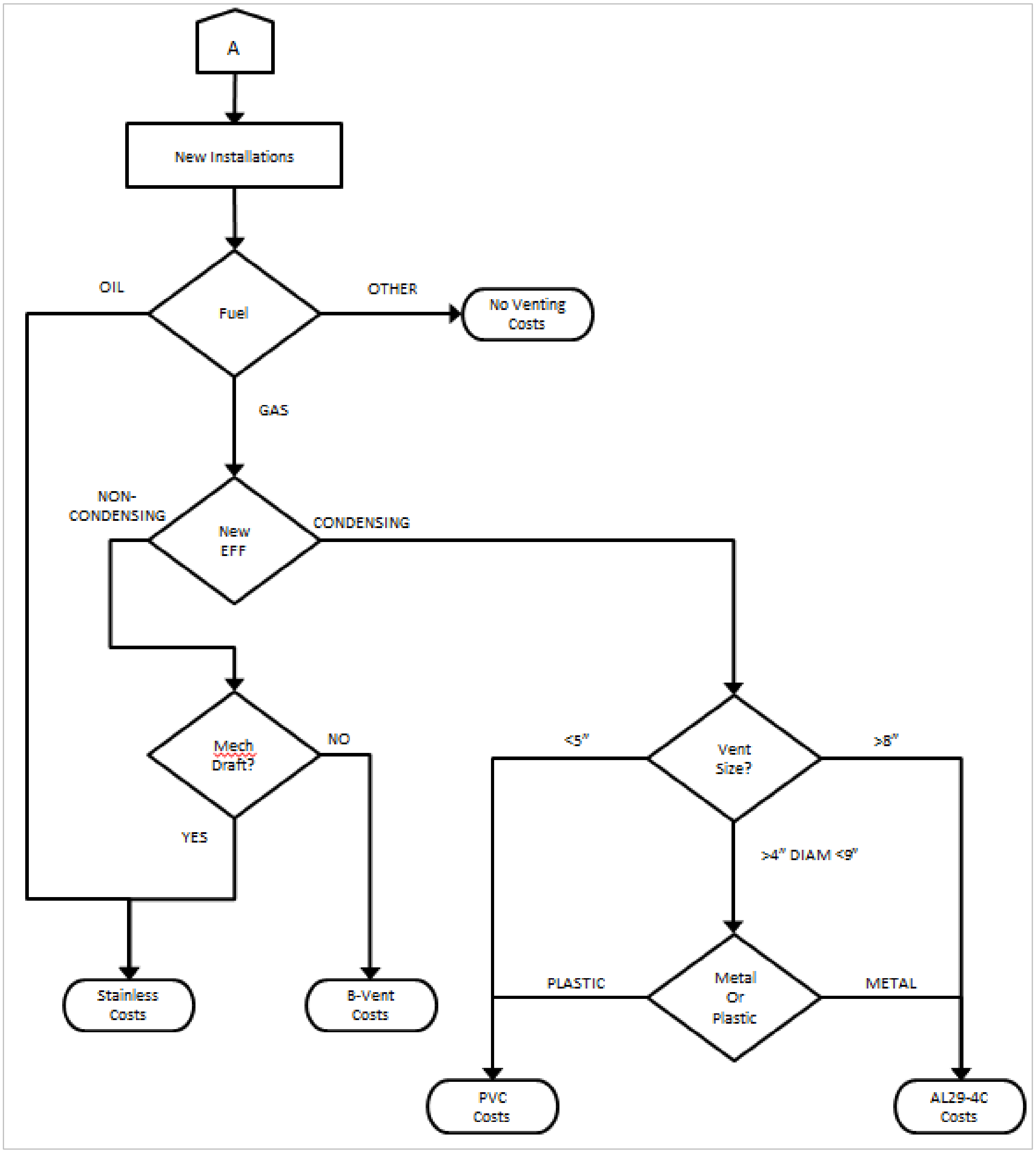

Figure 8D.3.2 Venting Logic Process Used for New Installations in the Life-Cycle Analysis

8D.3.7 Replacement Installations

DOE estimates that nationally in 2019, a growing number of replacement installations would be from non-condensing to condensing boilers. DOE considered the possible variations that may occur in installation of replacements boilers and has evaluated six cases: (1) switching from a non-condensing natural draft boiler to another non-condensing natural draft boiler, (2) switching from a non-condensing natural draft boiler to another non-condensing mechanical draft boiler, (3) switching from a non-condensing natural draft boiler to a condensing mechanical draft boiler (90 percent or greater TE), (4) switching from a non-condensing mechanical draft boiler to a higher efficiency non-condensing mechanical draft boiler, (5) switching from a non-condensing mechanical draft boiler to a condensing mechanical draft boiler, and (6) switching from a condensing mechanical draft boiler to a higher efficiency condensing mechanical draft boiler. DOE acknowledges that additional cases may relate to replacing a condensing boiler with a lower efficiency boiler. For such cases, DOE assumes that the existing venting is metallic Category IV and notes that the metallic venting suitable for condensing applications may alternatively be utilized in non-condensing applications and hence no cost increase would be realized.

8D.3.7.1 Non-Condensing Natural Draft to Non-Condensing Natural Draft Boiler Installations

DOE recognizes that in the case of replacing a non-condensing natural draft with a higher efficiency non-condensing natural draft boiler requires venting modifications to meet current NFGC requirements. Specifically, when replacing a non-condensing boiler with a more efficient non-condensing boiler, the venting may require resizing to properly exhaust the flue gas. Therefore, for this replacement scenario, DOE assumed that that for cases where an older (pre-1976) boiler is replaced with the same category boiler, Type-B venting needs to be reinstalled. The costs include the labor cost associated with removing for the existing venting system and the cost of installing a new Type-B venting system. Alternatively, in installations where a chimney is used for venting, the cost of chimney relining is included, noting that there would be no cost to remove venting or install replacement venting.

8D.3.7.2 Non-Condensing Natural Draft to Non-Condensing Mechanical Draft Boiler Installations

In cases where an existing non-condensing natural draft boiler (Category I venting) is replaced with mechanical draft boiler (Category II venting), DOE assumed that the existing venting system is removed and a new 300 series stainless steel venting system is installed. DOE considers this case to adequately represent the small number of horizontally vented natural draft vent systems as well as Category II venting installations.

8D.3.7.3 Non-Condensing Natural Draft to Condensing Boiler Installations

For the case where a condensing boiler replaces an existing non-condensing natural draft boiler, DOE assumes that a new PVC/AL29-4C venting is installed for the replacement boiler, where the selection of vent material is based on the diameter of the required venting and the existing Type-B venting system is removed.

Furthermore, DOE recognizes that a number of installations may elect to install 300 series stainless steel in lieu of plastic or AL29-4C, and that such installations would require additional venting replacement cost within the lifetime of the condensing boiler. Therefore, the DOE model assumed that 10 percent of condensing boilers with vent diameters larger than 6 inches use stainless steel venting systems.

8D.3.7.4 Non-Condensing Mechanical Draft to Non-Condensing Mechanical Draft Boiler Installations

DOE assumes that all non-condensing mechanical draft boiler installations would have stainless steel venting. DOE assumes that for replacement situations, if the existing boiler is vented with stainless steel, then the stainless steel venting could be reused. Therefore, DOE did not include any cost for venting replacement for this case.

8D.3.7.5 Non-Condensing Mechanical Draft to Condensing Boiler Installations

When replacing an existing non-condensing mechanical draft boiler with a condensing boiler, a new venting system will need to be installed. If a stainless steel vent already exists, then the vent system may be reused. The criteria to determine whether the existing vent is stainless steel are described above in section 8D.3.1. If a stainless steel vent does not already exist, then the flue considerations are the same in replacements as they are new construction. For the plastic venting, both PVC and CPVC are common.

8D.3.7.6 Condensing Mechanical Draft to Condensing Mechanical Draft Boiler Installations

DOE assumes that when condensing boilers are replaced with higher efficiency condensing equipment, no replacement venting costs are incurred by the customer, as the existing venting system can be reused.

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APPENDIX 8E. MAINTENANCE AND REPAIR COST DETERMINATION FOR COMMERCIAL PACKAGED BOILERS

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APPENDIX 8E. MAINTENANCE AND REPAIR COST DETERMINATION FOR COMMERCIAL PACKAGED BOILERS

8E.1 INTRODUCTION

This appendix provides further details about the derivation of maintenance and repair costs for commercial packaged boilers (CPBs).

The U.S. Department of Energy (DOE) estimates maintenance and repair costs for boilers based on RS Means, a construction estimation database that is used by professional estimators for up-to-date labor, materials, and overhead costs for specific project types and locations, as well as manufacturer literature and information from expert consultants. Table 8E.1.1 offers an example of the cost calculation method using RS Means data. The cost calculation consists of first estimating the material and labor costs, and then applying appropriate markups and summing the two quantities to get a final cost value. All labor costs are derived using the latest commercial 2015 RS Means labor costs by crew type[1] Maintenance and repair cost tables sometimes include a trip charge, which is often charged by contractors and estimated to be equal to one half hour of labor per crew. Labor hours (or person-hours) are based on RS Means data, expert consultant information, or engineering judgment. Bare costs include all costs without any markups. Material costs are based on RS Means data, expert data, or other sources. The subtotal column is the sum of the material and labor costs without markups. The final total column includes overhead and profit (O&P). To clarify, the labor costs shown in the tables in this appendix are the national average values; DOE uses in its analysis regional labor and material markups to more accurately estimate installation costs by region. Section 8E.3 describes the derivation of regional labor costs. DOE then applies the appropriate regional labor cost to each Commercial Building Energy Consumption Survey (CBECS) sample building.

Table 8E.1.1 Example Cost Table

Description	**Crew**	**Labor Hours**	**Unit**	**Bare Costs** *2014$*			**Quantity**	**Total incl. O&P**
				Material	**Labor**	**Subtotal**		
Trip Charge	CREW1	0.5	-	0.00	23.00	23.00	1	35.00
Description of Installation Item	CREW1	0.5	Ea.	15.00	23.00	48.00	1	51.50
Total		1.0		15.00	46.00	71.00		**86.50**

8E.2 MAINTENANCE COST FOR COMMERCIAL PACKAGED BOILERS

The maintenance cost is the routine cost to the commercial consumer of general maintenance for equipment operation. DOE estimates the labor hours and costs for each maintenance task from *2015 RS Means Facilities Maintenance and Repair Cost Data*.[1] The maintenance cost depends on boiler capacity and heating medium (hot water or steam). Within an equipment class, DOE assumes that the maintenance cost is the same at all non-condensing efficiency levels, and that the maintenance cost at condensing efficiency levels is slightly higher, due to an added cost for a condensate neutralizer. Table 8E.2.1 presents an example of the considered maintenance costs for a 120–500 kBtu/h hot water boiler. Each maintenance task has an associated crew type, number of labor hours, and frequency of occurrence. RS Means does not itemize material costs by task, but presents them as a total annualized value. 8E-2

Table 8E.2.1 Example Maintenance Tasks and Costs of 120–500 kBtu/h Hot Water Boiler Based on 2015 RS Means Data

Task ID	Task Description	Labor Hours	Material Cost	Frequency *times per year*
1	Check combustion chamber for air or gas leaks.	0.077	-	1
2	Inspect and clean oil burner gun and ignition assembly where applicable.	0.835	-	1
3	Inspect fuel system for leaks and change fuel filter element, where applicable.	0.125	-	1
4	Check fuel lines and connections for damage.	0.023	-	12
5	Check for proper operational response of burner to thermostat controls.	0.169	-	4
6	Check and lubricate burner and blower motors.	0.099	-	4
7	Check main flame failure protection and main flame detection scanner on boiler equipped with spark ignition (oil burner).	0.155	-	12
8	Check electrical wiring to burner controls and blower.	0.100	-	1
9	Clean firebox (sweep and vacuum).	0.793	-	1
10	Check operation of mercury control switches (*i.e.,* steam pressure, hot water temperature limit, atomizing or combustion air proving, etc.).	0.185	-	12
11	Check operation and condition of safety pressure relief valve.	0.038	-	12
12	Check operation of boiler low water cut off devices.	0.070	-	12
13	Check hot water pressure gauges.	0.073	-	12
14	Inspect and clean water column sight glass (or replace).	0.160	-	12
15	Clean fire side of water jacket.	0.433	-	1
16	Check condition of flue pipe, damper, and exhaust stack.	0.183	-	4
17	Check boiler operation through complete cycle, up to 30 minutes.	0.806	-	1
18	Check fuel level with gauge pole, add as required.	0.046	-	12
19	Clean area around boiler.	0.137	-	12
20	Fill out maintenance checklist and report deficiencies.	0.022	-	12
Total		15.881	$107	

Reference: 2015 RS Means Maintenance and Repair Cost Data, Page 413, D3025 130 2950.

Table 8E.2.2 shows the annualized maintenance costs for representative commercial packaged boilers.

Table 8E.2.2 Annualized Maintenance Costs Based on 2015 RS Means Data

Description	Crew	Labor Hours		Material Cost	
		Steam	Hot Water	Steam	Hot Water
Maintenance (Small Boilers)	1 STPI	20.70	17.38	$221	$114
Maintenance (Large Boilers)	1 STPI	27.72	26.66	$309	$174

DOE assumes that all steam boilers and oil-fired boilers are maintained regularly by on-site maintenance staff, and that the maintenance tasks occur at the frequency specified in RS Means. DOE assumes that gas-fired hot water boilers may or may not be maintained regularly. The CBECS and Residential Energy Consumption Survey (RECS) survey data provide information on whether building owners maintain their equipment regularly. For gas-fired hot water boilers, if the building owner reported that the site maintenance staff did not maintain the building's equipment regularly, then DOE assumes maintenance occurred one third as often as specified in RS Means. If the building owner reported regular equipment maintenance, then DOE assumes maintenance occurred at the frequency specified in RS Means.

DOE investigated the effects of recent low-sulfur fuel oil requirements on oil boiler maintenance. DOE assumed that all fuel oil boilers, regardless of fuel oil sulfur content, will be maintained with the same frequency. Therefore, the maintenance costs between boilers using regular and low-sulfur fuel oil are assumed to be the same.

8E.3 REPAIR COST FOR COMMERCIAL PACKAGED BOILERS

The repair cost is the cost to the commercial consumer for replacing or repairing components in the boiler that have failed. DOE estimates repair costs at each considered efficiency level using a variety of sources, including *2015 RS Means Facility Maintenance and Repair Cost Data*,[1] manufacturer literature, and information from expert consultants. Heat exchanger replacement costs are assumed to be one-third of the total boiler replacement cost. DOE accounts for regional differences in labor costs, as is discussed in appendix 8D of this TSD.

Table 8E.3.1 and Table 8E.3.2 show repair rate and cost assumptions used in the analysis. The failure year distribution is assumed to be a Weibull function for each component. The mean failure years for the ignition, controls, mechanical vent damper, and power vent were based on RS Means. DOE believes that commercial boilers are generally designed to allow for heat exchanger replacement and has provided for that as part of the repair costs used in the analysis. For non-condensing heat exchangers, the mean failure year is based on a report from the Gas Research Institute (GRI).[2] For condensing heat exchangers, the GRI report, which was published when condensing boiler technology was still new, estimated a mean average service life of 14.4 years, but notes that this estimate is not based on actual serviced units, but rather expectations of service staff who responded to the survey. During this rulemaking, references were made to a reduced life for condensing boilers, which DOE believes is due to degradation in heat exchangers, a replaceable component. As discussed in appendix 8F of this TSD, DOE assumed that the lifetime of the boiler is the same at different efficiency levels, but provided for a shorter heat exchanger life and a higher heat exchanger replacement rate for condensing boilers. In this analysis, the mean failure year was set to 15 and a 50% repair rate was used for condensing boilers. For non-condensing boilers, the mean failure year was set to 20 and a 17% repair rate was used. DOE assumes that all boilers have a 1-year warranty for parts and labor and a 10-year warranty on the heat exchanger. If any component of a boiler fails in 1 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. In establishing the Weibull function parameters for condensing boilers, DOE adjusted the shape and delay such that claims occurring within the assumed 10-year warranty period in the analysis for condensing and non-condensing boilers were similar.

Table 8E.3.1 Boiler Repair Rates

Repair Description	Mean Failure Year	Repair Rate
Ignition, Controls	7.0	50%
Mechanical Vent Damper or Power Vent Blower	15.0	35%
Heat Exchanger – Non-Condensing	20.0	17%
Heat Exchanger – Condensing	15.0	50%

Table 8E.3.2 Boiler Repair Costs and Labor Hours

Repair Description	Bare Material Cost *2014$**				Total Labor Hours			
	Gas		Oil		Gas		Oil	
	Large	Small	Large	Small	Large	Small	Large	Small
Ignition, Controls, Gas Valve, Automatic Means (Baseline)	$4407	$1795	$413	$405	15	6	4	4
Ignition, Controls, Gas Valve, Automatic Means (Condensing)	$4407	$1795	$413	$405	15	6	4	4
Mechanical Vent Damper	$64	$64	$64	$64	7	7	7	7
Power Vent Blower	$256	$249	$256	$249	7	7	7	7

*Does not include sales tax or markups.

8E.4 REGIONAL MATERIAL AND LABOR COSTS

DOE uses regional material and labor costs to more accurately estimate installation, maintenance, and repair costs by region. RS Means provides average national labor costs for different trade groups as shown in Table 8E.4.1. Bare costs are given in RS Means, while labor costs, including O&P, are the bare costs multiplied by the RS Means markups by trade shown in Table 8E.4.2.

Table 8E.4.1 RS Means 2015 National Average Labor Costs by Crew

Crew No.	Crew Description	No. of Laborers	Cost per Labor-Hour	
			Bare Costs	Incl. O&P
Q1	1 Plumber, 1 Plumber Apprentice	2	$52.83	$79.78
1 STPI	1 Steamfitter or Pipefitter	1	$59.75	$93.20
Q5	1 Steamfitter, 1 Steamfitter Apprentice	2	$53.77	$83.88
Q7	1 Steamfitter Foreman, 2 Steamfitters, 1 Steamfitter Apprentice	4	$56.89	$85.90

* O&P includes markups in Table 8E.4.2

Table 8E.4.2 RS Means Labor Costs Markups by Trade

Trade	Workers Comp.	Average Fixed Overhead	Overhead	Profit	Total
Plumber, Steamfitter, and Pipefitter (Repair/ Remodel)	6.7%	17.9%	16.0%	15.0%	55.6%

RS Means also provides material and labor cost factors for 295 cities and towns in the United States. To derive average labor cost values by state, DOE weights the price factors by city or town population size using 2012 census data. DOE uses the material and labor cost factors for cost associated with fire suppression, plumbing, and heating, ventilating, and air conditioning. See appendix 8D of this TSD for more details.

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APPENDIX 8F. COMMERCIAL PACKAGED BOILER LIFETIME DETERMINATION

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APPENDIX 8F. COMMERCIAL PACKAGED BOILER 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 notes that a large percentage of commercial packaged boiler equipment now on the market was not available 10+ years ago and therefore comprehensive lifetime data is not yet available. There is also an ongoing evolution of the commercial packaged boiler component lifetime, which has not yet been thoroughly assessed.[1]

DOE uses national survey data, published studies, and projections based on manufacturer shipment data to calculate the distribution of commercial packaged boiler lifetimes. Based on a review of boiler equipment literature, in this analysis DOE assumes a median lifetime value of 24 years for both gas and oil-fired commercial packaged boilers. Furthermore, DOE assumes that the lifetime of a commercial packaged boiler is the same at different efficiency levels. See section 8F.2 for sources found in the literature review.

8F.2 LIFETIME LITERATURE REVIEW

To capture variances in commercial packaged boiler lifetimes, DOE performed a literature review. Many sources provide average lifetimes or a range of lifetimes for one or multiple groups of boilers. For example, some sources provide average lifetimes for gas boilers and oil boilers, while others provide average lifetimes for boilers by heat exchanger materials. Still other sources do not specify any boiler characteristics, but provide an average lifeteime across all boilers. All of the sources DOE researched are shown below in Table 8F.2.1, which lists a given equipment lifetime (or range of lifetimes) and the characteristics of the boiler(s) to which it applies. DOE determines the overall average equipment lifetime across all the sources researched and uses that as the mean commercial packaged boiler lifetime in the lifetime distribution.

Table 8F.2.1 Commercial Packaged Boilers: Product Lifetime Estimates and Sources

Boiler Characteristics	Typical Lifetime *years*	Reference
Condensing boilers	10	Navigant Consulting (2014), Manufacturer 5[2]
Steel core boiler - heat exchanger boilers	10-15	CDW Engineering (n.d.)[3]
Condensing boilers	10-15	Navigant Consulting (2014), Manufacturer 1[2]
Condensing boilers	10-15	PM Engineer Magazine (2012)[4]
Boilers, unspecified	10-15	Navigant Consulting (2014), Manufacturer 5&7[2]
Steel water-tube, forced draft, hot water	10-33	ASHRAE (2014)[5]
Steel water-tube, natural draft, hot water boilers	11-23	ASHRAE (2014)[5]
Boilers, unspecified	12-14	VHK (2007)[6]
Copper Gas Boilers	14-16	Consortium for Energy Efficiency (1998)[7]
Steel boilers (MTHW/LTHW)	15	Chartered Institution of Building Service Engineers (n.d.)[8]

Boiler Characteristics	**Typical Lifetime** *years*	**Reference**
Condensing boilers	15	Chartered Institution of Building Service Engineers (n.d.)[8]
Floor standing Gas Boilers	15-20	VHK (2007)[6]
Copper core boiler - heat exchanger boilers	15-20	CDW Engineering (n.d.)[3]
Oil Boilers	15-25	VHK (2007)[6]
Boilers	17	VHK (2007)[6]
Steam boilers	18-20	Mazurkiewicz (1999)[9]
Larger commercial, copper tube boilers	19	PM Engineer Magazine (2002)[10]
Light commercial, copper tube boilers	19	PM Engineer Magazine (2002)[10]
Boilers, unspecified	19.5-20	GDS Associates (2007)[11]
Boilers, unspecified	Average = 20; Low = 17; High = 24	Appliance Magazine (2009)[12], Appliance Magazine (2010)[13]
Copper boilers	20	Navigant Consulting (2014), Manufacturer 1[2]
Boilers, unspecified	20	Navigant Consulting (2014), Manufacturer 8[2]
Boilers, unspecified	20-25	Control Engineering (1999)[14]
Boilers, unspecified	20-25	Rochester District Heating Cooperative (2008)[15]
New cast iron core boiler – heat exchanger boilers	20-25	CDW Engineering (n.d.)[3]
Oil Boilers	20-25	VHK (2007)[6]
Boilers, unspecified	20-35	American Boiler Manufacturers Association (2010)[16]
Steel tube boilers	20 - 40	CDW Engineering (n.d.)[3]
Light commercial, steel boilers	22	PM Engineer Magazine (2002)[10]
Steel water-tube hot water boilers	24	Menlo Park Fire District (n.d.)[17]
Steel water tube hot water boilers	24	Building Owners and Managers Association International (n.d.)[18]
Condensing boilers	25	Navigant Consulting (2014), Manufacturer 4[2]
Steel fire-tube, forced draft, hot water	25	ASHRAE (2014)[5]
Larger commercial, steel	25	PM Engineer Magazine (2002)[10]
Boilers, unspecified	25	Efficiency Vermont (2013)[19]
Water tube boilers (MTHW/LTHW)	25	Chartered Institution of Building Service Engineers (n.d.)[8]
Cast iron sectional boilers (MTHW/LTHW)	25	Chartered Institution of Building Service Engineers (n.d.)[8]
Steel fire-tube hot water boilers	25	Building Owners and Managers Association International (n.d.)[18]
Steel fire tube steam boilers	25	Building Owners and Managers Association International (n.d.)[18]
Boilers, unspecified	25	Cleaver Brooks (2012)[20]

Boiler Characteristics	Typical Lifetime *years*	Reference
Steel fire-tube hot water boilers	25	Menlo Park Fire District (n.d.)[17]
Light commercial, cast iron boilers	26	PM Engineer Magazine (2002)[10]
Boilers	25	Burnham Commercial (n.d.)[21]
Steel water-tube steam boilers	25	Menlo Park Fire District (n.d.)[17]
Hot water boilers	25-30	Mazurkiewicz (1999)[9]
Steel Gas Boilers	25-30	Consortium for Energy Efficiency (1998)[7]
Boilers, unspecified	25-35	Environmental Defense Fund (2009)[22]
Larger commercial, cast iron boilers	26	PM Engineer Magazine (2002)[10]
Light commercial, stainless steel boilers	27	PM Engineer Magazine (2002)[10]
Steel water tube steam boilers	28	Building Owners and Managers Association International (n.d.)[18]
Larger commercial, stainless steel boilers	28	PM Engineer Magazine (2002)[10]
Steel fire-tube steam boilers	28	Menlo Park Fire District (n.d.)[17]
Steel boilers	30	Navigant Consulting (2014), Manufacturer 1[2]
Cast iron boilers	30	Navigant Consulting (2014), Manufacturer 1[2]
Cast iron steam boilers	30	Menlo Park Fire District (n.d.)[17]
Cast iron boilers	30	NoesisEnergy (n.d.)[23]
Steam boilers	30	Ceils (2011)[24]
Cast iron steam boilers	30	Building Owners and Managers Association International (n.d.)[18]
Boilers, unspecified	30	McDonough (2008)[25]
Boilers, unspecified	30	Navigant Consulting (2014), Manufacturer 3&4[2]
Boilers, unspecified	30-40	Piper (2011)[26]
Old cast iron core boiler – heat exchanger boilers	30 - 50	CDW Engineering (n.d.)[3]
Cast iron hot water boilers	35	Building Owners and Managers Association International (n.d.)[18]
Cast iron boilers	35+	Weil-McLain (n.d.)[27]
Cast iron hot water boilers	35	Menlo Park Fire District (n.d.)[17]
Boilers, unspecified	40-60	Navigant Consulting (2014), Manufacturer 6[2]

8F.3 METHODOLOGY

DOE's lifetime methods are based on a paper by Lutz, et al, on methods for using national survey data to estimate lifetimes of residential appliances.[28]

A Weibull distribution is a probability distribution function commonly used to measure failure rates.[29] Its form is similar to an exponential distribution, which would model a fixed failure rate, except that it allows for a failure rate that changes over time in a particular fashion. The cumulative distribution takes the form:

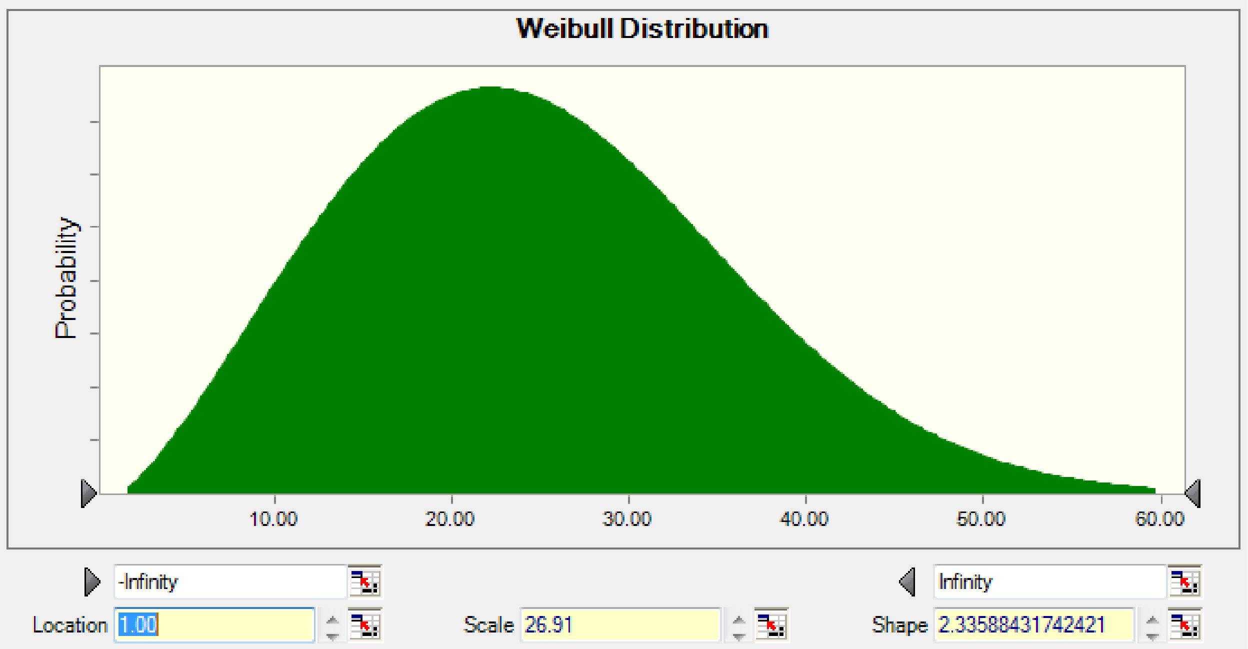
$$P(x) = e^{-\left(\frac{x-\theta}{\alpha}\right)^{\beta}} \quad \text{for } x > \theta \text{ and } P(x) = 1 \text{ for } x \leq \theta,$$

Eq. 8F.1

Where:

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

When *β* = 1, the failure rate is constant over time, and this distribution takes the form of a cumulative exponential distribution. For the case of equipment, *β* is commonly greater than 1, which results from a rising failure rate as the equipment ages. A plot of a Weibull distribution (DOE's calculated boiler survival function) is shown as Figure 8F.3.1.



-Infinity
Infinity
Location 1.00
Scale 26.91
Shape 2.33588431742421

Figure 8F.3.1 Lifetime Distribution for Commercial Packaged Boilers

Typically, shipments data over multiple years and equipment stock from survey data over multiple years are used together to determine the input parameters needed to define the distribution. However, in the case of commercial packaged boilers the available data was very limited (see chapter 9). Additionally, while the Energy Information Administration's (EIA) Commercial Building Energy Consumption Survey (CBECS) survey data are available across multiple years, CBECS provides information on the presence of a boiler but not the number of boilers present in each building.[30] Without the number of boilers per building, it is not possible to determine the equipment stock. DOE did consider the potential for using its estimated historical shipments data based on CBECS survey data from 1979 and 1983 and the EPA database of boilers[a], as described in chapter 9. However, DOE determined that the data limitations, age, and lack of smoothness would not provide a reasonable data-set to determine input parameters for the Weibull distribution.

The input parameters needed to define the Weibull distribution have been determined based on the data that was available. As discussed above, the mean boiler lifetime is determined based on the average of all of the sources found in the literature review. The boiler lifetime mean value is determined to be 24.8 years. Because DOE assumes that all boilers have a warranty period of at least one year, the boiler lifetime low value is set to 1 year.

The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) *Service Life and Maintenance Cost Database* is used to determine the spread of boiler lifetimes.[5] There are 92 buildings with boilers in the database (not including buildings with electric boilers). From the age of the boilers in each building, DOE has determined that 82.2 percent of the buildings have boilers less than 35 years old. Therefore, the high value has been set to 35 years and the percentile of high value to 82.2 percent.

The mean value, high value, low value, and percentile of high value were used to derive the α and β values for the Weibull Distribution.

8F.3.1 Assumptions

DOE's lifetime-calculation technique depends on several assumptions.

- Equipment lifetime can be modeled by a survival function. In particular, a Weibull distribution is an appropriate survival function.
- The equipment survival function does not change over time.
- The survival function is independent of other building factors (such as building size, region, etc.).
- The survival function is independent of boiler characteristics such as fuel type, heat exchanger material, and efficiency level.
- The age of equipment as reported in ASHRAE's Service Life and Maintenance Cost Database is accurate.
- The Weibull delay parameter, θ, is limited to between 1 and 5 years.

Two of these assumptions are of particular importance. The first is the assumption that a Weibull distribution is the correct distribution to use for equipment retirement rates. This distribution is the standard distribution for use in lifetime analysis, but it is not guaranteed to reflect actual commercial consumer behavior.

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[a] Environmental Protection Agency. 13 State Boiler Inspector Inventory Database with Projections (Area Sources). EPA-HQ-OAR-2006-0790-0013. April 2010. Available at www.epa.gov/ttnatw01/boiler/boilerpg.html.

DOE limits the delay parameter to between 1 and 5 years to reflect the range of common appliance warranties. A delay of less than 1 year would imply that some appliances fail or are replaced within their initial year of use, a period during which they are commonly covered by parts and labor warranties. A delay of greater than 5 years implies that no appliances are replaced for some length of time after the end of the longest standard warranty. Fits with $\theta > 5$, in this case, also commonly show unpredictable behavior with sharp changes in commercial consumer behavior or appliance survival immediately following the "delay" period.

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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 10 years of 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.

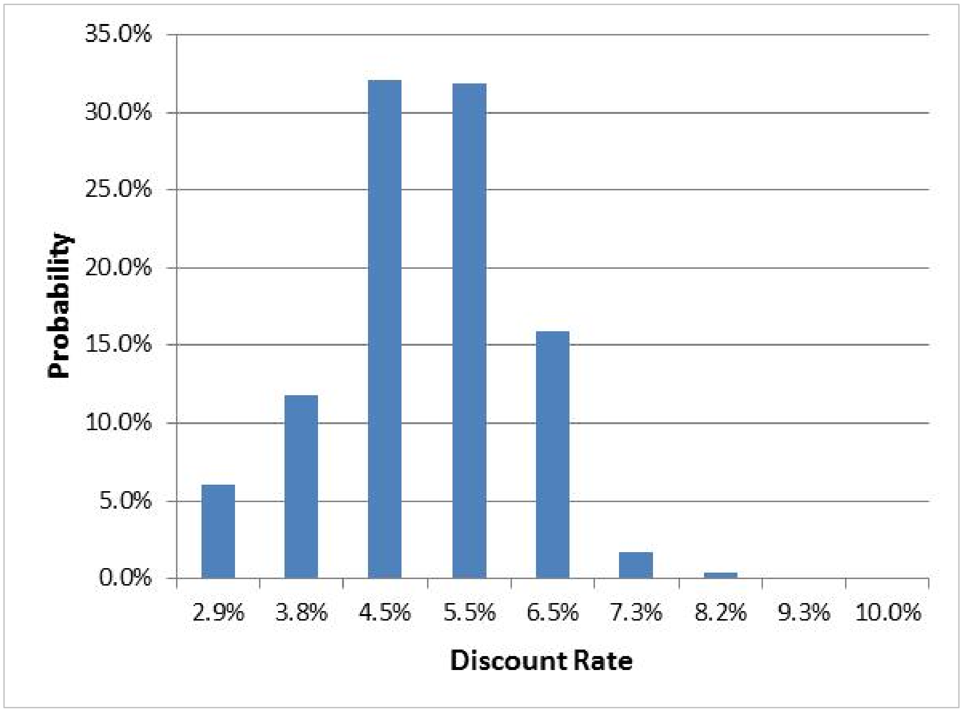

Figure 8G.2.1 Distribution of Commercial Discount Rates: Retail

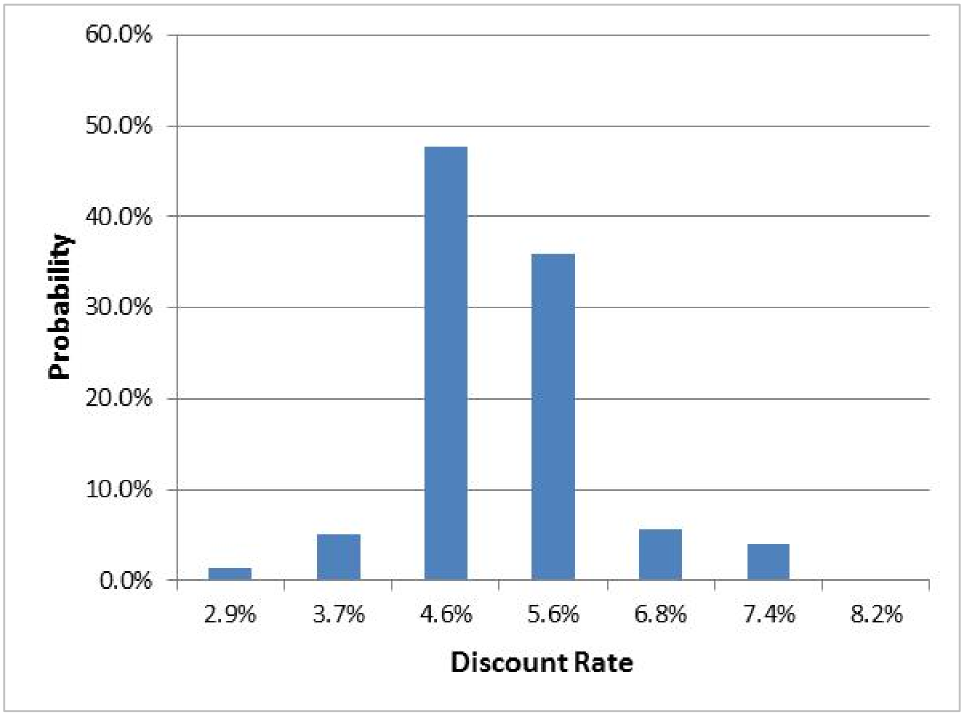

Figure 8G.2.2 Distribution of Commercial Discount Rates: Property

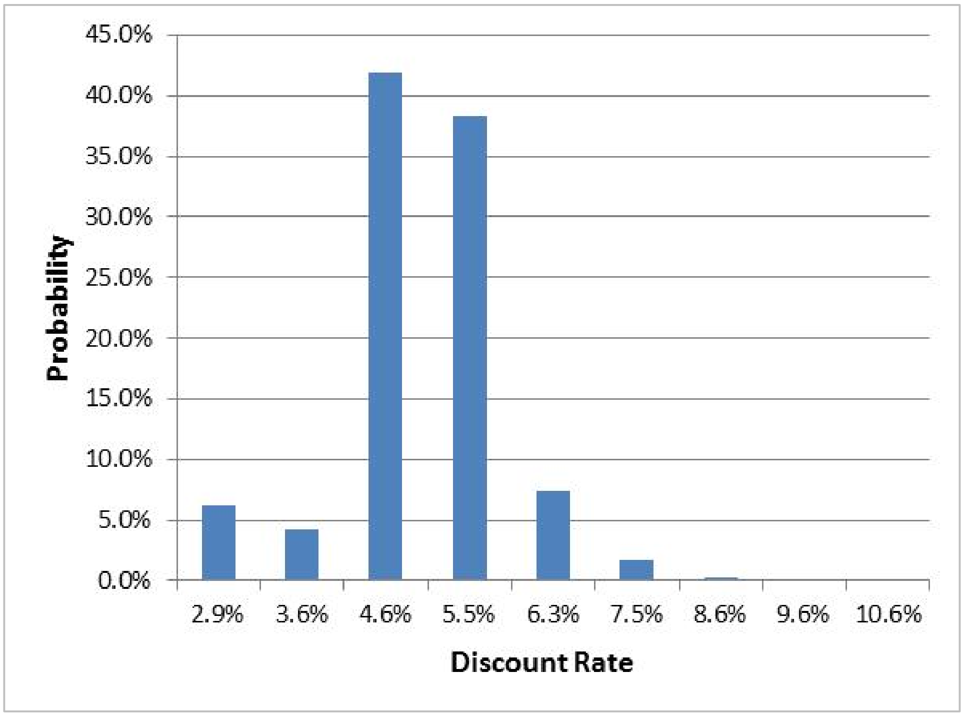

Figure 8G.2.3 Distribution of Commercial Discount Rates: Medical

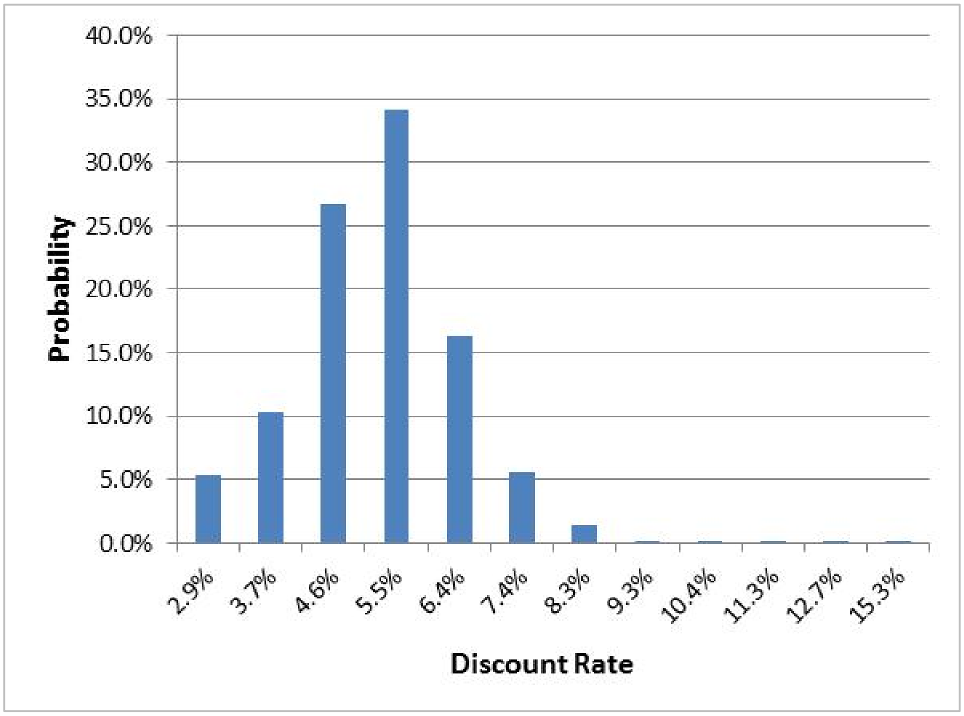

Figure 8G.2.4 Distribution of Commercial Discount Rates: Industrial

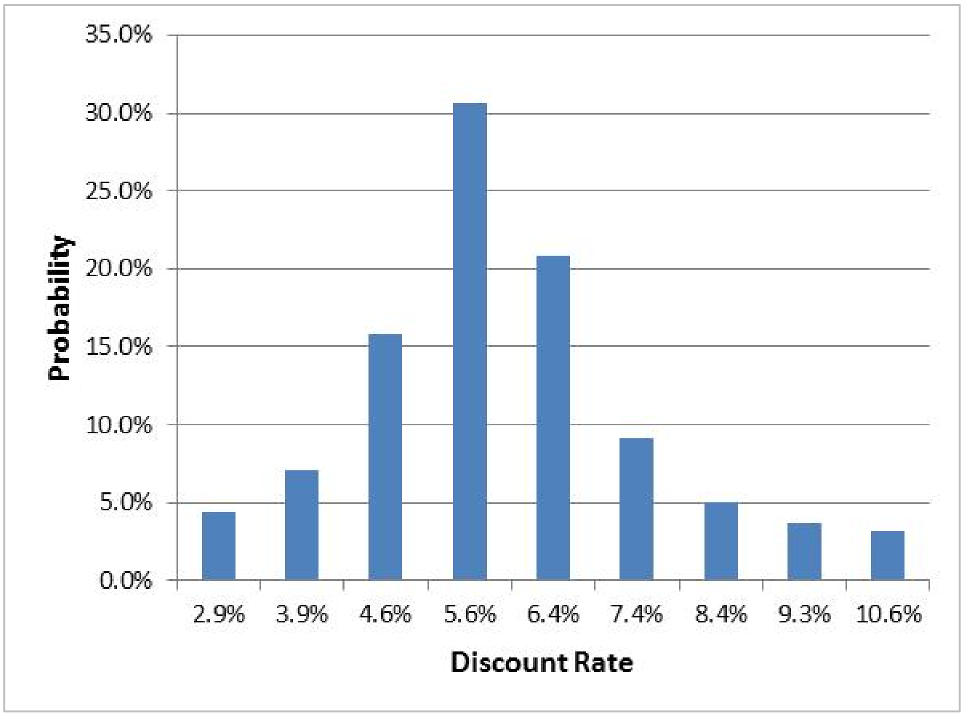

Figure 8G.2.5 Distribution of Commercial Discount Rates: Lodging

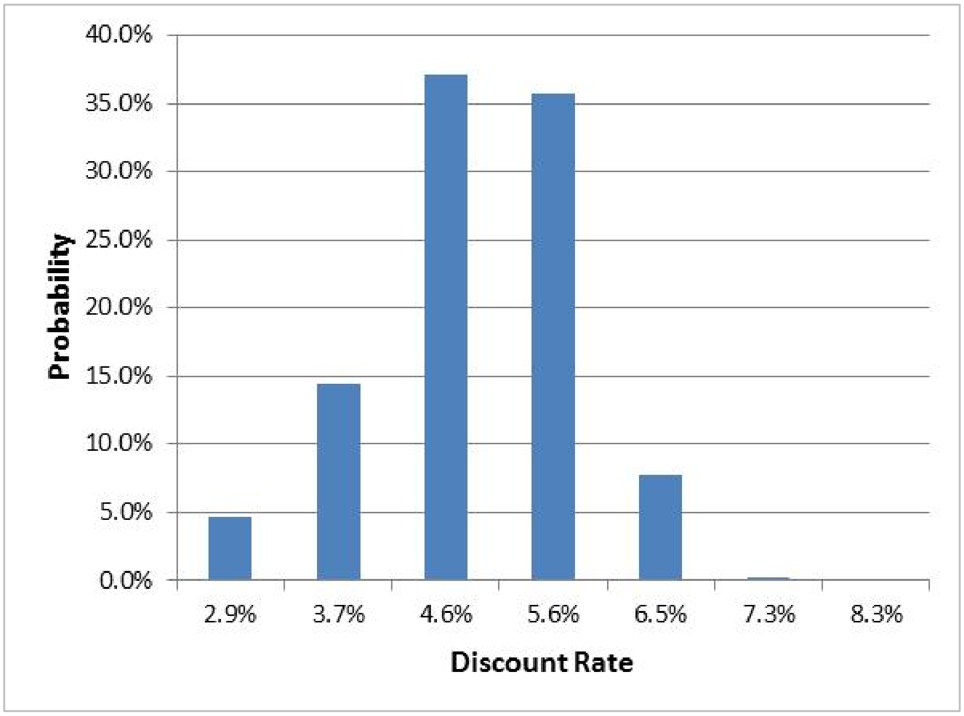

Figure 8G.2.6 Distribution of Commercial Discount Rates: Food Service

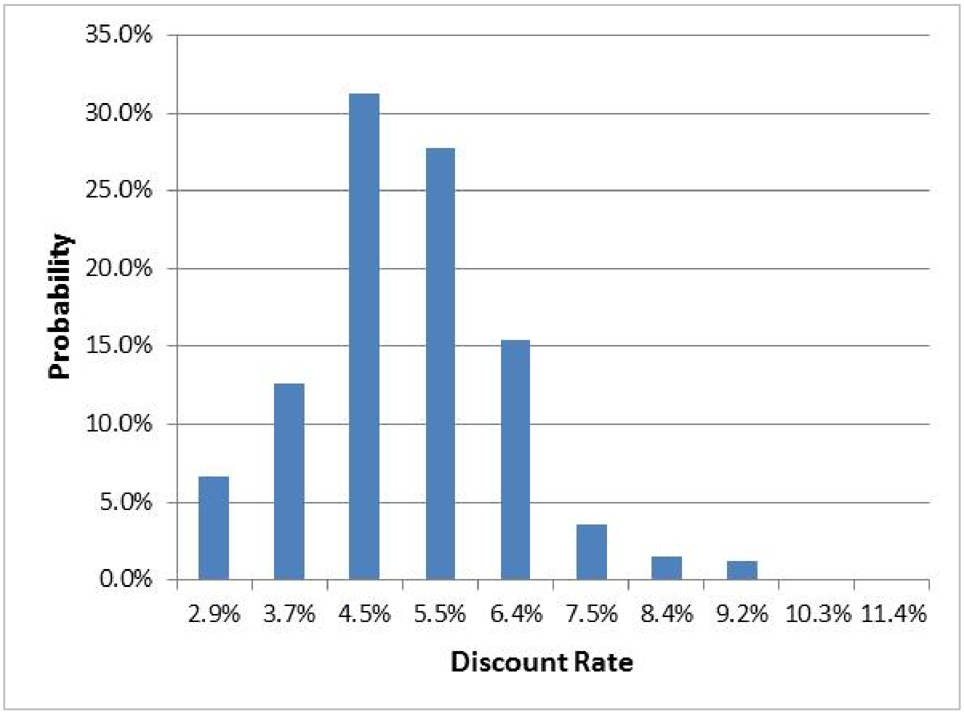

Figure 8G.2.7 Distribution of Commercial Discount Rates: Office

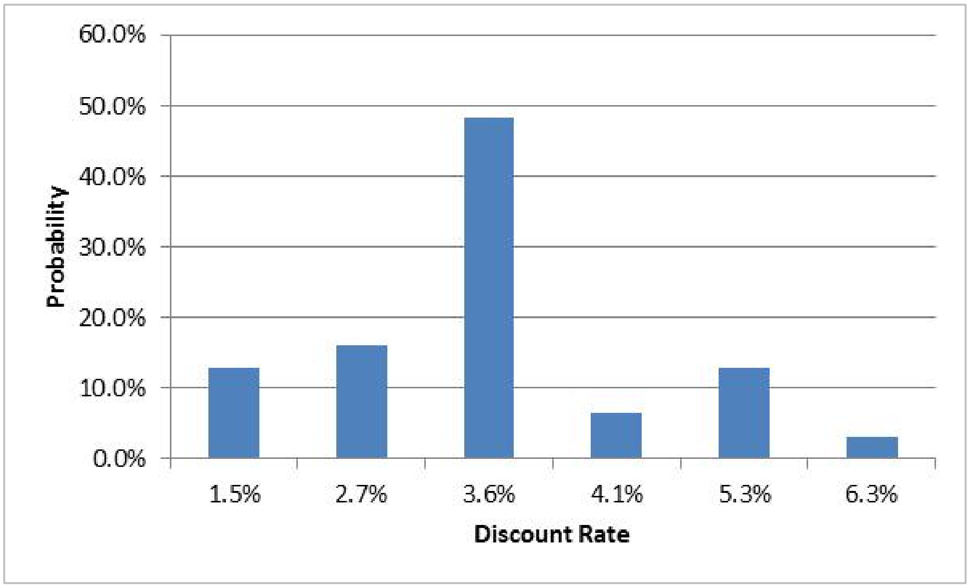

Figure 8G.2.8 Distribution of Commercial Discount Rates: State and Local Government

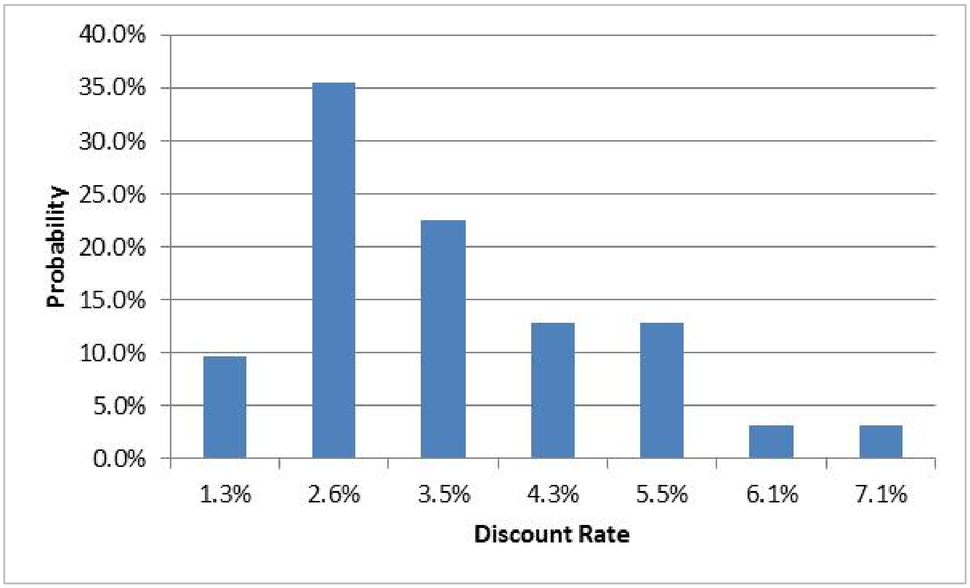

Figure 8G.2.9 Distribution of Commercial Discount Rates: Federal Government

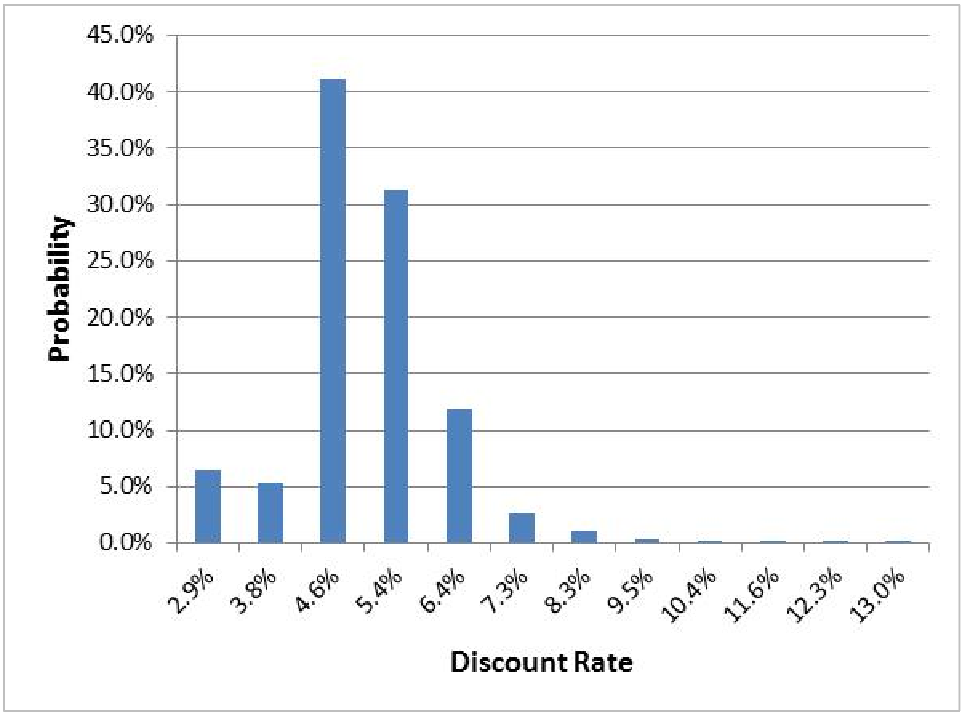

Figure 8G.2.10 Distribution of Commercial Discount Rates: Other

8G.3 DISTRIBUTIONS USED FOR RESIDENTIAL CONSUMER DISCOUNT RATES

DOE derives consumer discount rates for the LCC analysis using interest or return rate data, 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.

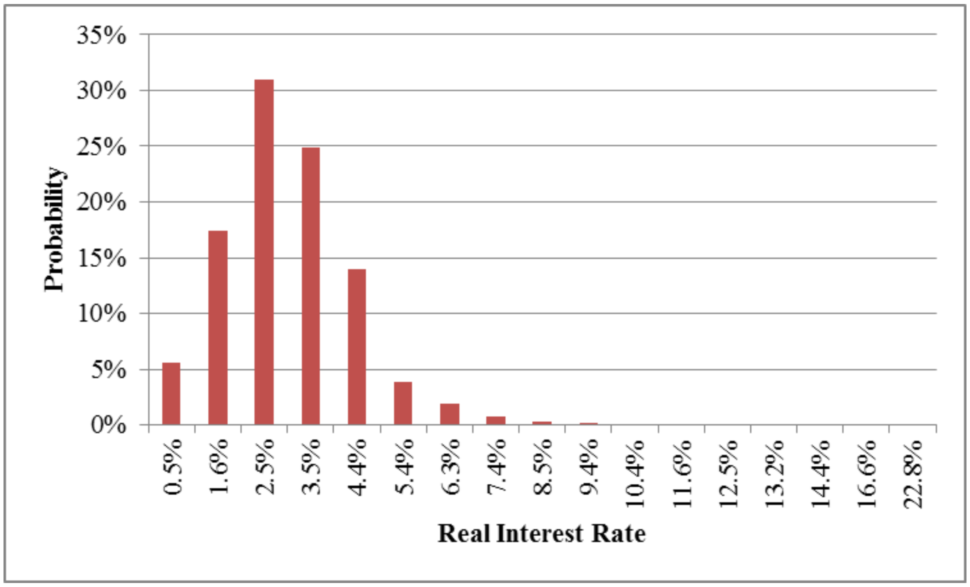

Figure 8G.3.1 Distribution of Mortgage Interest Rates

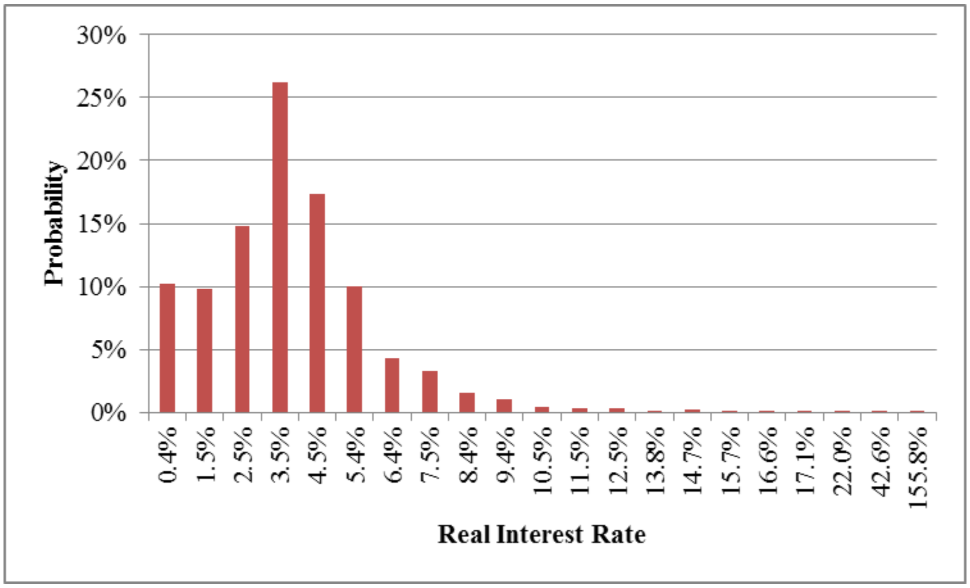

Figure 8G.3.2 Distribution of Home Equity Loan Interest Rates

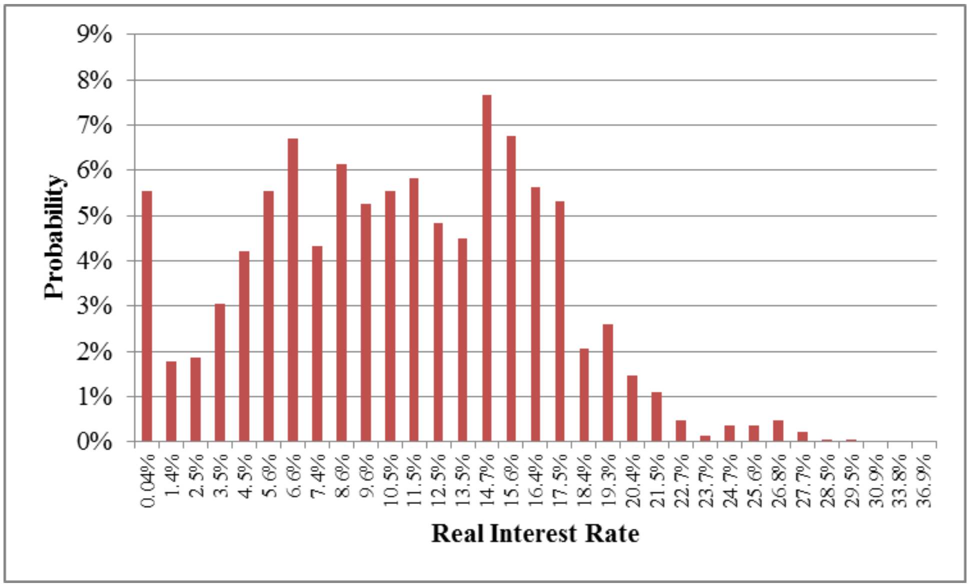

Figure 8G.3.3 Distribution of Credit Card Interest Rates

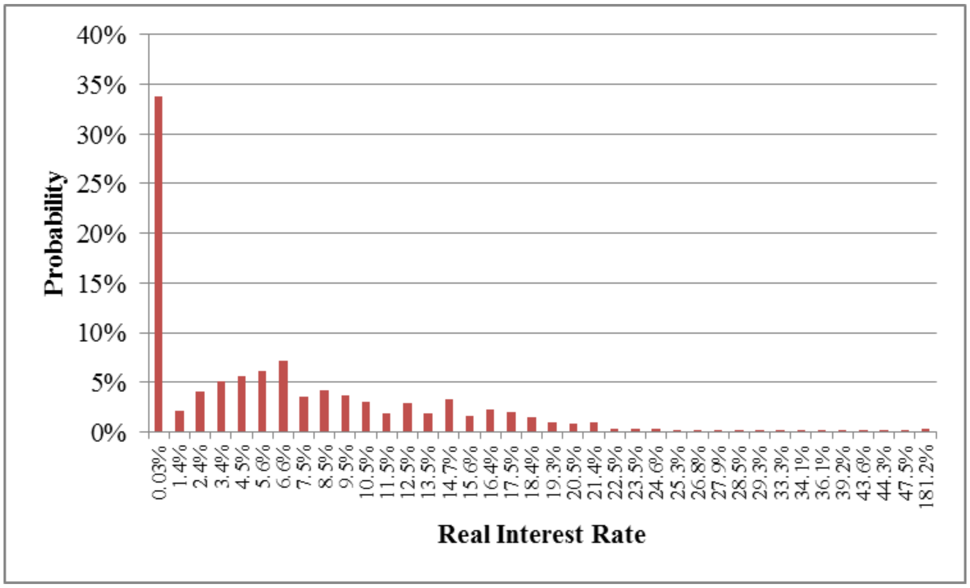

Figure 8G.3.4 Distribution of Installment Loan Interest Rates

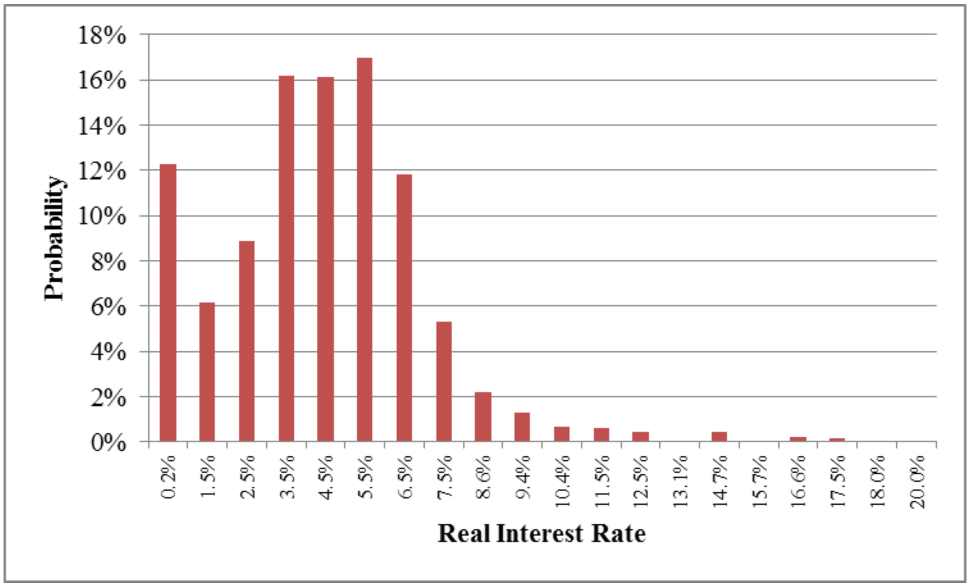

Figure 8G.3.5 Distribution of Other Residence Loan Interest Rates

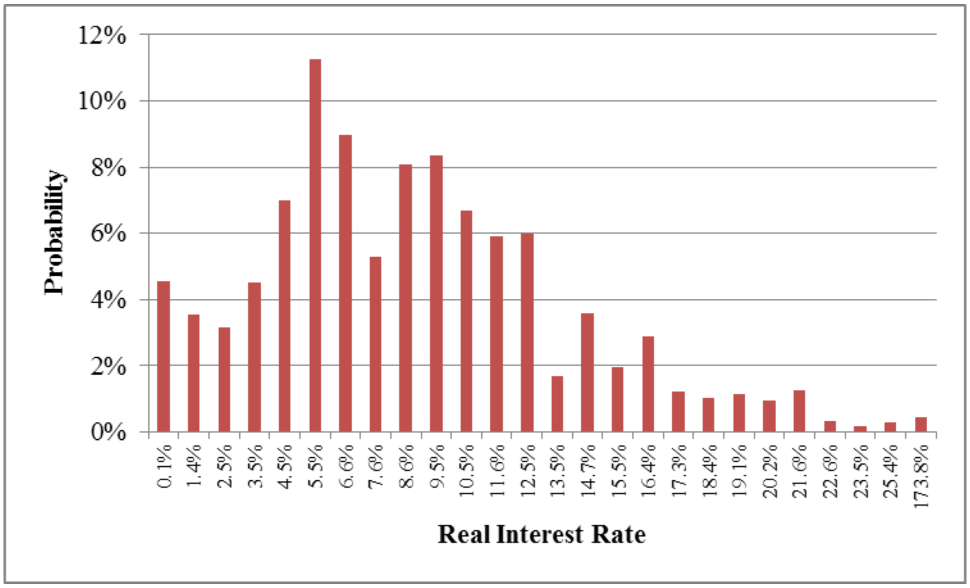

Figure 8G.3.6 Distribution of Other Lines of Credit Loan Interest Rates

8G.3.2 Distribution of Rates for Equity Classes

Figure 8G.3.7 through Figure 8G.3.12 show the distribution of real interest rates for different types of equity. Data for equity classes are not available from the Federal Reserve Board's *SCF*, so DOE derived data for these classes from national-level historical data (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 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.

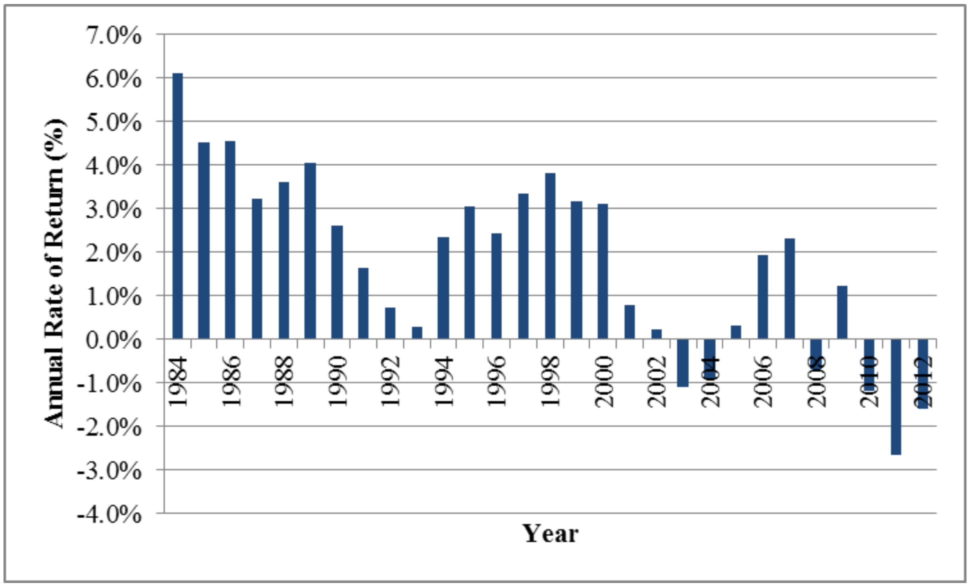

Figure 8G.3.7 Distribution of Annual Rate of Return on Certificates of Deposit

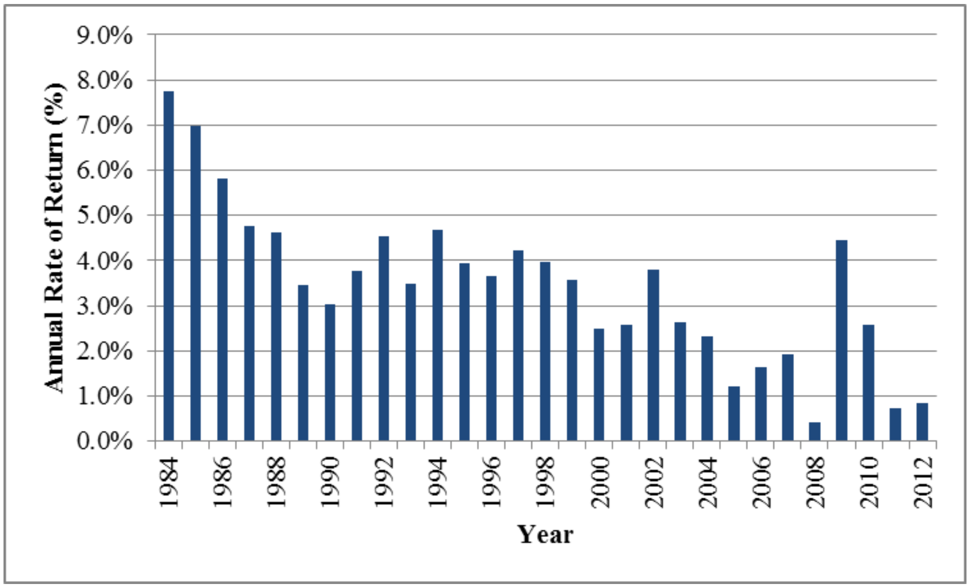

Figure 8G.3.8 Distribution of Annual Rate of Return on Savings Bonds

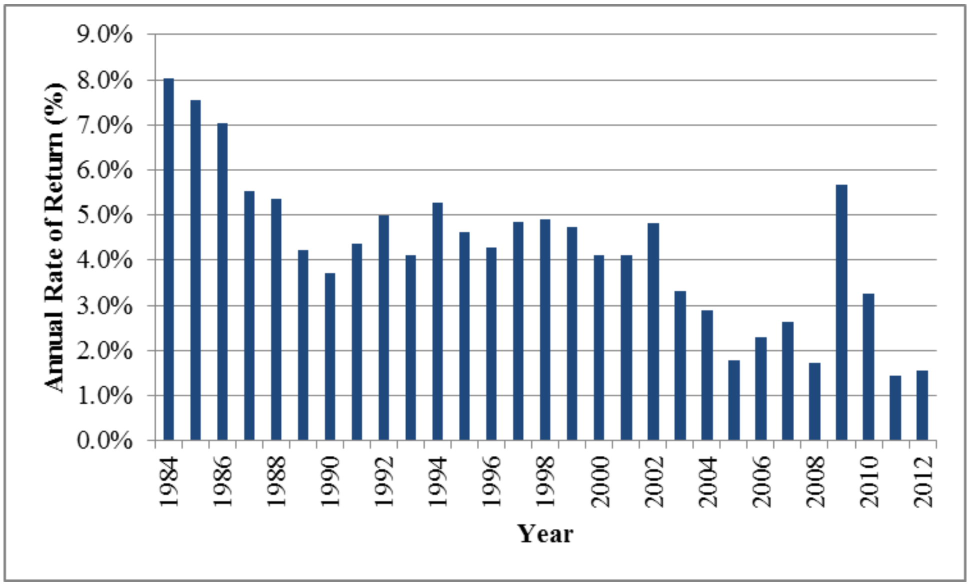

Figure 8G.3.9 Distribution of Annual Rate of Return on Corporate AAA Bonds

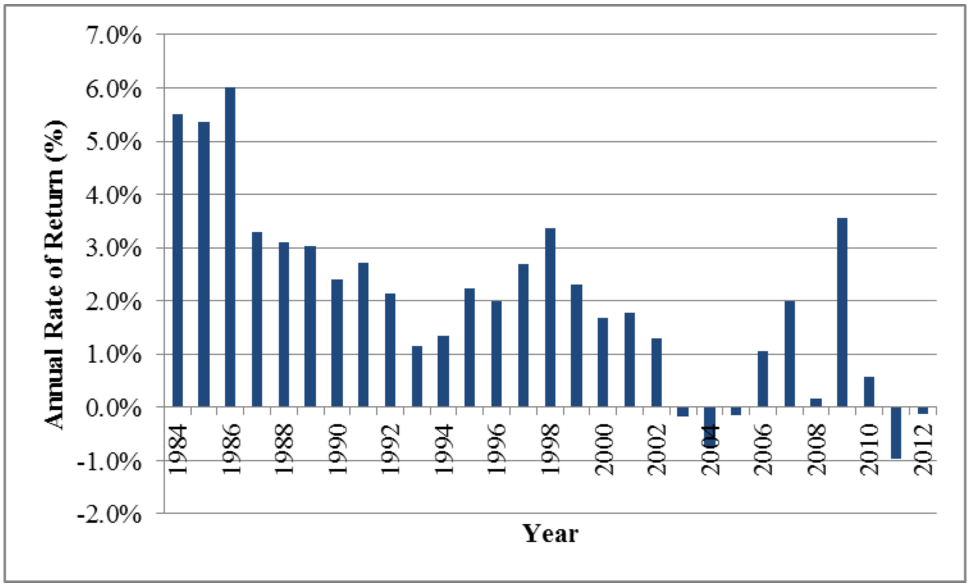

Figure 8G.3.10 Distribution of Annual Rate of Savings and Money Market Accounts

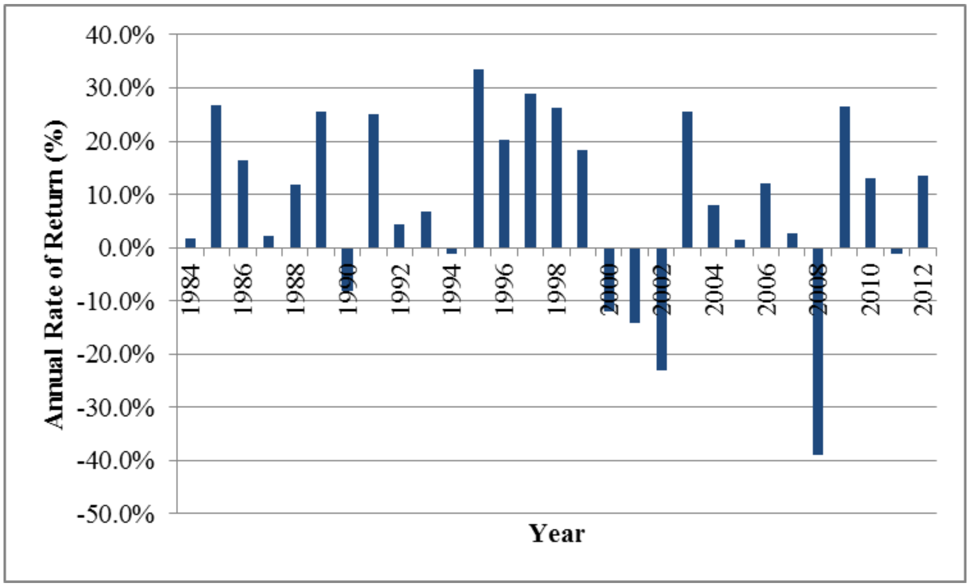

Figure 8G.3.11 Distribution of Annual Rate of Return on Standard and Poor's 500

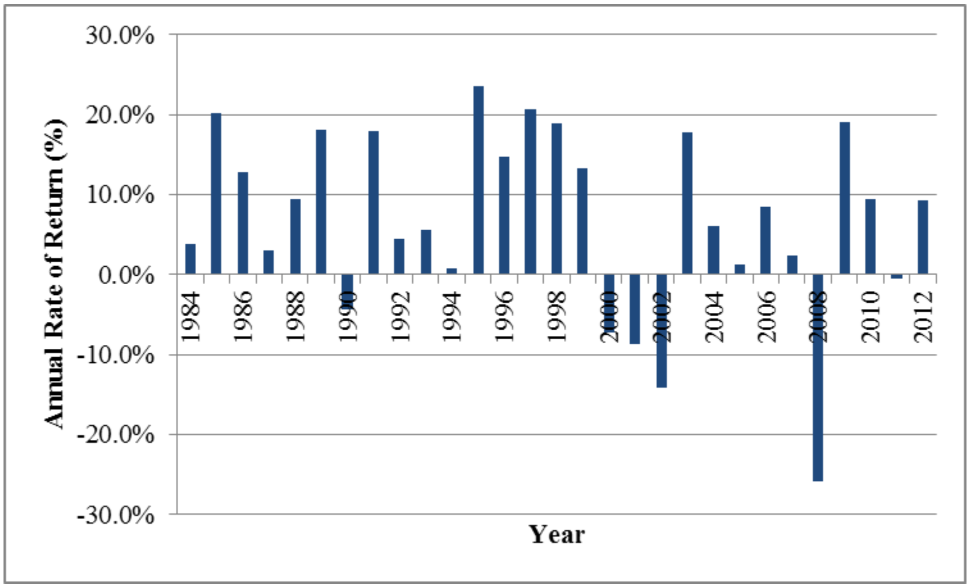

Figure 8G.3.12 Distribution of Annual Rate of Return on Mutual Funds

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.

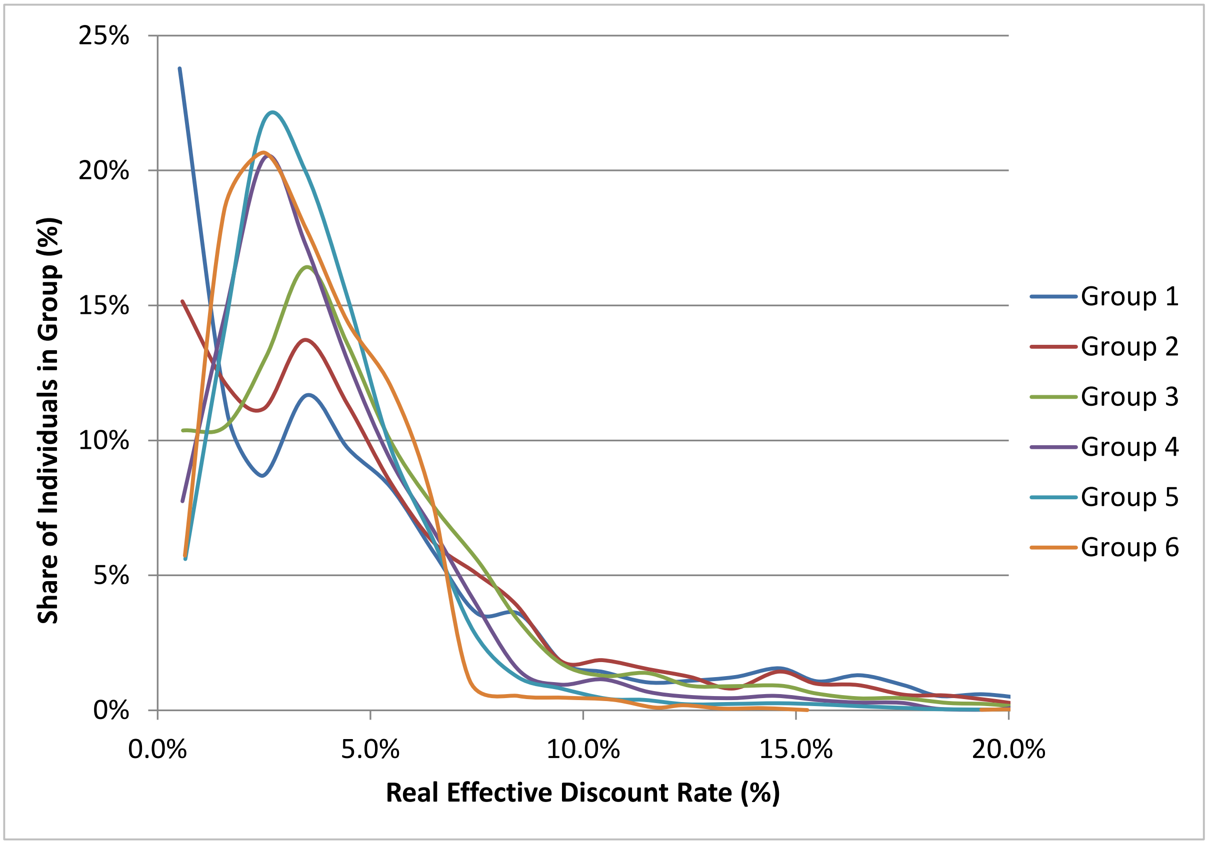

Figure 8G.4.1 Distribution of Real Discount Rates by Income Group

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 (91-100 percentile)	
	rate	**weight**	**rate**	**weight**	**rate**	**weight**	**rate**	**weight**	**rate**	**weight**	**rate**	**weight**
0-1	0.5%	0.238	0.6%	0.152	0.6%	0.104	0.6%	0.077	0.6%	0.056	0.6%	0.057
1-2	1.6%	0.110	1.6%	0.120	1.6%	0.105	1.6%	0.146	1.6%	0.142	1.6%	0.185
2-3	2.5%	0.087	2.5%	0.112	2.6%	0.131	2.5%	0.205	2.5%	0.219	2.5%	0.207
3-4	3.5%	0.117	3.5%	0.137	3.5%	0.164	3.5%	0.173	3.5%	0.200	3.5%	0.178
4-5	4.5%	0.097	4.5%	0.113	4.5%	0.136	4.5%	0.129	4.5%	0.153	4.5%	0.144
5-6	5.5%	0.083	5.5%	0.084	5.5%	0.100	5.5%	0.093	5.5%	0.098	5.5%	0.120
6-7	6.5%	0.058	6.5%	0.062	6.5%	0.075	6.5%	0.067	6.5%	0.063	6.4%	0.079
7-8	7.5%	0.036	7.5%	0.051	7.6%	0.054	7.4%	0.041	7.4%	0.029	7.3%	0.011
8-9	8.5%	0.036	8.4%	0.039	8.4%	0.034	8.5%	0.015	8.4%	0.012	8.5%	0.005
9-10	9.5%	0.017	9.5%	0.018	9.5%	0.017	9.5%	0.010	9.5%	0.008	9.6%	0.005
10-11	10.5%	0.014	10.5%	0.019	10.5%	0.013	10.5%	0.011	10.6%	0.004	10.7%	0.004
11-12	11.5%	0.010	11.5%	0.015	11.5%	0.014	11.5%	0.007	11.4%	0.004	11.7%	0.001
12-13	12.5%	0.011	12.5%	0.012	12.5%	0.009	12.4%	0.005	12.4%	0.002	12.4%	0.002
13-14	13.6%	0.012	13.5%	0.008	13.5%	0.009	13.5%	0.004	13.5%	0.002	13.3%	0.001
14-15	14.6%	0.016	14.6%	0.014	14.6%	0.009	14.5%	0.005	14.6%	0.003	14.2%	0.001
15-16	15.5%	0.011	15.5%	0.010	15.5%	0.006	15.6%	0.004	15.6%	0.002	15.3%	0.000
16-17	16.5%	0.013	16.5%	0.009	16.5%	0.004	16.5%	0.003	16.5%	0.001	0.0%	0.000
17-18	17.5%	0.009	17.6%	0.006	17.5%	0.005	17.5%	0.003	17.6%	0.001	17.7%	0.001
18-19	18.4%	0.005	18.5%	0.005	18.6%	0.003	18.4%	0.001	18.2%	0.000	0.0%	0.000
19-20	19.4%	0.006	19.4%	0.004	19.4%	0.002	19.7%	0.000	19.7%	0.000	19.4%	0.000
20-21	20.6%	0.004	20.4%	0.002	20.5%	0.001	20.3%	0.001	20.5%	0.000	20.3%	0.000
21-22	21.4%	0.003	21.4%	0.002	21.4%	0.001	21.5%	0.001	0.0%	0.000	21.4%	0.000
22-23	22.5%	0.002	22.4%	0.001	22.6%	0.001	22.9%	0.000	22.8%	0.000	22.3%	0.000
23-24	23.6%	0.001	23.4%	0.001	23.6%	0.001	0.0%	0.000	0.0%	0.000	24.0%	0.000
24-25	24.6%	0.001	24.5%	0.000	24.6%	0.000	24.1%	0.000	24.3%	0.000	0.0%	0.000
25-26	25.4%	0.001	25.4%	0.001	25.5%	0.000	0.0%	0.000	0.0%	0.000	0.0%	0.000
26-27	26.5%	0.001	26.5%	0.000	26.4%	0.000	0.0%	0.000	0.0%	0.000	0.0%	0.000
27-28	27.8%	0.000	27.6%	0.000	27.8%	0.000	0.0%	0.000	0.0%	0.000	0.0%	0.000
28-29	28.2%	0.000	0.0%	0.000	0.0%	0.000	0.0%	0.000	0.0%	0.000	0.0%	0.000
29-23	29.9%	0.000	29.3%	0.000	0.0%	0.000	0.0%	0.000	0.0%	0.000	0.0%	0.000
>30	59.1%	0.001	142.7%	0.002	0.0%	0.000	53.3%	0.000	0.0%	0.000	0.0%	0.000

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APPENDIX 8H. NO-NEW-STANDARDS-CASE DISTRIBUTION OF EFFICIENCY LEVELS

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APPENDIX 8H. NO-NEW-STANDARDS-CASE DISTRIBUTION OF EFFICIENCY LEVELS

8H.1 INTRODUCTION

The U.S. Department of Energy (DOE) derives no-new-standards-case efficiency distributions of efficiency levels by equipment class for commercial packaged boilers (CPBs), which recognizes that commercial consumers already purchasing equipment at efficiencies greater than or equal to a prospective standard level are not impacted by the standard. This appendix describes the distributions.

DOE did not have access to sales data describing the actual distribution of efficiencies in current sales, nor was such information provided by industry for this rulemaking. As a consequence, DOE developed estimates of the distribution of efficiency levels for each of the eight CPB equipment classes. DOE further disaggregated the classes by draft-type to permit adequate estimation of costs associated with natural draft and mechanical draft CPB equipment within the models. The distributions are based on the Air-Conditioning, Heating, and Refrigeration Institute (AHRI) Directory of Certified Product Performance obtained on the following dates:[1]

- March 1, 2007
- March 3, 2008
- January 30, 2009
- January 11, 2011
- January 3, 2012
- April 1, 2013
- May 26, 2014
- May 19, 2015

The AHRI Directory provides a review of efficiencies on the market for each equipment class. Note that the database from 2010 is not used.

8H.2 ESTIMATE OF 2015 EFFICIENCY DISTRIBUTIONS BY EQUIPMENT CLASS AND EFFICIENCY LEVEL

DOE develops data regarding the share of models in each equipment class which are of the different designs based on the May 19, 2015, AHRI certification shown in Table 8H.2.1 and Table 8H.2.2.

Table 8H.2.1 Fraction of Commercial Packaged Boiler Models in 2015 by Efficiency, Natural Draft Boilers

Efficiency	SGHW*	LGHW	SOHW	LOHW	SGST	LGST	SOST	LOST**
77					69.8%	16.9%		
78					7.2%	78%		
79					22.3%			
80	19.9%				0.7%	3.4%		
81	22.8%					1.7%	3.2%	
82	45.1%	51.2%	45.9%				41.9%	
83	3.9%	19.5%	9.8%				38.7%	
84	2.4%	22%	14.8%	37.5%				
85	5.8%	7.3%	4.9%				16.1%	
86			4.9%					
87			11.5%	62.5%				
88			8.2%					
89								
90								
91								
92								
93								
94								
95								
96								
97								
98								
99								

* SGHW = Small Gas-fired Hot Water; LGHW = Large Gas-fired Hot Water; SOHW = Small Oil-fired Hot Water; LOHW = Large Oil-fired Hot Water; SGST = Small Gas-fired Steam; LGST = Large Gas-fired Steam; SOST = Small Oil-fired Steam; LOST = Large Oil-fired Steam

** No natural-draft LOST CPB equipment was listed in 2015.

Table 8H.2.2 Fraction of Commercial Packaged Boiler Models in 2015 by Efficiency, Mechanical Draft Boilers

Efficiency	SGHW	LGHW	SOHW	LOHW	SGST	LGST	SOST	LOST
77								
78								
79					2%			
80	3.8%				36.7%	28.4%		
81	7.6%				39.8%	16.2%		
82	3.9%	9.6%	21.6%		9.2%	17.6%	27.5%	20.3%
83	5.2%	20.7%	28.8%		12.2%	36.5%	42.9%	20.3%
84	6.5%	8.6%	17.1%	20.2%		1.4%	16.5%	15.9%
85	20.9%	17.7%	16.2%	28.6%			12.1%	40.6%
86	4.3%	1%	11.7%	34.5%			1.1%	1.4%
87	1.7%	5.6%	3.6%					1.4%
88				10.7%				
89	0.4%			2.4%				
90	1.2%	1%						
91	0.4%							
92	3.6%	4.5%						
93	8.5%	10.6%						
94	10.9%	14.1%						
95	14.9%	4%		1.2%				
96	3.7%	2%	0.9%	1.2%				

Efficiency	SGHW	LGHW	SOHW	LOHW	SGST	LGST	SOST	LOST
97	1.8%	0.5%		1.2%				
98	0.5%							
99	0.1%							

To create the fractions of boilers by efficiency levels, DOE used the following criteria to process the AHRI model directory data:

1) Only boilers that meet the current standard are included.
2) Reported efficiency is rounded down to the nearest whole number. For example, 92 percent represents reported efficiencies from 92 percent to 93 percent, including 92 percent and excluding 93 percent.
3) Rounded efficiency from Step 2 is rounded to the nearest considered efficiency level.
4) Boilers that are listed as both hot water and steam are included in both the hot water and steam analysis.

Table 8H.2.3 and Table 8H.2.4 show the adjusted fractions of CPB models by efficiency level in 2015. The adjusted fractions are equivalent to the assumed distribution of CPB efficiency in 2015.

Table 8H.2.3 Fraction of Commercial Packaged Boiler Models in 2015 by Efficiency Level, Natural Draft Boilers

Efficiency	SGHW[*]	LGHW	SOHW	LOHW	SGST	LGST	SOST	LOST[**]
77					69.8%	16.9%		
78					7.2%	78%		
79					22.3%			
80	19.9%				0.7%	3.4%		
81	22.8%					1.7%	24.2%	
82	47.1%	51.2%	45.9%					
83		19.5%	9.8%				59.7%	
84	4.4%	22%	14.8%	37.5%			8.1%	
85	5.8%	7.3%	7.4%					
86				31.3%			8.1%	
87			13.9%					
88			8.2%	31.3%				
89								
90								
91								
92								
93								
94								
95								
96								
97								
98								
99								

[*] SGHW = Small Gas-fired Hot Water; LGHW = Large Gas-fired Hot Water; SOHW = Small Oil-fired Hot Water; LOHW = Large Oil-fired Hot Water; SGST = Small Gas-fired Steam; LGST = Large Gas-fired Steam; SOST = Small Oil-fired Steam; LOST = Large Oil-fired Steam

[**] No natural draft LOST CPB equipment was listed in 2015.

Table 8H.2.4 Fraction of Commercial Packaged Boiler Models in 2015 by Efficiency Level, Mechanical Draft Boilers

Efficiency	SGHW*	LGHW	SOHW	LOHW	SGST	LGST	SOST	LOST
77								
78								
79					2%			
80	3.8%				36.7%	28.4%		
81	7.6%				44.4%	16.2%	13.7%	10.1%
82	6.5%	9.6%	21.6%			35.8%		
83		20.7%	28.8%		16.8%		56.6%	38.4%
84	9.1%	8.6%	17.1%	34.5%		19.6%	22.5%	
85	27.4%	24.2%	22.1%					49.3%
86				48.8%			7.1%	
87			9.5%					2.2%
88				10.7%				
89				2.4%				
90								
91								
92								
93	19.2%							
94		34.3%						
95	25%							
96								
97		2.5%	0.9%	3.6%				
98								
99	1.5%							

* SGHW = Small Gas-fired Hot Water; LGHW = Large Gas-fired Hot Water; SOHW = Small Oil-fired Hot Water; LOHW = Large Oil-fired Hot Water; SGST = Small Gas-fired Steam; LGST = Large Gas-fired Steam; SOST = Small Oil-fired Steam; LOST = Large Oil-fired Steam

8H.3 PROJECTED MARKET SHARES FROM 2015 TO 2019 AND BEYOND

8H.3.1 Condensing Unit Market Share

DOE assumes that the condensing boiler market share will increase linearly by equipment class from 2015 through 2049. DOE determines the linear fit parameters based on the percent of condensing models in the AHRI Directory from 2008 through 2015, excluding 2010.

From 2007 through 2009, the percent of condensing gas-fired hot water commercial packaged boilers increased by approximately 5 percent per year for small boilers and on average 1.1 percent per year for large boilers. From 2011 through 2015, the growth rate slows down to an average of approximately 1.5 percent per year for small gas-fired hot water boilers, 0.7 percent for large gas-fired hot water boilers, -1.6 percent for small oil-fired hot water boilers, and -2.4 percent for large oil-fired hot water boilers. DOE assumes that the growth rate of gas-fired hot water boilers from 2011 through 2015 is representative of the future market share of condensing gas-fired hot water commercial packaged boilers and uses this growth rate from 2016 through 2049.

From 2007 through 2009, there were no condensing oil-fired hot water commercial packaged boilers. From 2011 through 2013, the market share of condensing models increased. In 2014 there was a sharp decrease in the condensing market share. DOE believes that the decrease that occurred in 2014 is due to one or more manufacturers discontinuing a certified product line.

Initially, DOE assumed that manufacturers would subsequently come out with a new product line that is not yet certified but likely would be. However, this did not occur in the 2015 AHRI dataset, suggesting that such product lines may not be developed or certified for business reasons. For this reason, DOE has decided to estimate the 2016 market share by averaging the five previous years of available data and assuming a 5-percent decline per annum, starting in 2017.

Figure 8H.3.1 through Figure 8H.3.4 plot the historical data and projections of market share of condensing units for

- gas-fired hot water commercial packaged boilers ≥300,000 Btu/h and ≤2,500,000 Btu/h,
- gas-fired hot water commercial packaged boilers >2,500,000 Btu/h and ≤10,000,000 Btu/h,
- oil-fired hot water commercial packaged boilers ≥300,000 Btu/h and ≤2,500,000 Btu/h, and
- oil-fired hot water commercial packaged boilers >2,500,000 Btu/h and ≤10,000,000 Btu/h, respectively.

See appendix 7B for the derivation of the historical fraction of condensing boilers.

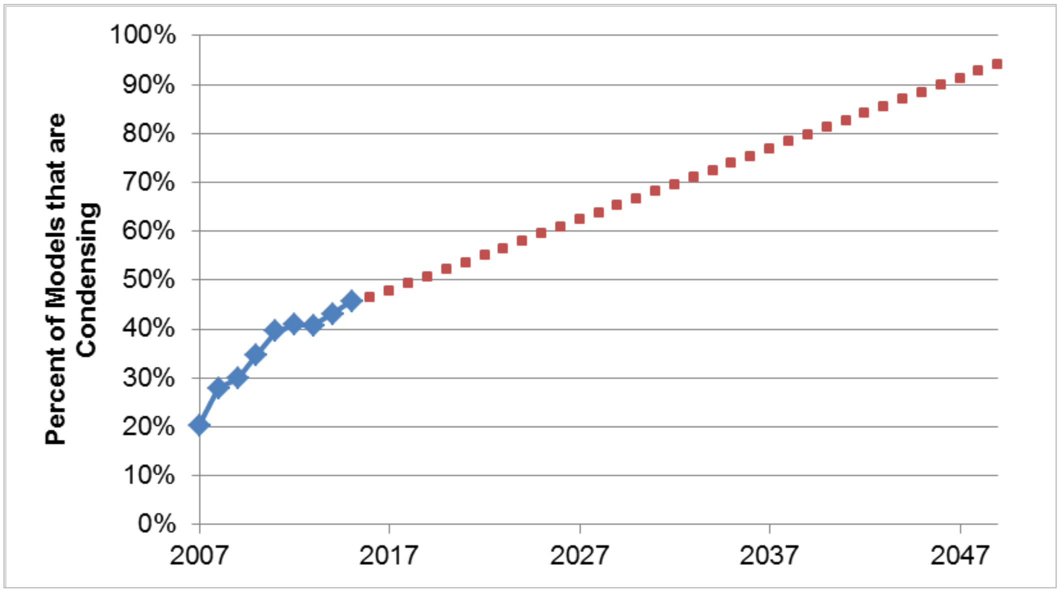

Figure 8H.3.1 Historical Data and Projection of No-New-Standards-Case Market Share for Condensing Gas-Fired Hot Water Commercial Packaged Boilers ≥300,000 Btu/h and ≤2,500,000 Btu/h

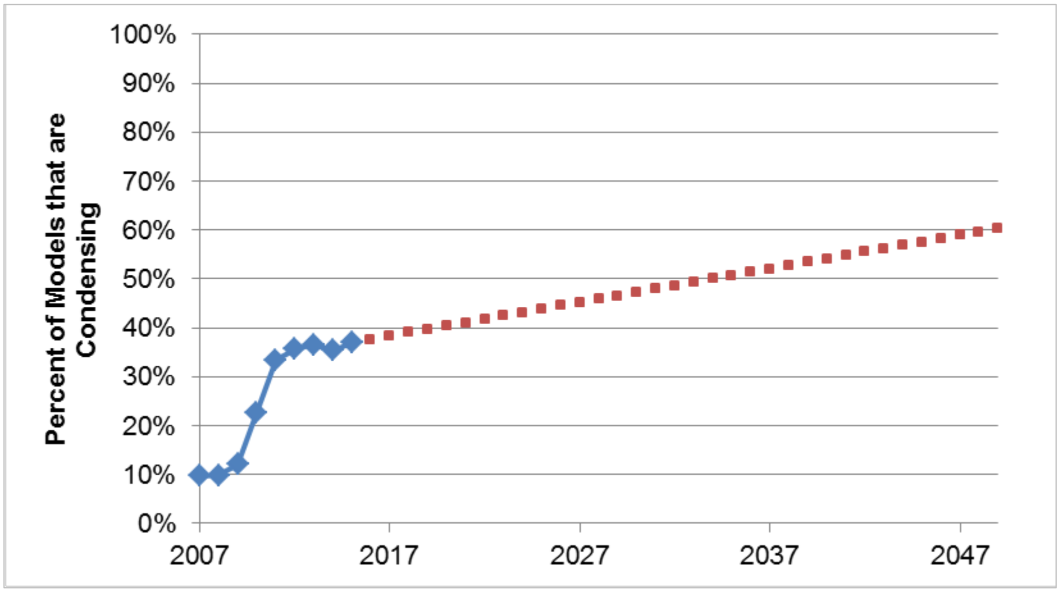

Figure 8H.3.2 Historical Data and Projection of No-New-Standards-Case Market Share for Condensing Gas-Fired Hot Water Commercial Packaged Boilers >2,500,000 Btu/h and ≤10,000,000 Btu/h

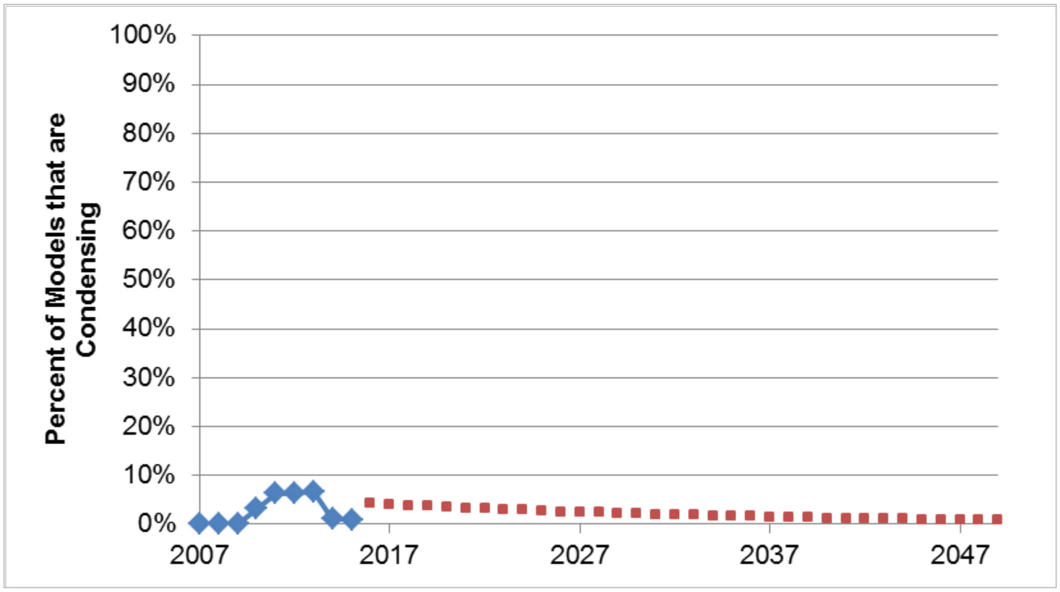

Figure 8H.3.3 Historical Data and Projection of No-New-Standards-Case Market Share for Condensing Oil-Fired Hot Water Commercial Packaged Boilers ≥300,000 Btu/h and ≤2,500,000 Btu/h

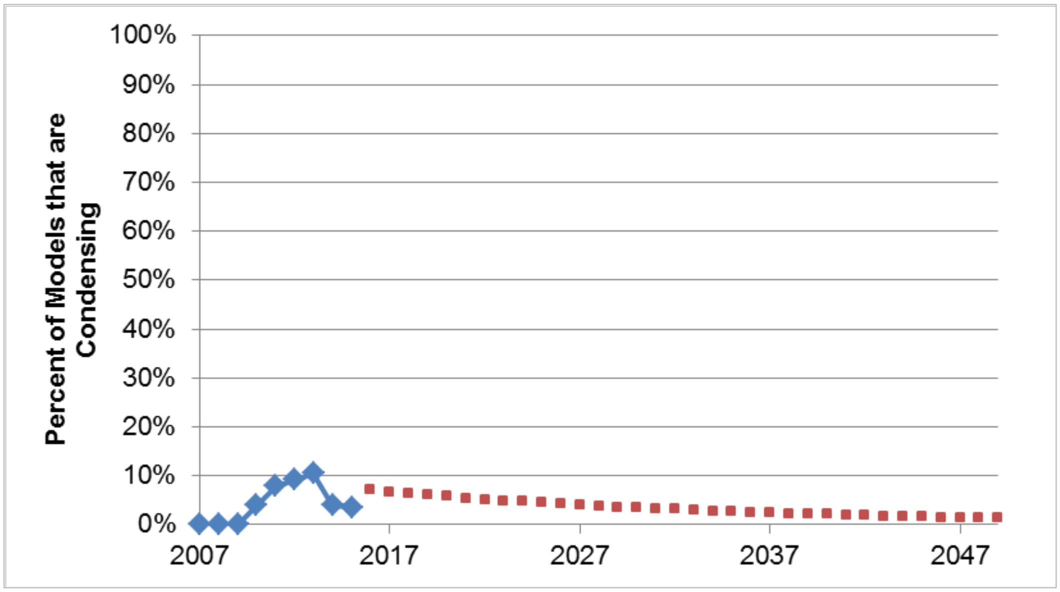

Figure 8H.3.4 Historical Data and Projection of No-New-Standards-Case Market Share for Condensing Oil-Fired Hot Water Commercial Packaged Boilers >2,500,000 Btu/h and ≤10,000,000 Btu/h

DOE assumes that the market shares of condensing steam boilers will be negligible during the period of analysis (2019–2049).

8H.4 ESTIMATE OF 2019 EFFICIENCY DISTRIBUTIONS BY EQUIPMENT CLASS AND DRAFT TYPE

DOE uses the efficiency distribution from 2011 through 2015, as well as the projections of the no-new-standards-case market share of condensing boilers from 2016 through 2019, to project the efficiency distributions in 2019. The no-new-standards case distributions of condensing gas-fired and oil-fired hot water boilers in 2019 are calculated by multiplying the market shares in 2015 with a factor that considers the increase in market share of condensing boilers from 2016 through 2019. The derivation of this factor is described in section 8H.3.1, and is different for fuel oil and gas. The non-condensing gas-fired and oil-fired hot water boilers will cover the rest of the market, with their shares kept in the same proportional relationship as the average market shares from 2009 and 2011 through 2014. For all steam boiler equipment classes and all natural draft equipment classes, DOE assumes that the no-new-standards-case efficiency distribution in 2016 was the average of the distribution from 2011 through 2015. DOE assumes that the distribution remained constant from 2016 through 2019. The calculated no-new-standards-case distribution of CPB efficiency in 2019 is summarized in Table 8H.4.1 and Table 8H.4.2. Table 8H.4.3 shows the calculated no-new-standards-case distribution of CPB efficiency in 2019, aggregating natural draft and mechanical draft CPB equipment.

Table 8H.4.1 No-New-Standards-Case Distribution of Commercial Packaged Boiler Efficiency in 2019 – Natural Draft

Efficiency	SGHW*	LGHW	SOHW	LOHW	SGST	LGST	SOST	LOST
77					72.9%	23.3%		
78					7.3%	47.3%		
79					17.9%	12.5%		
80	19.6%				1.8%	11.6%		
81	21%				-	5.3%	56.2%	45.3%
82	59.3%	72.5%	52.7%			-		
83		19%	12.7%		-		37.6%	49.5%
84	-	7.1%	13.6%	65.1%		-	3.1%	
85	-	1.4%	10.2%					5.3%
86				33.7%			3.1%	
87			8.4%					-
88			2.3%	1.2%				
89				-				
90								
91								
92								
93	-							
94		-						
95	-							
96								
97		-	-	-				
98								
99	-							

* SGHW = Small Gas-fired Hot Water; LGHW = Large Gas-fired Hot Water; SOHW = Small Oil-fired Hot Water; LOHW = Large Oil-fired Hot Water; SGST = Small Gas-fired Steam; LGST = Large Gas-fired Steam; SOST = Small Oil-fired Steam; LOST = Large Oil-fired Steam

Table 8H.4.2 No-New-Standards-Case Distribution of Commercial Packaged Boiler Efficiency in 2019 – Mechanical Draft

Efficiency	SGHW*	LGHW	SOHW	LOHW	SGST	LGST	SOST	LOST
77					-	-		
78					-	-		
79					13.6%	15.5%		
80	4.8%				44.6%	36.5%		
81	6%				29.1%	5.8%	26.5%	38.6%
82	4.9%	4.2%	27.7%			25.8%		
83		25.5%	28%		12.7%		55.3%	32.5%
84	10.8%	7.4%	7.7%	31.4%		16.4%	12.9%	
85	22.9%	23.2%	18.2%					28.2%
86				48%			5.3%	
87			11.4%					0.7%
88			3.5%	13.4%				
89				1.2%				
90								
91								
92								
93	22.6%							
94		36.6%						
95	24.8%							
96								
97		3%	3.7%	6%				

Efficiency	SGHW[*]	LGHW	SOHW	LOHW	SGST	LGST	SOST	LOST
98								
99	3.3%							

* SGHW = Small Gas-fired Hot Water; LGHW = Large Gas-fired Hot Water; SOHW = Small Oil-fired Hot Water; LOHW = Large Oil-fired Hot Water; SGST = Small Gas-fired Steam; LGST = Large Gas-fired Steam; SOST = Small Oil-fired Steam; LOST = Large Oil-fired Steam

Table 8H.4.3 No-New-Standards-Case Distribution[*] of Commercial Packaged Boiler Efficiency in 2019

Efficiency	SGHW[**]	LGHW	SOHW	LOHW	SGST	LGST	SOST	LOST
77					47%	13%		
78					7%	31%		
79					16%	13%		
80	7%				16%	21%		
81	8%				10%	5%	34%	41%
82	12%	17%	35%			11%		
83		21%	24%		4%		51%	39%
84	11%	6%	9%	44%		7%	10%	
85	22%	16%	16%					19%
86				42%			5%	
87			11%					0%†
88			3%	9%				
89				1%				
90								
91								
92								
93	19%							
94		37%						
95	19%							
96								
97		3%	3%	4%				
98								
99	3%							

* Results may not add up to 100% due to rounding

** SGHW = Small Gas-fired Hot Water; LGHW = Large Gas-fired Hot Water; SOHW = Small Oil-fired Hot Water; LOHW = Large Oil-fired Hot Water; SGST = Small Gas-fired Steam; LGST = Large Gas-fired Steam; SOST = Small Oil-fired Steam; LOST = Large Oil-fired Steam

† Result is zero due to rounding

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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 necessary inputs to calculations of 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) uses to project annual equipment shipments and presents results for commercial packaged boiler (CPB) equipment classes considered in this analysis.

The shipments model divides the shipments of commercial packaged boilers into specific sectors. 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 the 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, which is integrated into the spreadsheet for the NIA, discussed in chapter 10 of this technical support document (TSD).[a] This chapter explains how the shipments model is constructed and provides some summary output. Sections 9.2 and 9.3 describe the methodological approach.

Table 9.1.1 summarizes the abbreviations of each equipment class analyzed. The CPB shipments model considers two equipment placement channels (hereafter referred to as "channels") as follows:

New construction: a certain fraction of new buildings acquire boilers in each future year. This fraction is defined as the new construction saturation, which varies by year and by equipment class.

Existing building owners (replacements): defined as existing buildings currently having boilers. Shipments to this channel are estimated by subtracting the shipments to new construction from the aggregate shipments. This category receives shipments when existing equipment fails and is replaced. For this analysis, existing owners also include building owners switching between different boiler equipment classes, and building owners substituting existing non-boiler heating equipment with boilers. DOE considers the later sub-segment to be negligible.

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[a] The "shipment forecast" and "historical shipments" worksheets of the NIA model present the scope of this analysis and the total shipments value in units for the commercial packaged boilers in scope.

Table 9.1.1 Name Abbreviations for Equipment Classes Considered in this Analysis

Abbreviation	Full Equipment Name
SGHW	Gas-Fired Hot Water Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h
LGHW	Gas-Fired Hot Water Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h
SOHW	Oil-Fired Hot Water Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h
LOHW	Oil-Fired Hot Water Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h
SGST	Gas-Fired Steam Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h
LGST	Gas-Fired Steam Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h
SOST	Oil-Fired Steam Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h
LOST	Oil-Fired Steam Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h

9.2 SHIPMENT MODEL METHODOLOGY

In the NIA model, the individual equipment class equipment stock is 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). Equipment vintage is a factor in calculating the annual energy use, as the energy use of the CPB stock is dependent on the efficiency of the equipment for the year in which it was shipped. 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 at age a in analysis year j,
$Rem_p(j, a)$ = number of units of equipment class p at 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

$$Rem_p(j,a) = \lfloor 1 - f_p(a) \rfloor \times Stock_p(j,a).$$

Eq. 9.3

In the standards case, there is also a second term that represents the extended repair stock that has been in use for 6 years following the repair date (see section 9.4.2 for discussion of extended repair).

Shipments are directed to one of the two channels:

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

Eq. 9.4

Where:

$Rpl_p(j)$ = number of units of equipment p replaced in year j, which depends on removed units and units in demolished buildings, and
$NC_p(j)$ = number of units installed in new construction of equipment p in year j.

9.2.1 Estimation of Stocks and Shipments

For estimation of stock from the Energy Information Administration's (EIA's) Commercial Buildings Energy Consumption Survey (CBECS) data and *Annual Energy Outlook* (*AEO*) data,[1] DOE used the following equation:

$$(\text{Boiler stock})_i = \text{Commercial Building Floor Space for (Building Type)}_{i,j} \times \text{(Percent Share of Area Heated by Boilers for (Building Type)}_{i,j} \times \text{Boiler Saturation for (Building Type)}_{i,j}$$

Eq. 9.5

Where:

i = year of the estimate (1986–2012), and
j = one of the 9 main building types and the "Other" building type (for the remaining buildings) for which commercial floor space building data is available from the reports of the *AEO* series.

The key data used in the above relationship for all the CBECS years is presented in TSD appendix 9A.

For projecting gas hot water boiler shipments from the respective stock projections, DOE used the following:

$$(\text{Shipment})_i = C_0 \times \text{(Stock increase from year i-1 to year i)} + C_1 \times \text{(Stock for the year i-1)} + C_2 \times \text{(Stock for the year i-5)}$$

Eq. 9.6

Where:

i = reference year, and
C_0, C_1 and C_2 = empirical constants.

For estimating the historical shipments from stock, DOE used linear correlations between the stock of the year *i* and the shipment for the year *i*. The values of the constants and the stock to shipment correlation factors for different types of boilers are given in appendix 9A.

9.2.2 Shipments to New Construction

DOE multiplies 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. 9.7

Where:

$NC\_Starts\_com(j)$ = number of new commercial building starts in year *j*,
$NC\_Sat\_com_p(j)$ = new commercial building 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 housing saturation for equipment class *p* and year *j*.

9.2.3 Replacement Shipments

Because the shipments forecast (discussed in more detail in section 9.3.1) incorporates both boiler replacements and trends in equipment class switching, the total number of units replaced in any given year is equal to the forecasted number of units shipped minus the shipments to new construction for that year.

9.3 DATA INPUTS AND SUPPORTING CALCULATIONS

9.3.1 Historical and Projected Shipments

In its shipments analysis, DOE developed shipment projections for commercial packaged boilers and, in turn, calculated equipment stock over the course of the analysis period. DOE used the shipments projection and the equipment stock to calculate the national impacts of potential amended energy conservation standards on energy use, NPV, and future manufacturer cash flows. DOE develops shipment projections based on estimated historical shipment and an analysis of key market drivers for each kind of equipment.

DOE estimated historical shipments in its NOPR analysis from stock estimates based on the CBECS data series from 1979 to 2012. Since no CBECS survey was conducted before 1979, DOE used the trends in historical shipment data for residential boilers to estimate the historical shipments for the 1960–1978 time period. For estimation of stocks of gas and oil boilers, DOE used the data on growth of commercial building floor space for nine main building types and one residual “Other” type from EIA’s *AEO* reports, percent floor space heated by boilers data from CBECS for these building types, and estimated saturations of boilers in these building types. From these stock estimates, DOE derived the shipments of gas and oil boilers using separate correlations between stock and shipment for gas and oil boilers. As noted in TSD chapter 7, to obtain individual equipment class shipments from the aggregate values, DOE used the steam-to-hot water and oil-to-gas shift trends that DOE derived from the Environmental Protection Agency (EPA) database for space heating boilers.[2] The equipment class shipments were further disaggregated between shipments to new construction and replacement/switch shipments.

Further details about shipments are described in appendix 9A. Figure 9.3.1 summarizes the historical shipments data that DOE has assembled.

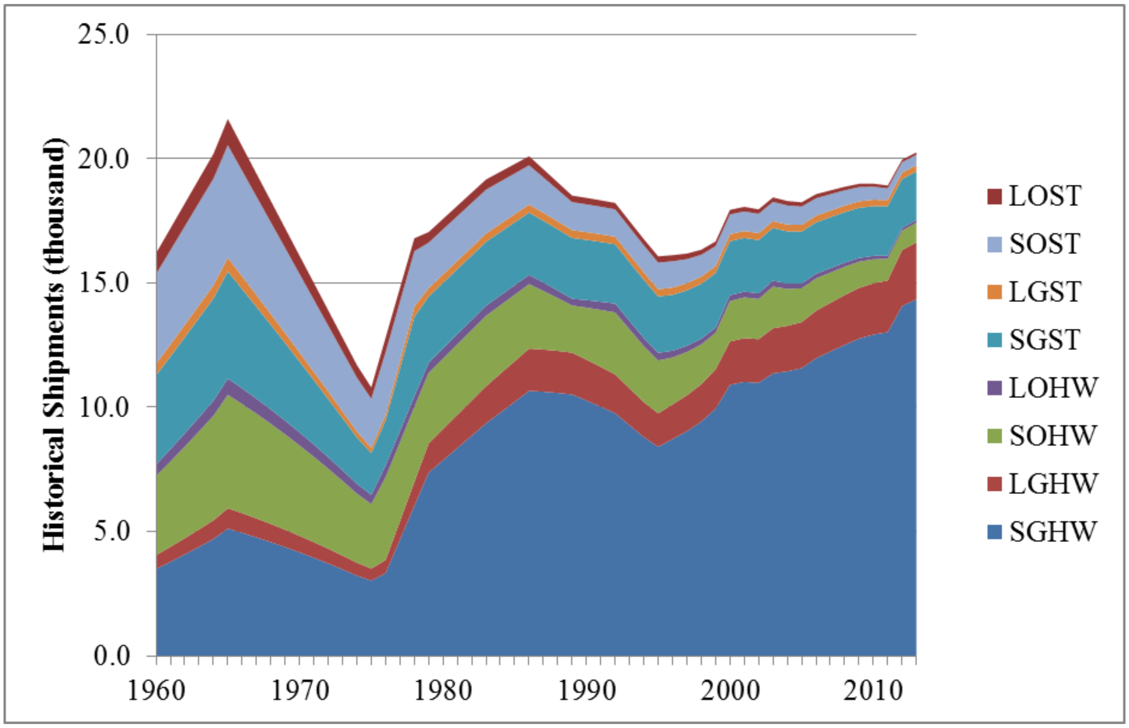

Figure 9.3.1 Historical Shipments of Commercial Packaged Boilers

A fraction of commercial packaged boilers are shipped to residential buildings; therefore, DOE considered any future shipments of commercial packaged boilers to residential buildings in this analysis. DOE used CBECS 2003, CBECS 2012, and the 2009 Residential Energy Consumption Survey (RECS) to determine the number of commercial packaged boilers in commercial and residential applications. DOE estimated that commercial packaged boilers shipped to residential buildings account for 15 percent of the total historical shipments of commercial packaged boilers. Details of the methodology to determine the fraction of commercial packaged boilers shipped to residential buildings are in appendix 9A.

9.3.2 Shipments to New Construction

To project equipment class shipments for new construction, DOE relied on building stock and floor space data obtained from the EIA's *AEO2015* report.[1] DOE assumes that CPB equipment is used in both commercial and residential multi-family dwellings. DOE estimated a total saturation rate for each equipment class based on prior CBECS data and size distribution of space heating boilers in the EPA database[2] noted in chapter 7. For estimation of saturation rates in the new construction, DOE compared the area heated by boilers in commercial buildings for two different 9-year periods (*i.e.*, 2000–2012 covered in CBECS 2012 and 1995–2003 covered in CBECS 2003). The new construction saturation rates were derived from the calculated saturation rate averaged over the 1995–2003 period and adjusted for the trends in the area heated by boilers, as well as oil-to-gas shift trends in CBECS 2012. The new construction saturation rates were projected into the future considering currently observed trends from CBECS 2012 and *AEO2015* (for oil-to-gas shifts). For residential multi-family units, DOE used RECS 2009 data and considered multi-family buildings constructed in the 9-year period from 2001 to 2009 as new construction for calculating the new construction saturation. DOE assumed that the new construction saturation trend in multi-family buildings for the period of analysis is identical to that for commercial buildings. DOE applied these new construction saturation rates to new building additions in each year over the analysis period (2019–2048), yielding shipments to new buildings.

Table 9.3.1 shows the projected saturations of commercial packaged boilers by building sector in year 2019.

Table 9.3.1 Saturation of Commercial Packaged Boilers in New Construction in 2019

Equipment Class	**Residential Buildings** ***thousand boilers/million HH***	**Commercial Buildings** ***thousand boilers/million SF***
Small Gas-Fired Hot Water Boiler	0.0783	0.0020
Large Gas-Fired Hot Water Boiler	0.0162	0.0004
Small Oil-Fired Hot Water Boiler	0.0096	0.0002
Large Oil-Fired Hot Water Boiler	0.0000	0.0000

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 boilers specifically; however, the data needed are not sufficient to perform a robust estimation. Hence, DOE adopts the same assumptions used for commercial unitary air conditioners and assumes that the purchase price elasticity is similar between the two commercial equipment types.

The purchase price elasticity is defined as the change in the percentage of consumers acquiring a boiler divided by a change in the *relative price* (defined in section 9.4.1) for that product. This elasticity, along with information obtained from the life-cycle cost (LCC) and payback period (PBP) analysis on the change in purchase price and operating costs at different ELs, are used in the shipments model to estimate the change in shipments under standards at different ELs.

9.4.1 Purchase Price Elasticity

Long-term price elasticity is a measure of how sensitive commercial packaged boiler shipments are to potential increases in price. Elasticity is defined as the percentage change in quantity purchased divided by the percentage change in price (or some other factor that influences purchase behavior). The basic formula DOE used to determine price elasticity is the following:

$$e = \frac{\left(\frac{dQ}{Q}\right)}{\left(\frac{dP}{P}\right)}$$

Eq. 9.8

Where:

dQ/Q = a small percentage change in quantity purchased (Q), and
dP/P = a small percentage change in price.

If the elasticity is constant, then the quantity purchased can be written in terms of the price, a reference price, a reference quantity, and the elasticity. Specifically, the following equation holds true when the elasticity is constant.

$$Q(P) = Q_0 \times \left(\frac{P - P_0}{P_0}\right) \times e + Q_0$$

Eq. 9.9

Where:

$Q(P)$ = the quantity purchased as a function of price P,
Q_0 = a reference quantity at a reference price P_0, and
e = the elasticity, which is almost always negative or zero (*i.e.*, non-positive) with respect to price.

For the shipments forecast, the reference price and the reference quantity are the price and quantity from the no-new-standards case. DOE used price elasticity to adjust forecasts of no-new-standards-case shipments for potential price increases due to a standard. A change in price due to a standard has an impact on the quantity purchased, *Q(P)*, as described by Eq. 9.9.

No historical purchase data were available for commercial packaged boilers. Because commercial packaged boilers are used primarily in commercial and industrial applications, as are unitary air conditioners, DOE used sales and price data for air conditioners to estimate price elasticity for commercial packaged boilers.[3] The resulting value of elasticity was -0.02. DOE assigned -0.02 as the reference scenario for commercial packaged boilers and incremented the elasticity to -0.20 to implement a high-estimate sensitivity to price change. The low-estimate scenario assumes zero elasticity, or no impact on purchase decisions from a price change.

Because projections of shipments and national impacts attributable to standards are calculated for a lengthy time period, DOE considers how the relative price elasticity is affected after a new standard takes effect. DOE considers the relative price elasticity, described above, to be a short-term value. DOE is not able to identify sources specific to commercial goods, such as HVAC equipment, to indicate how short-run and long-run price elasticities differ. Therefore, to estimate how the relative price elasticity changes over time, DOE relies on a study pertaining to automobiles.[4] This study shows that the automobile price elasticity of demand changes in the years following a purchase price change, becoming smaller (more inelastic) until it reaches a terminal value around the twentieth year after the price change. Table 9.4.1 shows the relative change in the price elasticity of demand for automobiles over time. DOE develops a time series of relative price elasticities based on the relative change in the automobile price elasticity of demand. For years not shown in Table 9.4.1, DOE performs a linear interpolation to obtain the relative price elasticity.

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

	Years Following Price Change					
	1	2	3	5	10	20
Relative Change in Elasticity to 1st year	1.00	0.78	0.63	0.46	0.35	0.33
Relative Price Elasticity	-0.020	-0.016	-0.013	-0.009	-0.007	-0.007

9.4.2 Efficiency and Discount Rates

While many studies have estimated the impact of residential appliance efficiency on consumers' choice of appliance, fewer studies have examined this impact within the commercial sector. Typically, this impact is summarized by the implicit discount rate; that is, the rate that consumers use to compare future savings in equipment operating costs against a higher initial purchase price of that equipment. One early and much-cited study concludes that consumers use a 20-percent implicit discount rate when purchasing room air conditioners.[5] Another survey of several studies of different appliances suggests that the consumer implicit discount rate has a broad range and averages about 37 percent.[6] A more recent study found that the mean discount rate for space heating equipment was 17 percent; this study developed a statistical distribution of the discount rate.[7] From this distribution, DOE elected to use a 56.7-percent implicit discount rate to reflect commercial consumer price sensitivity.

9.4.3 Impact from Increase in Relative Price

When a boiler fails, it is removed from the stock, replaced, or is repaired for extended use. 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 $Rem_p(j)$. 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. 9.10

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. 9.11

The number of demolished buildings is calculated by

$$D(j) = H\_Stock(j-1) + H\_Starts(j) - H\_Stock(j)$$

Eq. 9.12

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.

Based on the assumption that the price elasticity for commercial unitary air conditioners is similar to commercial packaged boilers, DOE is able to apply the relative price elasticity to estimate the impact of the increase in relative price from a particular standard level for commercial packaged boilers. The impact, as shown in the equation below, is expressed as a percentage drop in market share for each year, dMS^p_j.

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

Eq. 9.13

Where:

dMS^p_j = percentage market share drop for class p, year j,
$RP\_std_p(j)$= relative price in the standards case for equipment class p, year j,
$RP_p(j)$= relative price in the no-new-standards (base) case for equipment class p, year j, and
$e_{RP}(j)$ = relative price elasticity in year j.

In Eq. 9.13, DOE uses real prices, as opposed to nominal, and an implicit discount rate of 56.7 percent to estimate the present value of operating costs.

To model the impact of the increase in relative price from a particular standard level on boiler shipments, DOE assumes that the affected commercial consumers would repair their equipment rather than replace it, extending the life of the equipment by six years. When the extended repaired units fail after six more years, they will be replaced with new ones.

The model calculates the relative percentage market drop, dMS^p_j, due to the equipment price increase from a particular standard level. The extended repair is only applicable to failed equipment that was purchased before 2019.

The number of failed boilers that will be repaired instead of being replaced is calculated as follows:

$$XR_j = \left(\sum_a Rem(j,a) - Dem(j)\right) \times dMS_i^p$$

Eq. 9.14

Where:

dMS^p_j = percentage market share drop for class p, year j,
a = age of equipment,
j = year,
$Rem(j,a)$ = retiring units in year j of age a,
XR_j = extended repair units, year j, for $(j - a) < 2020$, and
$Dem\ (j)$ = number of units retired with demolished buildings in analysis year j.

Thus, the number of replacement units is calculated as follows:

$$Rpl(j) = \sum_a (Ship\ (j) - NC\ (j)) - XR_i + XR_{j-6}$$

Eq. 9.15

Where:

$Rpl(j)$ = number of replacement units in year j,
a = age of equipment,
j = year,
$Ship(j)$ = number of units shipped in year j,
$NC(j)$ = number of units installed in new construction in year j, *and*
XR_j = extended repair units, year j.

9.5 RESULTS

Figure 9.5.1 shows the historic and projected no-new-standards case shipments of commercial packaged boilers by equipment class.

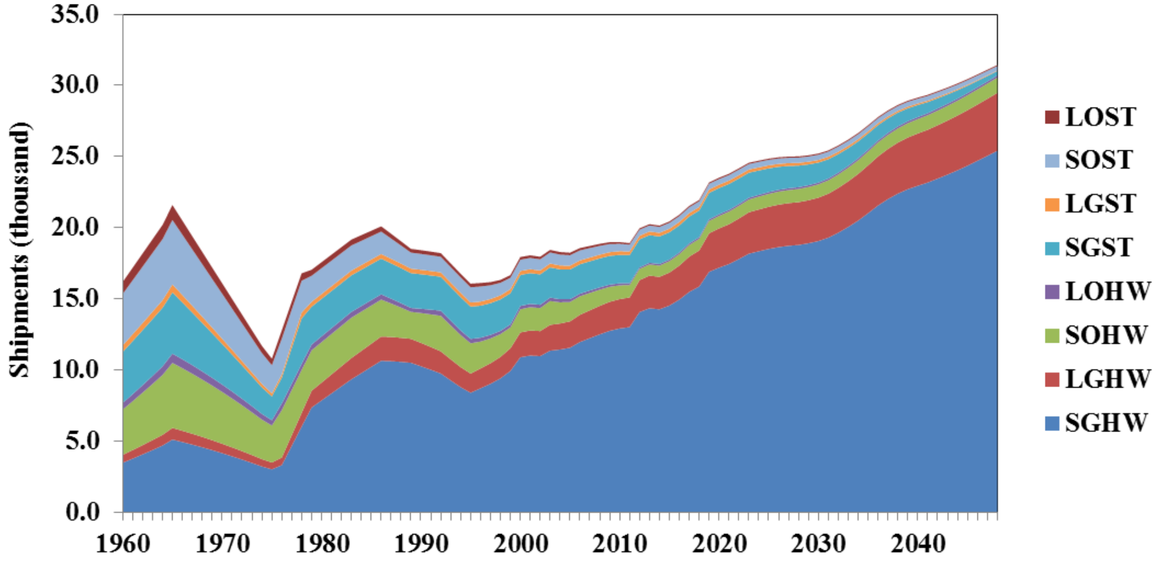

Figure 9.5.1 Historic and Projected Base Case Shipments Commercial Packaged Boilers by Equipment Class

Appendix 9A contains shipment projections in the no-new-standards case and under each standards case for the CPB equipment classes.

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APPENDIX 9A. ADDITIONAL SHIPMENTS DATA

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APPENDIX 9A. ADDITIONAL SHIPMENTS DATA

9A.1 INTRODUCTION

To calculate historical shipments of commercial packaged boilers (CPBs), the U.S. Department of Energy (DOE) used the Commercial Buildings Energy Consumption Survey (CBECS) data series from 1979 through 2012. Using these data, DOE first estimated the CPB stock in commercial buildings from 1979 through 2012 for gas-fired and oil-fired boilers separately and subsequently used correlations between shipments to stock for estimating the historical shipments for this period. Because 1979 is when the first CBECS was conducted, DOE used historical shipments of residential boilers from 1960 through 1978 to develop the shipment trend characteristics for oil-fired and gas-fired boilers over this period, and used the observed trend to estimate the CPB shipments from 1960 through 1978. The following sections describe the data sources and DOE's methodology for deriving historical shipments of commercial packaged boilers.

9A.2 HISTORICAL SHIPMENTS DATA AVAILABILITY (COMMERCIAL BOILERS)

DOE could not obtain detailed historical shipment time series data for commercial packaged boilers and found only limited historical shipments data for three randomly dispersed years, *i.e.*, 1989, 1993, and 2007, from secondary sources (see Table 9A.2.1).

Table 9A.2.1 Commercial Packaged Boiler Shipment Data for 1989, 1993, and 2007

Fuel Type	1989*	1993**	2007†
Gas	14,800	10,295	NA
Oil	NA	9,345	NA
Total	NA	19,640	36,000

* *Commercial Gas Space Heating Equipment: Opportunities to Increase Energy Efficiency*. 1992. Centre for Energy and Environment, Minneapolis. (Data reported by Gas Research Institute from Gas Appliance Manufacturers Association (GAMA).
** *Current and Projected Commercial Space Heating, Space Cooling, and Water Heating Equipment Use in the United States: Update 1995*. January 1996. E. Richman. Prepared for DOE U.S. Department of Energy under Contract DE-AC06-76RLO 1830, Pacific Northwest National Laboratory, Richland, WA. Source data: Hydronic Institute.
† Reported in the Technical Support Document, Chapter 2 of 2009 commercial packaged boiler final rule at 74 FR 36312 (July 22, 2009). Data Source: The Air Conditioning, Heating, and Refrigeration Institute (AHRI), formed in 2008 by a merger of the Air-Conditioning and Refrigeration Institute (ARI) and GAMA.

In 1999, Pacific Northwest National Laboratory (PNNL) received historical shipment data from the Gas Appliance Manufacturers Association (GAMA) through DOE and concluded that the data could not be disaggregated for subsequent use.[a] However, PNNL compared the shipment data from GAMA in 1999 and from the Hydronic Institute (HI) in 1996, which included projected shipments from 1994 through 2000. PNNL noted that the high growth rates in the shipment forecast by HI in 1996 did not materialize and that shipments stagnated from 1994

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[a] *Screening Analysis for EPACT-Covered Commercial HVAC and Water-Heating Equipment*. April 2000. S.Somasundaram et al. Prepared for the U.S. Department of Energy under Contract DE-AC06-76RLO 1830, Pacific Northwest National Laboratory, Richland, WA. Source data: Hydronic Institute and GAMA

through 2000. The Centre for Energy and Environment study[b] of 1992 noted that combined shipments of commercial and residential boilers declined by 19 percent from 1988 through 1991. Details of PNNL's estimated aggregate annual CPB shipment at 20,592 units for 1994–2000 are presented in Table 9A.2.2. The most recent data reported in Table 9A.2.1 was from AHRI for the year 2007. For the commercial buildings, the growth in floor space from 2000 through 2007 is computed at 12.7 percent (data from the Energy Information Administration's (EIA's) *Annual Energy Outlook* (*AEO*) reports). Applying this growth rate to the shipment of 20,592 units per year for 2000, the 2007 shipment is estimated at 23,207 units. The reported shipment of 36,000 for the year 2000 implies a growth of about 75 percent and appears inconsistent with other shipment data. Further breakdown of the 2007 shipment across fuel input rate classes, fuel types, and heating mediums was not provided, and hence these data could not be validated and checked for internal consistency.

Table 9A.2.2 Estimated Annual Shipments for Boilers (1994–2000)

Equipment Fuel Input Rate *kBtu/h*	**Typical Fuel Input Rate *kBtu/h***	**Gas-Fired**		**Oil-Fired**	
		Hot Water	**Steam**	**Hot Water**	**Steam**
300–400	400	2,821	1,268	2,389	987
400–1,000	800	3,077	1,731	2,641	1,213
1,000–2,500	1,500	540	424	1,337	850
>2,500	3,000	178	135	627	374
	TOTALS	**6,616**	**3,558**	**6,994**	**3,424**
TOTAL SHIPMENTS		**20,592**			

9A.3 ESTIMATION OF HISTORICAL BOILER INVENTORY

DOE estimated the CPB inventory directly in 1979 and 1983, using the corresponding CBECS survey results from those years. Surveys for these years included responses to the number of boilers in the survey questionnaire, and thus DOE estimated the boiler inventory directly. Details of the boiler inventory for these 2 years are in Table 9A.3.1.

Table 9A.3.1 Estimated Commercial Package Boiler Inventory for 1979 and 1983

CBECS Year	**Total**	**Gas-Fired**		**Oil-Fired**	
		Hot Water	**Steam**	**Hot Water**	**Steam**
1979	409,458	172,831	87,718	83,091	65,818
1983	419,753	184,470	86,896	83,047	65,251

Since the individual capacities of the boilers were not available in the CBECS data, DOE used the sizing methodology described in the TSD chapter 7 to identify the boilers with capacities that exceeded the DOE threshold size of 300,000 Btu/h and thereby qualified to be counted as a commercial packaged boiler as defined by DOE.

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[b] Hewett, M. J. and M. S. Lobenstein. *Commercial Gas Space Heating Equipment: Opportunities to Increase Energy Efficiency*. 1992. Centre for Energy and Environment: Minneapolis, MN. Report No. CEUE/TR91-3-CM. (Data reported by Gas Research Institute from GAMA).

For all the subsequent years, DOE estimated the boiler inventory using the following:

$$(\textit{Boiler stock})_i = \textit{Commercial Building Floor Space for } (\textit{Building Type})_{i,j} \times (\textit{Percent Share of Area Heated by Boilers for } (\textit{Building Type})_{i,j} \times \textit{Boiler Saturation for } (\textit{Building Type})_{i,j} \qquad \textbf{Eq. 9A.1}$$

Where:

i = year of the estimate (1986–2012), and
j = one of the nine main building types and the "Other" building type (for the remaining buildings) for which commercial floor space building data are available from the reports of the *AEO* series.

The key data used in the above relationship for all CBECS years are shown in Table 9A.3.2, Table 9A.3.3, and Table 9A.3.4.

Table 9A.3.2 Commercial Building Floorspace (billions square feet)

CBECS Year	Building Type									
	Assembly	**Education**	**Food Sales**	**Food Service**	**Health Care**	**Lodging**	**Office**	**Mercantile/ Service**	**Warehouse**	**Other**
1986	6.47	7.54	0.59	1.24	1.48	3.25	9.95	11.75	7.62	4.19
1989	6.57	7.66	0.61	1.28	1.54	3.37	10.25	12.10	7.92	4.38
1992	6.67	7.77	0.63	1.33	1.60	3.50	10.61	12.47	8.23	4.57
1995	6.77	7.89	0.65	1.37	1.66	3.63	10.98	12.85	8.56	4.77
1999	7.05	8.28	0.69	1.45	1.78	3.94	11.54	13.64	9.22	5.21
2003	8.36	9.59	1.08	2.01	2.01	4.95	14.01	15.24	11.62	4.78
2012	8.36	11.89	1.42	1.88	2.32	6.05	14.47	17.82	11.61	6.52

Table 9A.3.3 Percent Share of Area Heated by Boilers for Commercial Building Types

CBECS Year	Building Type									
	Assembly	**Education**	**Food Sales**	**Food Service**	**Health Care**	**Lodging**	**Office**	**Mercantile/ Service**	**Warehouse**	**Other**
1986	43%	64%	27%	17%	68%	37%	37%	20%	15%	26%
1989	32%	65%	22%	27%	61%	41%	34%	18%	16%	24%
1992	40%	64%	9%	23%	63%	31%	36%	17%	14%	19%
1995	31%	62%	7%	7%	62%	36%	32%	15%	9%	25%
1999	31%	58%	11%	11%	66%	40%	34%	13%	13%	24%
2003	33%	52%	5%	20%	78%	54%	33%	12%	10%	25%
2012	31%	55%	5%	8%	73%	36%	29%	10%	6%	17%

Table 9A.3.4 Boiler Saturation by Building Types (Number per million square feet of Buildings with Boilers)

CBECS Year	Building Type									
	Assem-bly	Edu-cation	Food Sales	Food Service	Health Care	Lodg-ing	Office	Mer-cantile/ Service	Ware-house	Other
1986	21.4	19.6	52.9	9.4	8.1	11.4	20.0	16.5	11.0	19.7
1989	23.3	20.0	51.0	9.6	7.9	11.8	19.8	18.4	12.4	19.8
1992	20.7	18.5	49.2	8.9	7.5	10.8	18.8	16.1	10.8	18.6
1995	19.4	17.7	47.4	8.5	7.3	10.3	18.0	15.0	10.0	17.7
1999	22.1	18.3	45.2	8.8	7.0	11.0	17.8	17.6	11.9	18.0
2003	21.3	17.5	43.1	8.5	6.7	10.5	17.0	16.9	11.5	17.2
2012	25.2	19.1	43.1	9.3	6.8	11.8	17.7	20.5	14.1	18.4

Disaggregated commercial building floor space data by the building types shown in Table 9A.3.2 were extracted from the *AEO* table data (Table 5: Commercial Sector Indicators and Consumption).[c] DOE used previous annual releases of the *AEO* reports to populate the table until *AEO1999*, which had the relevant data up to 1997. DOE estimated these data to develop the time series for the commercial building floor space from 1996 to 1979 using the annual average building type growth rates for 2013–2040 available in *AEO2015*.

The percent share of area heated by boilers in commercial building floor space for various building types shown in Table 9A.3.3 is computed directly from the CBECS results for the respective years. For the intervening years between two consecutive CBECS, DOE estimated this parameter using linear interpolation. The percent area shares for four major building types are shown in Figure 9A.3.1.

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[c] www.eia.gov/forecasts/aeo/pdf/0383(2015).pdf

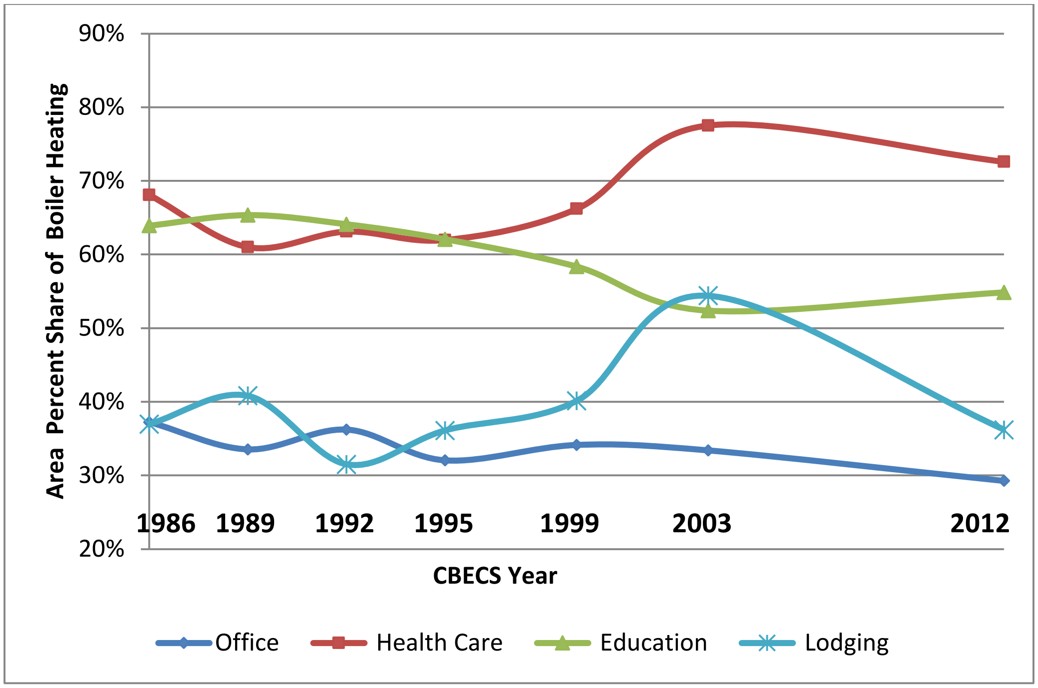

Figure 9A.3.1 Percent Share of Area Heated by Boilers for Various Commercial Building Types

The boiler saturation data by building types (number of boilers per million square feet of floor space in buildings with boilers) shown in Table 9A.3.4 was directly computed for only three CBECS years, *i.e.*, 1979, 1983, and 2003. From these values, DOE estimated that the boiler saturations have globally declined at about 1.2 percent per year in the 1986–2003 period. DOE used the directly computed saturation values of 2003 to estimate the total saturations from 2002 to 1986. DOE could not directly compute the saturations for 2012 because the required public use CBECS microdata file was not available before the publication of this analysis for the notice of proposed rulemaking (NOPR) for commercial packaged boilers and is not expected to be released until April 2016. Consequently, DOE assumed that the total saturations did not change between 2003 and 2012. To disaggregate the total saturation between oil-fired and gas-fired boilers, DOE estimated the oil-fired boilers saturation using the saturations estimated from CBECS 2003 and applying a decline factor for oil-fired boilers using share of heated area between gas-fired and oil-fired boilers from the CBECS data for the corresponding year.

The stock of gas-fired and oil-fired boilers in service in commercial buildings for 1979–2012 is shown in Figure 9A.3.2.

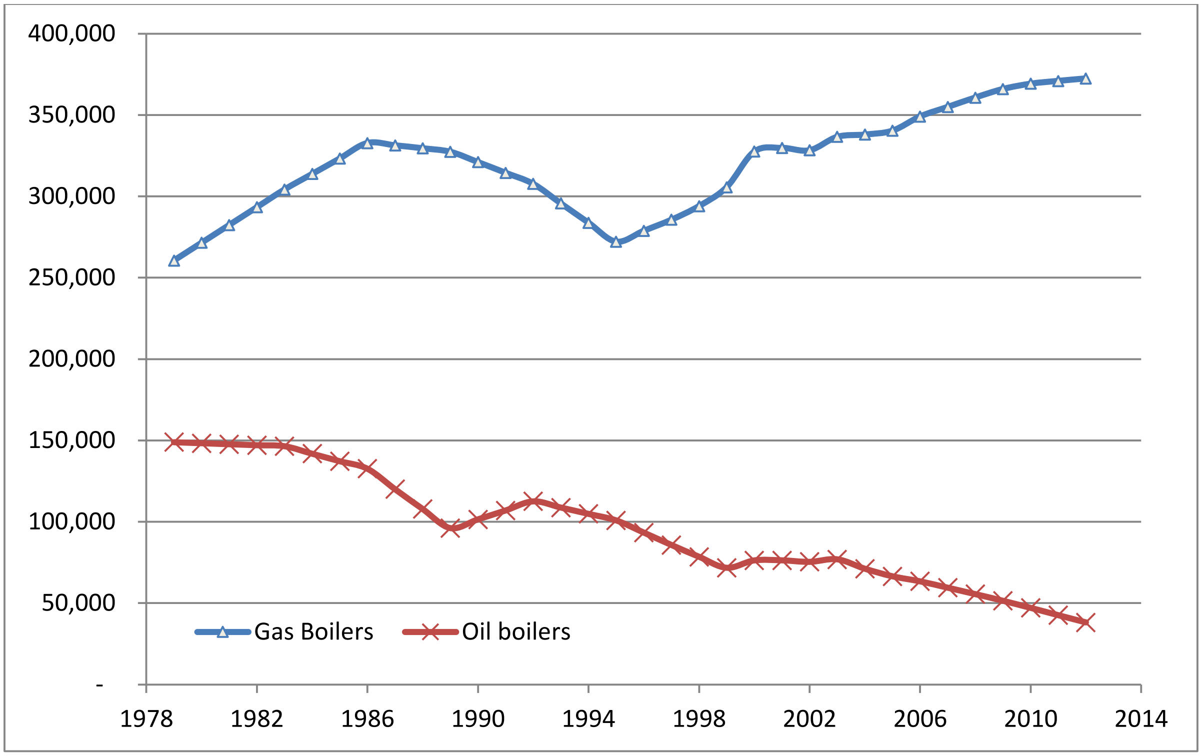

Figure 9A.3.2 Historical Inventory: Gas-Fired and Oil-Fired Boilers

DOE further disaggregated the historical inventory of gas-fired and oil-fired boilers by the heating medium, *i.e.*, hot water and steam. Since there are no relevant data in CBECS, DOE used data from an EPA database[1] that included the heating medium and vintage information of over 120,000 space heating boilers to estimate the trends in the share of steam and hot water boilers. DOE estimated the shares in some benchmark years and used linear interpolation to estimate the shares for the intervening years. DOE estimated that for the gas-fired boilers, the share of steam boilers was 33.3 percent in 1980, declining to 30 percent by 1990 and finally to 25 percent by 2000. From 1980 onwards, there was serious decline in the population of oil-fired boilers. DOE assumed that the replacement shipments mostly tracked the original boiler configuration, and no switching from steam to hot water took place, as was the case for the gas-fired boilers. Consequently for the oil-fired boilers, DOE estimated that the starting share of steam boilers was 44 percent in 1980, which declined to 40 percent in 2000 and remained constant thereafter. The hot water and steam splits for the gas-fired and oil-fired boiler inventory are shown in Figure 9A.3.3and Figure 9A.3.4, respectively.

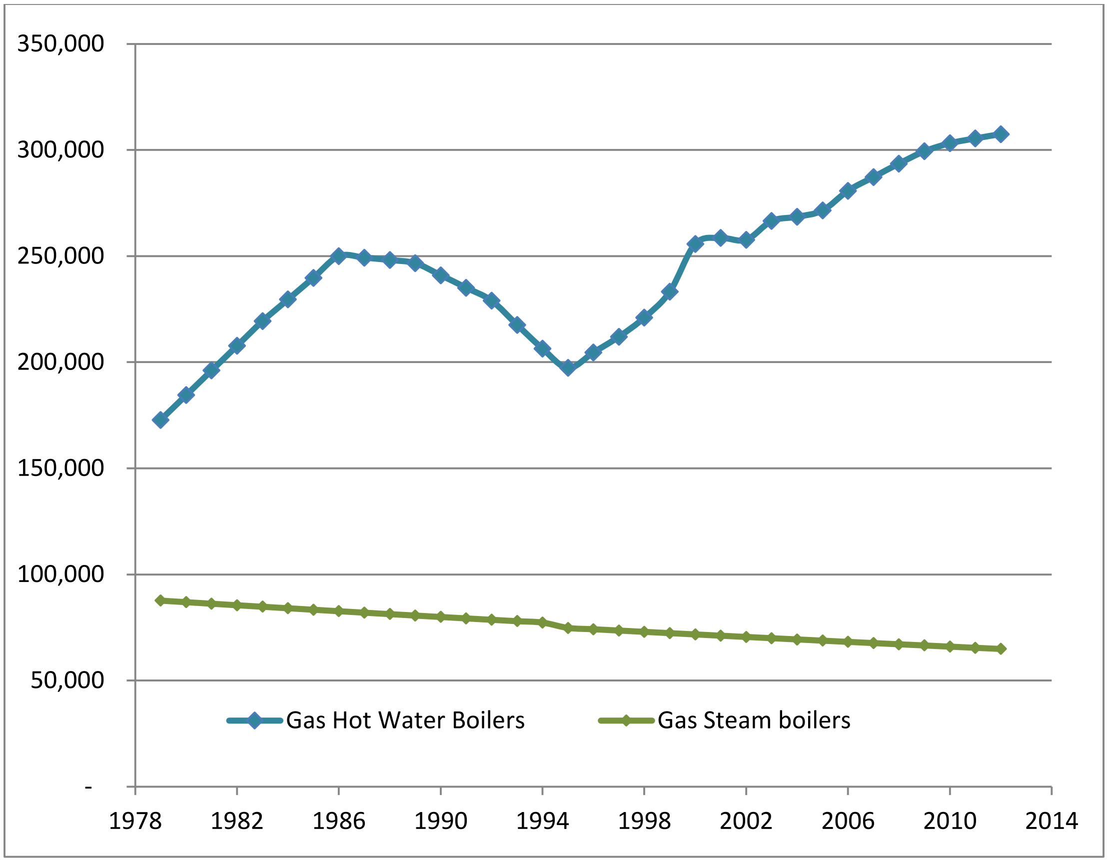

Figure 9A.3.3 Historical Inventory: Hot Water and Steam Gas-Fired Boilers

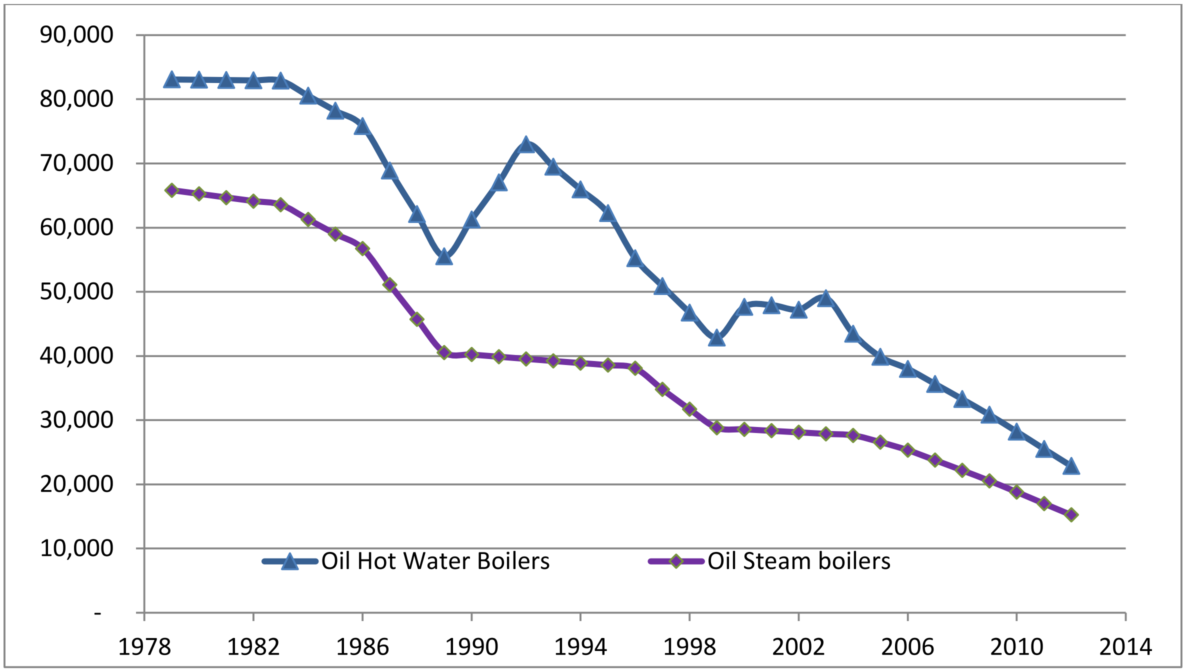

Figure 9A.3.4 Historical Inventory: Hot Water and Steam Oil-Fired Boilers

9A.4 ESTIMATED HISTORICAL SHIPMENTS OF COMMERCIAL BOILERS (1979–2012)

DOE derived the historical boiler shipments from the boiler inventory data using stock to shipment factors estimated on the basis of positive and negative growth trends observed in the historical inventories and boiler life time parameters discussed in TSD appendix 8F. For the growth segments, the shipments to stock factors are higher than the corresponding factors for declining segments (steam and oil-fired boilers) since the shipments include replacement shipments and shipments to “new construction.” For the gas-fired hot water boilers, this ratio was estimated at 4.3 percent of the reference year’s stock and for oil-fired hot water boilers, the same is 3.4 percent of the stock. For the steam boilers (both oil- and gas-fired), the ratio was 2.98 percent of stock, accounting only for partial replacement of the retired and failed stock. Based on the ratio of relative sample weights for sample buildings in CBECS 2003[2] and Residential Energy Consumption Survey (RECS) 2009[3] (discussed in chapter 7 of the TSD), DOE provided for an additional 15 percent (of the commercial shipments) to account for the multi-family buildings in the residential sector. The estimated aggregate historical shipments for 1979 and 2012 are shown in Table 9A.4.1.

Table 9A.4.1 Historical Shipments of Commercial Boilers (1979–2012)

Year	Gas-Fired		Oil-Fired		Total
	Hot Water	Steam	Hot Water	Steam	
1979	7,432	2,610	2,825	1,959	14,826
1980	7,932	2,588	2,824	1,942	15,286
1981	8,432	2,567	2,822	1,925	15,746
1982	8,932	2,545	2,820	1,908	16,206
1983	9,432	2,524	2,819	1,891	16,666
1984	9,872	2,503	2,739	1,823	16,937
1985	10,311	2,482	2,659	1,756	17,208
1986	10,750	2,461	2,579	1,689	17,479
1987	10,718	2,441	2,342	1,521	17,022
1988	10,670	2,421	2,112	1,361	16,563
1989	10,606	2,400	1,889	1,207	16,102
1990	10,363	2,380	2,083	1,197	16,023
1991	10,109	2,360	2,280	1,187	15,937
1992	9,845	2,341	2,481	1,177	15,844
1993	9,357	2,321	2,364	1,167	15,209
1994	8,876	2,302	2,242	1,157	14,577
1995	8,483	2,227	2,118	1,148	13,975
1996	8,797	2,208	1,879	1,133	14,018
1997	9,116	2,190	1,732	1,036	14,073
1998	9,503	2,171	1,590	943	14,208
1999	10,028	2,153	1,458	858	14,497
2000	10,996	2,135	1,620	851	15,602
2001	11,117	2,118	1,630	844	15,708
2002	11,080	2,100	1,606	836	15,622
2003	11,460	2,082	1,667	830	16,039
2004	11,546	2,065	1,479	823	15,912
2005	11,674	2,048	1,356	791	15,868
2006	12,074	2,031	1,292	754	16,151
2007	12,350	2,014	1,213	708	16,284
2008	12,623	1,997	1,132	660	16,413
2009	12,872	1,980	1,049	612	16,513
2010	13,035	1,964	960	560	16,519
2011	13,133	1,947	868	506	16,455
2012	14,195	1,931	777	454	17,358

9A.5 HISTORICAL SHIPMENTS OF COMMERCIAL BOILERS (1960–1978)

DOE used historical shipments data for residential boilers from 1960 through 2000 to develop the trends in relative annual shipments of both oil-fired and gas-fired commercial packaged boilers and used these trends to estimate the shipments from 1978 through 1960. From the adjusted residential boiler shipment data,[d] it was noted that the residential boiler shipments peaked in 1965, rapidly growing from 1960 by 33 percent, and then subsequently declining by 50 percent by 1975. The share of oil-fired and gas-fired boilers remained steady at 50 percent each for this period until 1976, after which the share of oil-fired boilers rapidly declined. DOE

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[d] Energy Conservation Standards for Commercial Packaged Boilers, Preliminary Analysis. November 2014. Technical Support document, Appendix 9-B, Table 9-B.5.1.

used the trends observed from the EPA boiler database for deriving the splits between steam and hot water boilers.

Table 9A.5.1 Historical Commercial Boiler Shipment (1960–1978)

Year	Gas- Fired		Oil-Fired		Total
	Hot Water	Steam	Hot Water	Steam	
1960	4,050	4,050	3,645	4,455	16,200
1961	4,386	4,214	3,927	4,673	17,200
1962	4,732	4,368	4,216	4,884	18,200
1963	5,088	4,512	4,512	5,088	19,200
1964	5,454	4,646	4,814	5,286	20,200
1965	5,940	4,860	5,220	5,580	21,600
1966	5,740	4,510	5,023	5,228	20,500
1967	5,529	4,171	4,818	4,882	19,400
1968	5,307	3,843	4,606	4,545	18,300
1969	5,074	3,526	4,386	4,214	17,200
1970	4,830	3,220	4,159	3,891	16,100
1971	4,575	2,925	3,925	3,575	15,000
1972	4,309	2,641	3,684	3,267	13,900
1973	4,032	2,368	3,435	2,965	12,800
1974	3,744	2,106	3,179	2,672	11,700
1975	3,510	1,890	2,970	2,430	10,800
1976	3,855	2,045	3,809	3,091	12,800
1977	5,418	2,833	3,629	2,921	14,800
1978	6,996	3,604	3,447	2,753	16,800

9A.6 PROJECTED SHIPMENTS OF COMMERCIAL PACKAGED BOILERS

To develop projected shipments of commercial packaged boilers, DOE used an approach similar to the approach used to develop the historical boiler shipments, *i.e.*, first projecting the boiler stock and subsequently using stock-to-shipment correlations to estimate future shipments. Because only partial data were available for CBECS 2012, DOE could compute only the share of area heated by boilers in 2012, but not the 2012 boiler saturations. For the projected commercial building floor space, DOE used the data from *AEO2015* tables,[c] which included projections through 2040. For 2040 through 2048, DOE used the average annual growth rates for 2010–2035 available in the *AEO2015* table to project the yearly floor space for the later years. In absence of a clear observed trend, DOE held the shares of area heated by boilers constant from 2012 through 2048. The total saturations were also assumed unchanged from 2003 through 2048. From the *AEO2015* fuel use projections in commercial buildings, DOE estimated that the stock of oil-fired boilers would be declining by about 0.6 percent per year and incorporated this shift in the projections from 2013. From the trends in the EPA boiler database, DOE projected that the share of steam in the stock of gas-fired boilers would decline from 25 percent in 2000 to 16 percent in 2019, eventually falling to 2.5 percent by 2047. For the oil-fired boilers, DOE held the share of steam unchanged at 40 percent. The projected stock of gas-fired and oil-fired boilers for the years 2019–2048 is shown in Figure 9A.6.1.

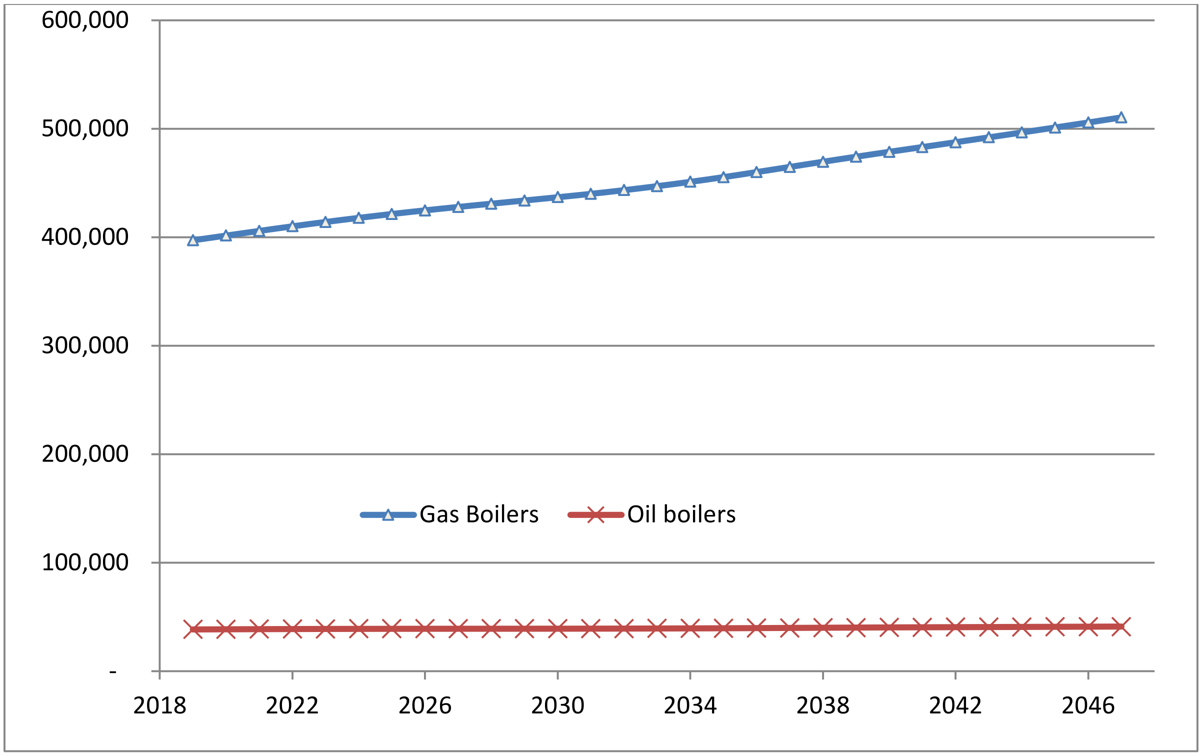

Figure 9A.6.1 Projected Stock of Gas-Fired and Oil-Fired Boilers (2019–2048)

To project gas-fire hot water boiler shipments from the respective stock projections, DOE used the following:

$$(Shipment)_i = C_0 \times (Stock\ increase\ from\ year\ i\text{-}1\ to\ year\ i) + C_1 \times (Stock\ for\ the\ year\ i\text{-}1 + C_2 \times (Stock\ for\ the\ year\ i\text{-}5)$$

Eq. 9A.2

Where:

i = reference year, and
C_0, $C_1$and C_2 = empirical constants.

Since no other commercial equipment has lifetime and shipment growth characteristics similar to the commercial packaged boilers, DOE used data for residential boiler projected stock and shipments for 2020–2049 to estimate the values of the constants. DOE obtained a value of 4.9 percent for C_0, 14.0 percent for C_1, and -10.3 percent for C_2. Thus, in a stable hypothetical boiler stock situation, where shipments are limited only to replacements, the shipment-to-stock relationship would simplify to the annual shipment being 3.7 percent of the reference stock, implying a mean equipment life of about 27 years.

For all the other commercial packaged boilers, DOE used the same stock to shipment factors as was used for estimating the historical shipments.

To disaggregate the projected annual shipments for gas-fired hot water, gas-fired steam, oil-fired hot water, and oil-fired steam boilers into the defined equipment classes, DOE needed to break up these shipments further in to two size groups. DOE obtained the small sizes to all sizes fractions primarily from the CBECS boiler sample weight estimates for 2003, and adjusted for steam to hot water, and oil-to-gas switching from 2003 to 2019. These values are 86.2 percent for the gas-fired hot water boilers, 87.4 percent for the oil-fired hot water boilers, 88.5 percent for the gas-fired steam boilers, and 81.1 percent for the oil-fired steam boilers.

9A.7 FRACTION OF COMMERCIAL PACKAGED BOILERS SHIPPED TO MULTI-FAMILY RESIDENTIAL BUILDINGS

DOE derived CPB shipments by building types from the CBECS 2003 and RECS 2009 data. DOE assumed that boilers in commercial and residential buildings that are larger than 10,000 ft^2 are commercial packaged boilers and that multiple boilers could be used per commercial building, depending on the size of the building. Results showed that 15 percent of commercial packaged boilers were shipped to the residential sector.

9A.8 PROJECTED SHIPMENTS BY EQUIPMENT CLASSES

Table 9A.8.1 through Table 9A.8.4 show the total projected shipments in the no-new-standards case and under each standards case (at each trial standard level—TSL), respectively:

- gas-fired hot water commercial packaged boilers ≥300,000 Btu/h and ≤2,500,000 Btu/h,
- gas-fired hot water commercial packaged boilers >2,500,000 Btu/h and ≤10,000,000 Btu/h,
- oil-fired hot water commercial packaged boilers ≥300,000 Btu/h and ≤2,500,000 Btu/h, and
- oil-fired hot water commercial packaged boilers >2,500,000 Btu/h and ≤10,000,000 Btu/h

Because the elasticity is modeled as a delayed replacement of a boiler, the projections for the standards cases show a decline in the early years but an increase in later years, once the delayed replacements are finally made. DOE understands that the elasticity parameter decreases over time, so the impact of standards on shipments diminishes.

Table 9A.8.1 Total Projected Shipments of Gas-Fired Hot Water Commercial Packaged Boilers ≥300,000 Btu/h and ≤2,500,000 Btu/h in the No-New-Standards Case and Each Standards Case

Year	No-New-Standards	TSL 1	TSL 2	TSL 3	TSL 4	TSL 5
2019	16,907	16,904	16,902	16,882	16,864	16,864
2020	17,201	17,198	17,197	17,181	17,168	17,168
2021	17,456	17,453	17,452	17,440	17,429	17,429
2022	17,804	17,802	17,801	17,790	17,781	17,781
2023	18,181	18,180	18,179	18,170	18,162	18,162
2024	18,350	18,348	18,347	18,339	18,331	18,331
2025	18,512	18,514	18,515	18,528	18,538	18,538
2026	18,643	18,645	18,646	18,654	18,660	18,660
2027	18,733	18,734	18,734	18,740	18,744	18,744
2028	18,794	18,795	18,795	18,799	18,803	18,803
2029	18,910	18,910	18,911	18,913	18,915	18,915
2030	19,066	19,066	19,067	19,069	19,071	19,071
2031	19,306	19,306	19,307	19,309	19,310	19,310
2032	19,656	19,656	19,656	19,658	19,659	19,659
2033	20,057	20,057	20,058	20,059	20,060	20,060
2034	20,506	20,506	20,506	20,508	20,508	20,508
2035	21,025	21,026	21,026	21,027	21,028	21,028
2036	21,566	21,566	21,566	21,568	21,569	21,569
2037	22,017	22,017	22,017	22,019	22,020	22,020
2038	22,403	22,403	22,404	22,405	22,407	22,407
2039	22,711	22,711	22,711	22,713	22,714	22,714
2040	22,953	22,953	22,953	22,955	22,956	22,956
2041	23,178	23,178	23,178	23,180	23,181	23,181
2042	23,454	23,454	23,454	23,456	23,458	23,458
2043	23,738	23,738	23,738	23,740	23,742	23,742
2044	24,040	24,040	24,040	24,042	24,043	24,043
2045	24,363	24,364	24,364	24,365	24,367	24,367
2046	24,707	24,707	24,708	24,709	24,710	24,710
2047	25,056	25,056	25,056	25,057	25,058	25,058
2048	25,409	25,409	25,409	25,410	25,411	25,411

Table 9A.8.2 Total Projected Shipments of Gas-Fired Hot Water Commercial Packaged Boilers >2,500,000 Btu/h and ≤10,000,000 Btu/h in the No-New-Standards Case and Each Standards Case

Year	No-New-Standards	TSL 1	TSL 2	TSL 3	TSL 4	TSL 5
2019	2,707	2,706	2,705	2,705	2,698	2,698
2020	2,754	2,753	2,753	2,753	2,748	2,748
2021	2,794	2,794	2,794	2,794	2,790	2,790
2022	2,850	2,850	2,850	2,850	2,847	2,847
2023	2,910	2,910	2,910	2,910	2,908	2,908
2024	2,937	2,937	2,937	2,937	2,935	2,935
2025	2,963	2,964	2,964	2,964	2,969	2,969
2026	2,984	2,984	2,984	2,984	2,987	2,987
2027	2,998	2,999	2,999	2,999	3,000	3,000
2028	3,008	3,008	3,008	3,008	3,010	3,010
2029	3,027	3,027	3,027	3,027	3,028	3,028
2030	3,052	3,052	3,052	3,052	3,053	3,053
2031	3,090	3,090	3,090	3,090	3,091	3,091
2032	3,146	3,146	3,146	3,146	3,147	3,147
2033	3,210	3,210	3,210	3,210	3,211	3,211
2034	3,282	3,282	3,282	3,282	3,283	3,283
2035	3,365	3,365	3,365	3,365	3,366	3,366
2036	3,452	3,452	3,452	3,452	3,453	3,453
2037	3,524	3,524	3,524	3,524	3,525	3,525
2038	3,586	3,586	3,586	3,586	3,587	3,587
2039	3,635	3,635	3,635	3,635	3,636	3,636
2040	3,674	3,674	3,674	3,674	3,674	3,674
2041	3,710	3,710	3,710	3,710	3,710	3,710
2042	3,754	3,754	3,754	3,754	3,755	3,755
2043	3,800	3,800	3,800	3,800	3,800	3,800
2044	3,848	3,848	3,848	3,848	3,848	3,848
2045	3,900	3,900	3,900	3,900	3,900	3,900
2046	3,955	3,955	3,955	3,955	3,955	3,955
2047	4,011	4,011	4,011	4,011	4,011	4,011
2048	4,067	4,067	4,067	4,067	4,067	4,067

Table 9A.8.3 Total Projected Shipments of Oil-Fired Hot Water Commercial Packaged Boilers ≥300,000 Btu/h and ≤2,500,000 Btu/h in the No-New-Standards Case and Each Standards Case

Year	No-New-Standards	TSL 1	TSL 2	TSL 3	TSL 4	TSL 5
2019	868	867	867	867	866	856
2020	877	876	876	876	875	868
2021	885	884	884	884	884	878
2022	893	892	892	892	891	887
2023	899	898	898	898	898	894
2024	904	904	904	904	903	900
2025	910	911	911	911	912	918
2026	914	915	915	915	916	920
2027	919	919	919	919	919	923
2028	923	923	923	923	923	926
2029	927	928	928	928	928	929
2030	932	932	932	932	932	934
2031	937	938	938	938	938	939
2032	945	945	945	945	945	946
2033	952	952	952	952	952	953
2034	960	960	960	960	960	961
2035	969	969	969	969	969	970
2036	979	979	979	979	979	980
2037	988	988	988	988	989	989
2038	997	997	997	997	997	998
2039	1,006	1,006	1,006	1,006	1,006	1,006
2040	1,014	1,014	1,014	1,014	1,014	1,014
2041	1,021	1,021	1,021	1,021	1,021	1,022
2042	1,029	1,029	1,029	1,029	1,029	1,030
2043	1,037	1,037	1,037	1,037	1,037	1,037
2044	1,045	1,045	1,045	1,045	1,045	1,045
2045	1,053	1,053	1,053	1,053	1,053	1,053
2046	1,061	1,061	1,061	1,061	1,061	1,061
2047	1,068	1,069	1,069	1,069	1,069	1,069
2048	1,076	1,077	1,077	1,077	1,077	1,077

Table 9A.8.4 Total Projected Shipments of Oil-Fired Hot Water Commercial Packaged Boilers >2,500,000 Btu/h and ≤10,000,000 Btu/h in the No-New-Standards Case and Each Standards Case

Year	No-New-Standards	TSL 1	TSL 2	TSL 3	TSL 4	TSL 5
2019	119	119	119	119	119	118
2020	121	121	120	120	120	120
2021	122	122	122	122	122	121
2022	123	123	123	123	123	122
2023	124	124	124	124	124	123
2024	125	125	125	125	125	124
2025	125	125	126	126	126	126
2026	126	126	126	126	126	127
2027	127	127	127	127	127	127
2028	127	127	127	127	128	128
2029	128	128	128	128	128	128
2030	129	129	129	129	129	129
2031	129	129	129	129	129	130
2032	130	130	130	130	130	130
2033	131	131	131	131	131	131
2034	132	132	132	132	132	132
2035	133	133	133	133	133	133
2036	134	134	134	134	134	135
2037	136	136	136	136	136	136
2038	137	137	137	137	137	137
2039	138	138	138	138	138	138
2040	139	139	139	139	139	139
2041	140	140	140	140	140	140
2042	141	141	141	141	141	141
2043	142	142	142	142	142	142
2044	143	143	143	143	143	143
2045	144	144	144	144	144	144
2046	145	145	145	145	145	145
2047	146	146	146	146	146	146
2048	147	147	147	147	147	147

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CHAPTER 10. NATIONAL IMPACT ANALYSES

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CHAPTER 10. NATIONAL IMPACT ANALYSES

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 trial standard level (TSL) for commercial packaged boiler (CPB) equipment. The chapter examines selected national impacts attributable to each TSL considered for commercial packaged boilers. The results presented here include (1) national energy savings (NES), (2) operating cost savings, (3) increased total installed costs, and (4) the net present value (NPV) of the difference between the value of operating cost savings and increased total installed costs.

The calculations were performed using a computer spreadsheet model, which is accessible on DOE's website at www1.eere.energy.gov/buildings/appliance_standards/rulemaking.aspx/ruleid/79.[a] The spreadsheet model, termed the NIA model, calculates energy savings and NPV for the nation. Details regarding and instructions for using the NIA model are provided in appendix 10A of this notice of proposed rulemaking (NOPR) technical support document (TSD).

Chapter 9 of this NOPR TSD provides a detailed description of the shipments model, including consumers' sensitivities to total installed cost, operating cost, and income, and how DOE captured those sensitivities within the model.[b]

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*) and using a relative price elasticity of -0.02, as described in chapter 9. [1] DOE also calculated NIA results using inputs from the high economic growth case and the low economic growth case in *AEO2015*, and using high and zero relative price elasticities. These alternative scenario results can be viewed in the NIA spreadsheet by selecting the high or low growth economic scenario or the high (relative price elasticity -0.20) or low elasticity (no impact) scenario, and in appendix 10D of this NOPR TSD.

10.2 TRIAL STANDARD LEVELS

DOE developed TSLs that combine efficiency levels for the eight CPB equipment classes analyzed. Table 10.2.1 presents the efficiency levels (EL), and Table 10.2.2 presents the thermal efficiency (E_T) or combustion efficiency (E_C) for each equipment class in each TSL. A more detailed description of the TSLs is included in appendix 10C.

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[a] DOE understands that Microsoft Excel is the most widely used spreadsheet calculation tool in the United States and there is general familiarity with its basic features. Thus, DOE's use of Microsoft Excel as the basis for the spreadsheet models provides interested parties with access to the models within a familiar context.

[b] The "shipment forecast" and "historical shipments" worksheets of the NIA model present the scope of the analysis and the total shipments in units for the commercial packaged boilers in scope.

The ELs in each TSL can be summarized as follows:

- TSL 5 corresponds to the max-tech EL for each equipment class.
- TSL 4 is composed of the ELs corresponding to the maximum NPV at a 7 percent discount rate for each equipment class.
- TSL 3 is composed of a mixture of condensing and non-condensing ELs.
- TSL 2 and TSL 1 are composed of a mixture of non-condensing ELs only.

Table 10.2.1 Trial Standard Levels for CPB Standards (Efficiency Level)

Equipment Class	TSL 1	TSL 2	TSL 3	TSL 4	TSL 5
	EL	EL	EL	EL	EL
Small Gas-Fired Hot Water Commercial Packaged Boilers	3	4	6	7	7
Large Gas-Fired Hot Water Commercial Packaged Boilers	2	3	3	5	5
Small Oil-Fired Hot Water Commercial Packaged Boilers	4	4	4	5	6
Large Oil-Fired Hot Water Commercial Packaged Boilers	1	2	2	3	4
Small Gas-Fired Steam Commercial Packaged Boilers	3	4	4	5	5
Large Gas-Fired Steam Commercial Packaged Boilers	4	5	5	6	6
Small Oil-Fired Steam Commercial Packaged Boilers	1	2	2	3	3
Large Oil-Fired Steam Commercial Packaged Boilers	1	2	2	3	3

Table 10.2.2 Trial Standard Levels for CPB Standards (E_T or E_C, %)

Equipment Class	Trial Standard Level*									
	1		2		3		4		5	
	E_T	E_C	E_T	E_C	E_T	E_C	E_T	E_C	E_T	E_C
Small Gas-Fired Hot Water Commercial Packaged Boilers	84%	n/a	85%	n/a	95%	n/a	99%	n/a	99%	n/a
Large Gas-Fired Hot Water Commercial Packaged Boilers	n/a	84%	n/a	85%	n/a	85%	n/a	97%	n/a	97%
Small Oil-Fired Hot Water Commercial Packaged Boilers	87%	n/a	87%	n/a	87%	n/a	88%	n/a	97%	n/a
Large Oil-Fired Hot Water Commercial Packaged Boilers	n/a	86%	n/a	88%	n/a	88%	n/a	89%	n/a	97%
Small Gas-Fired Steam Commercial Packaged Boilers	80%	n/a	81%	n/a	81%	n/a	83%	n/a	83%	n/a
Large Gas-Fired Steam Commercial Packaged Boilers	81%	n/a	82%	n/a	82%	n/a	84%	n/a	84%	n/a
Small Oil-Fired Steam Commercial Packaged Boilers	83%	n/a	84%	n/a	84%	n/a	86%	n/a	86%	n/a
Large Oil-Fired Steam Commercial Packaged Boilers	83%	n/a	85%	n/a	85%	n/a	87%	n/a	87%	n/a

* E_T stands for thermal efficiency, and E_C stands for combustion efficiency.

10.3 OVERVIEW OF THE NATIONAL IMPACT ANALYSIS

10.3.1 National Energy Savings

DOE calculates annual NES as the difference between two projections: the no-new-standards case (referred to as the base case in the equation subscripts) and a standards case. Positive values of NES represent energy savings (that is, national annual energy consumption (AEC) under a standard is less than in the no-new standards case). The following expression represents the calculation of annual national energy savings (NES_y):

$$NES_y = AEC_{natl-base} - AEC_{natl-std}$$

Eq. 10.1

Cumulative energy savings are the sum of annual NES throughout the forecast period, which extends over the lifetime of equipment shipped in 2019–2048. The following equation represents this calculation:

$$NES_{cum} = \sum NES_y$$

Eq. 10.2

DOE calculates *AEC* by multiplying the number or stock of a given type of equipment (by vintage) by its unit energy consumption (also by vintage). The following equation represents the calculation of the national *AEC*:

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

Eq. 10.3

Where:

AEC = annual energy consumption each year for the Nation in quadrillion British thermal units (Btu), or quads, summed over vintages of the equipment stock, $STOCK_V$,
NES_y = national annual energy savings (quads),
NES_{cum} = national cumulative energy savings (quads),
$STOCK_V$ = stock of equipment (thousands of units) of vintage V that survive in the year for which DOE calculated annual energy consumption,
UEC_V = annual energy consumption per equipment in kilowatt-hours (kWh); electricity consumption is converted from site energy to power plant energy (quads) by applying a time-dependent conversion factor,
$natl$ = designates the quantity corresponding to the Nation,
$base$ = designates the quantity corresponding to the no-new-standards or base case,
std = designates the quantity corresponding to the standards case,
y = year in the projection,
cum = cumulative over the projection period, and
V = year in which the equipment was purchased as a new unit.

The stock of equipment depends on annual shipments and the lifetime of the given equipment. As described in chapter 9, DOE projects shipments for the no-new-standards case and each standards case. The NES from commercial packaged boilers in the standards cases includes the saving from both commercial and residential boiler users. Based on analysis of historical information, DOE estimates that 15-percent of commercial packaged boilers are shipped to residential households.

10.3.2 Net Present Value of Consumer Benefit

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

$$\boldsymbol{NPV = PVS - PVC}$$

Eq. 10.4

Where:

PVS = present value of savings in operating cost (including costs for energy, repair, and maintenance), and
PVC = present value of increase in total installed cost (including costs for equipment and installation).

DOE determines the PVS and PVC according to the following equations:

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

Eq. 10.5

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

Eq. 10.6

DOE calculates the total annual savings in operating cost by multiplying the number or stock of a given equipment (by vintage) by its per-unit operating cost savings (also by vintage). DOE calculates the total annual increase in installed cost by multiplying the number or stock of a given equipment (by vintage) by its per-unit total installed cost increase (also by vintage). Total annual savings in operating cost and increases in installed cost are calculated using the following equations:

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

Eq. 10.7

$$TIC_y = \sum STOCK_V \times UTIC_V$$

Eq. 10.8

Where:

OCS = total annual savings in operating cost each year summed over vintages of the equipment stock, $STOCK_V$,
TIC = total annual increase in installed cost each year summed over vintages of the equipment stock, $STOCK_V$,
DF =discount factor in each year,
$STOCK_V$ = stock of equipment (millions of units) of vintage V that survive in the year for which DOE calculated annual energy consumption,
$UOCS_V$ = annual per-unit savings in operating cost,
$UTIC_V$ = annual total per-unit increase in installed cost,
V = year in which the equipment was purchased as a new unit, and
y = year in the projection.

The net present value of commercial consumer benefits in the standard cases includes the benefits from both commercial and residential boiler users.

DOE determines the *PVC* for each year from the compliance date of the standard through 2048. DOE determines the *PVS* for each year from the compliance date of the standard until the year when units purchased in 2019−2048 retire. DOE calculates costs and savings as the difference between each standards case and the no-new-standards case.

DOE calculates a discount factor from the discount rate and the number of years between the “present” (2015, the 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 PROJECTED EFFICIENCY TRENDS

A key component of the NIA is the energy efficiency of boilers projected over time for the no-new-standards case and for each of the standards cases (with potential new standards).

10.4.1 No-New-Standards and Standards Case Efficiencies in 2019

For each CPB equipment class, DOE develops a distribution of efficiencies in the no-new-standards cases for 2019 (the assumed compliance date for new standards), as described in chapter 8 of this NOPR TSD. In each standards case, DOE assumes a “roll-up” scenario to establish the efficiency distribution for 2019. Equipment efficiencies in the no-new-standards case that do not meet the standard under consideration would “roll up” to meet the new standard level. All efficiency shares in the no-new-standards case that are above the standard under consideration would not be affected. Table 10.4.1 and Table 10.4.2 present the efficiency distributions in 2019 for the no-new-standards case and standards case used in commercial applications and residential applications, respectively.

Table 10.4.1 Commercial Packaged Boilers: Efficiency Distributions for the No-New-Standards and Standards Cases in Commercial Applications in 2019

Efficiency Level		Market Share* %							
		No-New-Standards Case	Efficiency Level (EL)						
			1	2	3	4	5	6	7
Gas-Fired Hot Water Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h									
0	80% E_T - Baseline	7.7							
1	81% E_T	8.4	16.1						
2	82% E_T	16.9	16.9	33.0					
3	84% E_T	8.3	8.3	8.3	41.2				
4	85% E_T	18.2	18.2	18.2	18.2	59.5			
5	93% E_T	18.2	18.2	18.2	18.2	18.2	77.7		
6	95% E_T	19.8	19.8	19.8	19.8	19.8	19.8	97.5	
7	99% E_T - Max Tech	2.5	2.5	2.5	2.5	2.5	2.5	2.5	100.0
Gas-Fired Hot Water Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h									
0	82% E_C - Baseline	24.1							
1	83% E_C	23.0	47.1						
2	84% E_C	7.2	7.2	54.3					
3	85% E_C	17.3	17.3	17.3	71.6				
4	94% E_C	26.5	26.5	26.5	26.5	98.1			
5	97% E_C - Max Tech	1.9	1.9	1.9	1.9	1.9	100.0		
Oil-Fired Hot Water Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h									
0	82% E_T - Baseline	39.5							
1	83% E_T	21.0	60.5						
2	84% E_T	10.5	10.5	71.0					
3	85% E_T	13.6	13.6	13.6	84.5				
4	87% E_T	9.5	9.5	9.5	9.5	94.1			
5	88% E_T	3.7	3.7	3.7	3.7	3.7	97.8		
6	97% E_T - Max Tech	2.2	2.2	2.2	2.2	2.2	2.2	100.0	
Oil-Fired Hot Water Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h									
0	84% E_C - Baseline	34.9							
1	86% E_C	46.5	81.4						
2	88% E_C	12.2	12.2	93.7					
3	89% E_C	1.2	1.2	1.2	94.9				
4	97% E_C - Max Tech	5.1	5.1	5.1	5.1	100.0			
Gas-Fired Steam Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h									
0	77% E_T - Baseline	43.2							
1	78% E_T	4.3	47.6						
2	79% E_T	15.4	15.4	63.0					
3	80% E_T	19.4	19.4	19.4	82.4				
4	81% E_T	12.1	12.1	12.1	12.1	94.5			
5	83% E_T - Max Tech	5.5	5.5	5.5	5.5	5.5	100.0		

Efficiency Level		**Market Share* %**							
Gas-Fired Steam Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h									
0	77% E_T - Baseline	10.2							
1	78% E_T	21.5	31.7						
2	79% E_T	13.4	13.4	45.1					
3	80% E_T	25.8	25.8	25.8	70.9				
4	81% E_T	5.6	5.6	5.6	5.6	76.5			
5	82% E_T	14.6	14.6	14.6	14.6	14.6	91.1		
6	84% E_T - Max Tech	8.9	8.9	8.9	8.9	8.9	8.9	100.0	
Oil-Fired Steam Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h									
0	81% E_T - Baseline	33.9							
1	83% E_T	51.5	85.4						
2	84% E_T	10.1	10.1	95.6					
3	86% E_T - Max Tech	4.4	4.4	4.4	100.0				
Oil-Fired Steam Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h									
0	81% E_T - Baseline	38.0							
1	83% E_T	33.4	71.4						
2	85% E_T	28.0	28.0	99.4					
3	87% E_T - Max Tech	0.6	0.6	0.6	100.0				

* Due to rounding not all columns add up to 100%.

Table 10.4.2 Commercial Packaged Boilers: Efficiency Distributions for the No-New-Standards and Standards Cases in Residential Applications in 2019

Efficiency Level		Market Share* %							
		No-New-Standards Case	Efficiency Level (EL)						
			1	2	3	4	5	6	7
Gas-Fired Hot Water Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h									
0	80% E_T - Baseline	7.7							
1	81% E_T	9.2	16.9						
2	82% E_T	16.2	16.2	33.0					
3	84% E_T	9.9	9.9	9.9	42.9				
4	85% E_T	19.2	19.2	19.2	19.2	62.1			
5	93% E_T	16.2	16.2	16.2	16.2	16.2	78.3		
6	95% E_T	19.8	19.8	19.8	19.8	19.8	19.8	98.1	
7	99% ET - Max Tech	1.9	1.9	1.9	1.9	1.9	1.9	1.9	100.0
Gas-Fired Hot Water Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h									
0	82% E_C - Baseline	22.1							
1	83% E_C	20.8	43.0						
2	84% E_C	7.4	7.4	50.3					
3	85% E_C	18.8	18.8	18.8	69.1				
4	94% E_C	28.9	28.9	28.9	28.9	98.0			
5	97% E_C - Max Tech	2.0	2.0	2.0	2.0	2.0	100.0		
Oil-Fired Hot Water Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h									
0	82% E_T - Baseline	39.4							
1	83% E_T	21.6	61.1						
2	84% E_T	10.2	10.2	71.2					
3	85% E_T	14.2	14.2	14.2	85.5				
4	87% E_T	9.5	9.5	9.5	9.5	95.0			
5	88% E_T	3.5	3.5	3.5	3.5	3.5	98.6		
6	97% E_T - Max Tech	1.4	1.4	1.4	1.4	1.4	1.4	100.0	
Oil-Fired Hot Water Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h									
0	84% E_C - Baseline	33.7							
1	86% E_C	47.9	81.6						
2	88% E_C	12.1	12.1	93.7					
3	89% E_C	0.9	0.9	0.9	94.6				
4	97% E_C - Max Tech	5.4	5.4	5.4	5.4	100.0			
Gas-Fired Steam Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h									
0	77% E_T - Baseline	45.3							
1	78% E_T	4.0	49.3						
2	79% E_T	14.1	14.1	63.4					
3	80% E_T	20.5	20.5	20.5	83.9				
4	81% E_T	12.1	12.1	12.1	12.1	96.0			
5	83% E_T - Max Tech	4.0	4.0	4.0	4.0	4.0	100.0		

Efficiency Level		**Market Share[*] %**							
		No-New-Standards Case	**Efficiency Level (EL)**						
			1	**2**	**3**	**4**	**5**	**6**	**7**
Gas-Fired Steam Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h									
0	77% E_T - Baseline	8.6							
1	78% E_T	14.0	22.6						
2	79% E_T	21.5	21.5	44.1					
3	80% E_T	25.8	25.8	25.8	69.9				
4	81% E_T	7.5	7.5	7.5	7.5	77.4			
5	82% E_T	19.4	19.4	19.4	19.4	19.4	96.8		
6	84% E_T - Max Tech	3.2	3.2	3.2	3.2	3.2	3.2	100.0	
Oil-Fired Steam Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h									
0	81% E_T - Baseline	34.6							
1	83% E_T	49.3	83.9						
2	84% E_T	11.3	11.3	95.2					
3	86% E_T - Max Tech	4.8	4.8	4.8	100.0				
Oil-Fired Steam Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h									
0	81% E_T - Baseline	40.6							
1	83% E_T	36.8	77.4						
2	85% E_T	22.6	22.6	100.0					
3	87% E_T - Max Tech	0.0	0.0	0.0	100.0				

* Due to rounding not all columns add up to 100%.

10.4.2 Projected Efficiency Trends After 2019

The market shares of condensing gas-fired hot water boilers are projected to gradually increase, while the projected shares of condensing oil-fired hot water boilers are projected to decrease. Figure 10.4.1 shows the assumed shares of gas-fired hot water boilers ≥300,000 Btu/h and ≤2,500,000 Btu/h at each EL in replacement applications (the shares in new construction are slightly different). DOE estimates that there would be linear growth in the overall market share of condensing gas-fired hot water residential boilers ≥300,000 Btu/h and ≤2,500,000 Btu/h from 40.5 percent in 2019 to 65.5 percent in 2048. The shares of the three condensing ELs (EL 4, EL 5 and EL 6) and the four non-condensing ELs are kept in the same proportional relationship as in 2019.

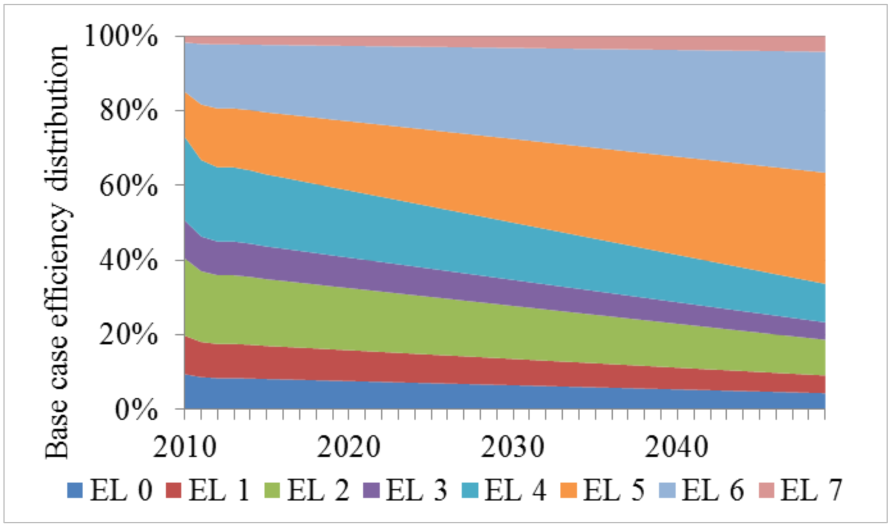

Figure 10.4.1 Projection of No-New-Standards Case Efficiency Distribution of Replacement Units for Gas-Fired Hot Water Commercial Packaged Boilers ≥300,000 Btu/h and ≤2,500,000 Btu/h

For standards cases 1 and 2, DOE applies the above described efficiency trend for the condensing boiler market share. The difference between these standards cases and the no-new-standards case is in the market shares of the various non-condensing boiler designs (ELs 0 through 3). For standard cases 3 through 5, the overall condensing boiler market share goes to 100 percent in 2019 and remains at that level. The shares of the specific condensing boiler designs (ELs 4 through 6) remain at the levels shown in the tables above.

Figure 10.4.2 shows the shares of gas-fired hot water boilers >2,500,000 Btu/h and ≤10,000,000 Btu/h at each EL. The shares of the three non-condensing ELs are kept in the same proportional relationship as in 2019. DOE estimates linear growth in the overall market share of condensing gas-fired hot water commercial packaged boilers >2,500,000 Btu/h and ≤10,000,000 Btu/h from 28.4 percent in 2019 to 100.0 percent by 2048.

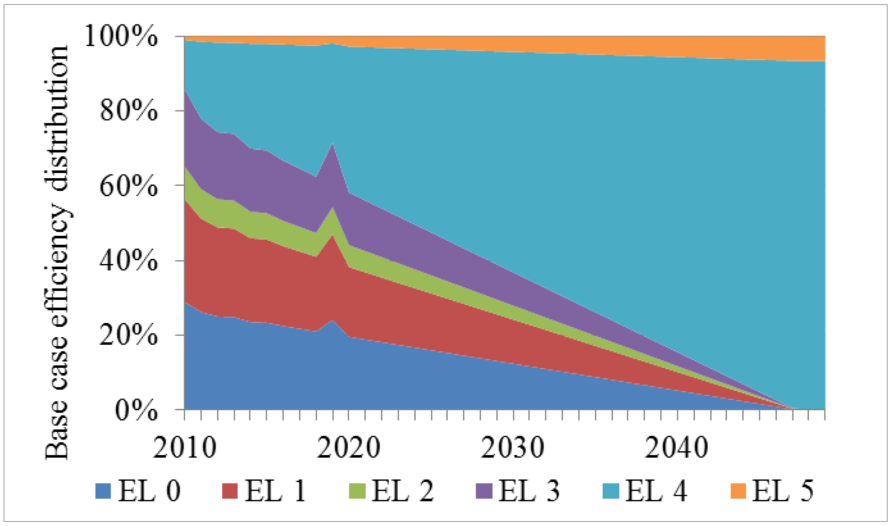

Figure 10.4.2 Projection of No-New-Standards Case Efficiency Distribution of Replacement Units for Gas-Fired Hot Water Commercial Packaged Boilers >2,500,000 Btu/h and ≤10,000,000 Btu/h

For standards cases 1 through 3, DOE applies the above described efficiency trend for the condensing boiler market share. The difference between these standards cases and the no-new-standards case is in the market shares of the various non-condensing boiler designs (ELs 0 through 3). For standard cases 4 and 5, the overall condensing boiler market share goes to 100 percent in 2019 and remains at that level. The shares of the specific condensing boiler designs (ELs 4 and 5) remain at the levels shown in the previous tables.

Figure 10.4.3 shows the assumed shares of oil-fired hot water boilers ≥300,000 Btu/h and ≤2,500,000 Btu/h at each EL in replacement applications (the shares in new construction are slightly different). DOE estimates that there would be a linear decline in the overall market share of condensing oil-fired hot water boilers ≥300,000 Btu/h and ≤2,500,000 Btu/h, from 2.2 percent in 2019 to 0.6 percent in 2048. The shares of the three non-condensing ELs are kept in the same proportional relationship as in 2019.

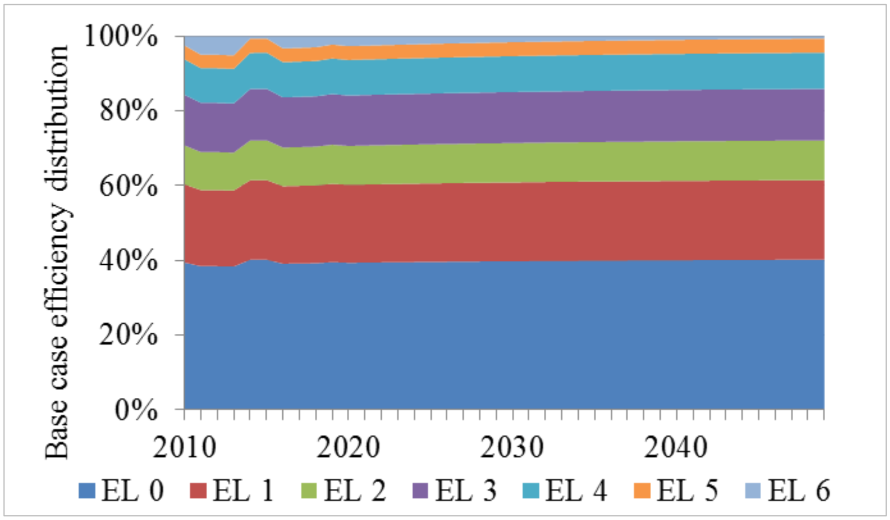

Figure 10.4.3 Projection of No-New-Standards Case Efficiency Distribution of Replacement Units for Oil-Fired Hot Water Commercial Packaged Boilers ≥300,000 Btu/h and ≤2,500,000 Btu/h

For standards cases 1 through 4, DOE applies the above described efficiency trend for the condensing boiler market share (EL 6). The difference between these standards cases and the no-new-standards case is in the market shares of the non-condensing boilers (ELs 0 through 5). For standard case 5, the condensing boiler market share goes to 100 percent in 2019 and remains at that level.

Figure 10.4.4 shows the shares of oil-fired hot water boilers >2,500,000 Btu/h and ≤10,000,000 Btu/h at each EL. The shares of the four non-condensing ELs are kept in the same proportional relationship as in 2019. DOE estimated a linear decline in the overall market share of condensing oil-fired hot water commercial packaged boilers >2,500,000 Btu/h and ≤10,000,000 Btu/h from 5.1 percent in 2019 to 0.8 percent by 2048.

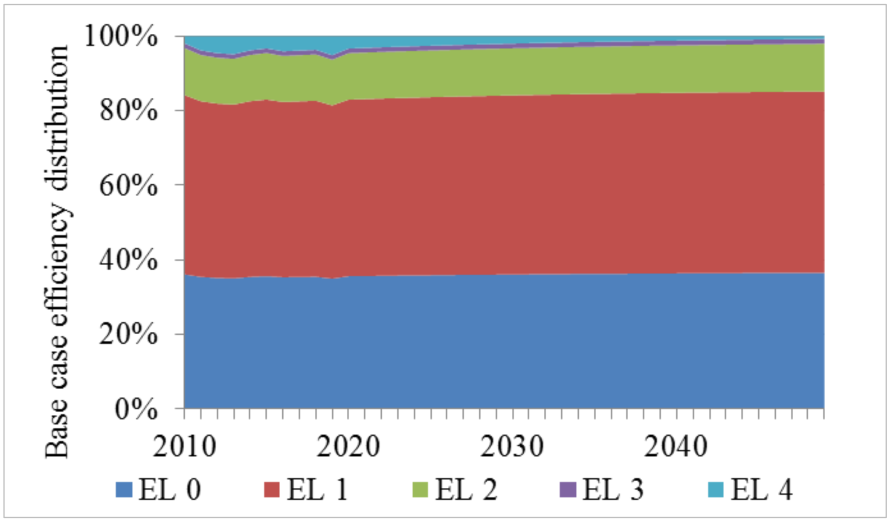

Figure 10.4.4 Projection of No-New-Standards Case Efficiency Distribution of Replacement Units for Oil-Fired Hot Water Commercial Packaged Boilers >2,500,000 Btu/h and ≤10,000,000 Btu/h

For standards cases 1 through 4, DOE applies the above described efficiency trend for the condensing boiler market share (EL 4). The difference between these standards cases and the no-new-standards case is in the market shares of the non-condensing boilers (ELs 0 through 3). For standard case 5, the condensing boiler market share goes to 100 percent in 2019 and remains at that level.

DOE considers that the standards for natural draft gas-fired steam commercial packaged boilers ≥300,000 Btu/h and ≤2,500,000 Btu/h and natural draft gas-fired steam commercial packaged boilers >2,500,000 Btu/h and ≤10,000,000 Btu/h are already scheduled to change on March 2, 2022 from 77 percent thermal efficiency to 79 percent thermal efficiency. DOE assumed that in 2022 all natural draft steam boilers below 79 percent thermal efficiency will roll-up to 79 percent thermal efficiency to meet the standard.

The shares of gas-fired and oil-fired steam boiler efficiency levels are kept in the same proportional relationship as in 2019.

10.5 NATIONAL ENERGY SAVINGS

The inputs for calculating NES are as follows:

- average annual energy consumption per unit (*UEC*),
- shipments,
- equipment stock ($STOCK_V$),
- annual energy consumption for the Nation (*AEC*), and
- power plant primary energy use factor (*src_conv*).

10.5.1 Annual Energy Consumption per Unit

For each equipment class, DOE presents the per-unit AEC by efficiency level in NOPR TSD chapter 7, Energy Use Analysis. Because the per-unit AEC is directly dependent on efficiency, DOE uses the shipments-weighted energy efficiency of the no-new-standards and standards cases presented in section 10.4, along with the annual energy use data presented in chapters 7 and 8, to estimate the shipment-weighted average annual per-unit energy consumption (UEC) under the no-new-standards and standards cases. Table 10.5.1 presents the no-new-standards case and standards case shipment-weighted annual UECs by EL, and Table 10.5.2 presents the shipment-weighted annual UECs by TSL for the eight equipment classes for which DOE is proposing standards. The values are a weighted average for commercial and residential boiler users. The tables show the energy use of commercial packaged boilers associated with higher-efficiencies. The values after 2019 change according to the projected efficiency trends in each case.

Table 10.5.1 Average Annual Boiler Energy Use for the No-New-Standards and Standards Cases in 2019 by Efficiency Level

Equipment Class	No-New-Standards Case	ELs						
		1	2	3	4	5	6	7
Small Gas-Fired Hot Water Commercial Packaged Boilers								
Average Annual Fuel Use (MMBtu/yr)	1055.8	1054.7	1052.5	1044.0	1038.8	1013.8	996.1	954.9
Average Annual Elec Use (kWh/yr)	858.8	858.1	856.7	851.1	847.7	1030.2	1013.1	973.0
Large Gas-Fired Hot Water Commercial Packaged Boilers								
Average Annual Fuel Use (MMBtu/yr)	4803.6	4787.9	4758.2	4724.6	4545.0	4386.4	4386.4	4386.4
Average Annual Elec Use (kWh/yr)	1684.7	1680.0	1671.0	1660.7	2061.3	1990.7	1990.7	1990.7
Small Oil-Fired Hot Water Commercial Packaged Boilers								
Average Annual Fuel Use (MMBtu/yr)	641.7	638.6	633.8	628.4	615.8	608.9	577.5	577.5
Average Annual Elec Use (kWh/yr)	482.4	480.1	476.8	472.9	464.0	459.1	606.1	606.1
Large Oil-Fired Hot Water Commercial Packaged Boilers								
Average Annual Fuel Use (MMBtu/yr)	4710.0	4673.3	4590.9	4545.1	4429.7	4429.7	4429.7	4429.7
Average Annual Elec Use (kWh/yr)	2097.9	2082.3	2047.2	2027.6	2812.0	2812.0	2812.0	2812.0
Small Gas-Fired Steam Commercial Packaged Boilers								
Average Annual Fuel Use (MMBtu/yr)	994.0	988.4	982.3	974.4	964.4	942.4	942.4	942.4
Average Annual Elec Use (kWh/yr)	551.2	548.1	544.9	540.7	535.4	523.6	523.6	523.6
Large Gas-Fired Steam Commercial Packaged Boilers								
Average Annual Fuel Use (MMBtu/yr)	4857.9	4851.4	4831.9	4804.1	4761.4	4716.3	4612.2	4612.2
Average Annual Elec Use (kWh/yr)	1463.9	1462.0	1456.4	1448.2	1435.6	1422.2	1391.4	1391.4
Small Oil-Fired Steam Commercial Packaged Boilers								
Average Annual Fuel Use (MMBtu/yr)	889.6	882.1	873.1	853.5	853.5	853.5	853.5	853.5
Average Annual Elec Use (kWh/yr)	742.8	736.9	729.7	714.1	714.1	714.1	714.1	714.1

Equipment Class	**No-New-Standards Case**	**ELs**						
		1	**2**	**3**	**4**	**5**	**6**	**7**
Large Oil-Fired Steam Commercial Packaged Boilers								
Average Annual Fuel Use (MMBtu/yr)	4678.1	4633.5	4553.7	4448.9	4448.9	4448.9	4448.9	4448.9
Average Annual Elec Use (kWh/yr)	2117.1	2097.4	2061.9	2015.6	2015.6	2015.6	2015.6	2015.6

Table 10.5.2 Average Annual Boiler Energy Use for the No-New-Standards and Standards Cases in 2019 by Trial Standard Level

Equipment Class	**No-New-Standards Case**	**TSLs**				
		1	**2**	**3**	**4**	**5**
Small Gas-Fired Hot Water Commercial Packaged Boilers						
Average Annual Fuel Use (*MMBtu/yr*)	1055.8	1044.0	1038.8	996.1	954.9	954.9
Average Annual Elec Use (*kWh/yr*)	858.8	851.1	847.7	1013.1	973.0	973.0
Large Gas-Fired Hot Water Commercial Packaged Boilers						
Average Annual Fuel Use (*MMBtu/yr*)	4803.6	4758.2	4724.6	4724.6	4386.4	4386.4
Average Annual Elec Use (*kWh/yr*)	1684.7	1671.0	1660.7	1660.7	1990.7	1990.7
Small Oil-Fired Hot Water Commercial Packaged Boilers						
Average Annual Fuel Use (*MMBtu/yr*)	641.7	615.8	615.8	615.8	608.9	577.5
Average Annual Elec Use (*kWh/yr*)	482.4	464.0	464.0	464.0	459.1	606.1
Large Oil-Fired Hot Water Commercial Packaged Boilers						
Average Annual Fuel Use (*MMBtu/yr*)	4710.0	4673.3	4590.9	4590.9	4545.1	4429.7
Average Annual Elec Use (*kWh/yr*)	2097.9	2082.3	2047.2	2047.2	2027.6	2812.0
Small Gas-Fired Steam Commercial Packaged Boilers						
Average Annual Fuel Use (*MMBtu/yr*)	994.0	974.4	964.4	964.4	942.4	942.4
Average Annual Elec Use (*kWh/yr*)	551.2	540.7	535.4	535.4	523.6	523.6
Large Gas-Fired Steam Commercial Packaged Boilers						
Average Annual Fuel Use (*MMBtu/yr*)	4857.9	4761.4	4716.3	4716.3	4612.2	4612.2
Average Annual Elec Use (*kWh/yr*)	1463.9	1435.6	1422.2	1422.2	1391.4	1391.4
Small Oil-Fired Steam Commercial Packaged Boilers						
Average Annual Fuel Use (*MMBtu/yr*)	889.6	882.1	873.1	873.1	853.5	853.5
Average Annual Elec Use (*kWh/yr*)	742.8	736.9	729.7	729.7	714.1	714.1
Large Oil-Fired Steam Commercial Packaged Boilers						
Average Annual Fuel Use (*MMBtu/yr*)	4678.1	4633.5	4553.7	4553.7	4448.9	4448.9

Equipment Class	**No-New-Standards Case**	**TSLs**				
		1	**2**	**3**	**4**	**5**
Average Annual Elec Use (*kWh/yr*)	2117.1	2097.4	2061.9	2061.9	2015.6	2015.6

DOE considers the effects of changes in climate and building shell efficiency on CPB energy use. The climate adjustment factor is based on the forecast of heating degree days (HDD) by region from *Annual Energy Outlook 2014* (*AEO2014*), which shows a declining trend due to warmer weather.[2] Regional building-shell efficiency factors are also from *AEO2014.* For both factors, DOE applies regional weights to make the factors specific to commercial and residential users of commercial packaged boilers. Figure 10.5.1 and Figure 10.5.2 show the adjustment factor for boiler energy use in the commercial sector and residential sectors, respectively.

DOE does not apply a rebound effect to adjust its estimates of energy savings because it is unlikely that commercial consumers will use a higher-efficiency boiler more than a baseline one, as the person using the boiler tends to not be the person who pays the bills for the boiler energy usage. Thus, the user would not perceive a difference and would not use the boiler more intensively as a result of the difference in the energy bill.

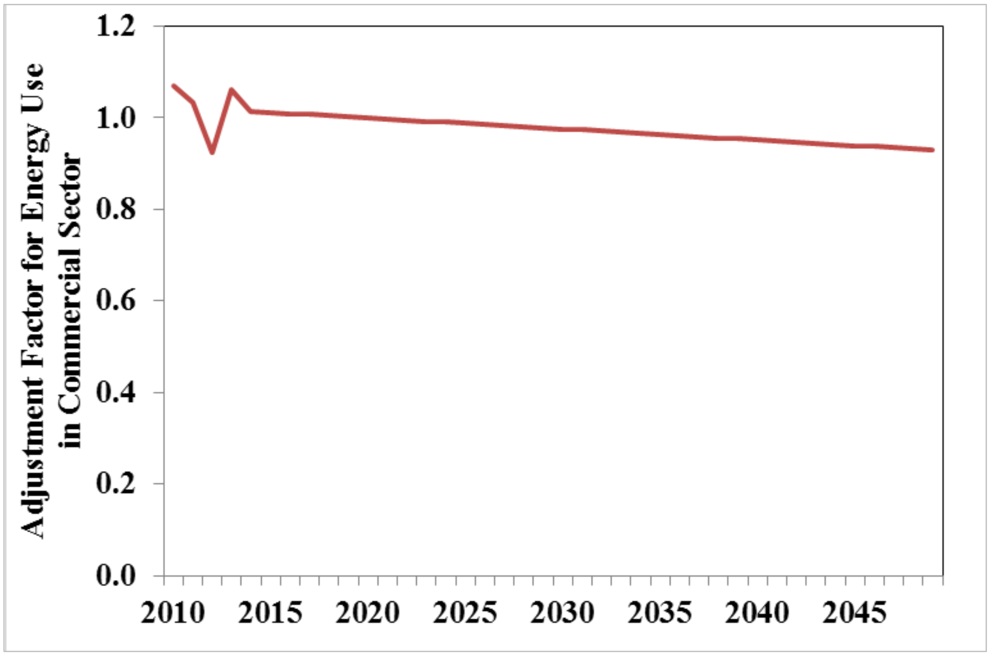

Figure 10.5.1 Combined Adjustment Factor for CPB Energy Use in Commercial Sector

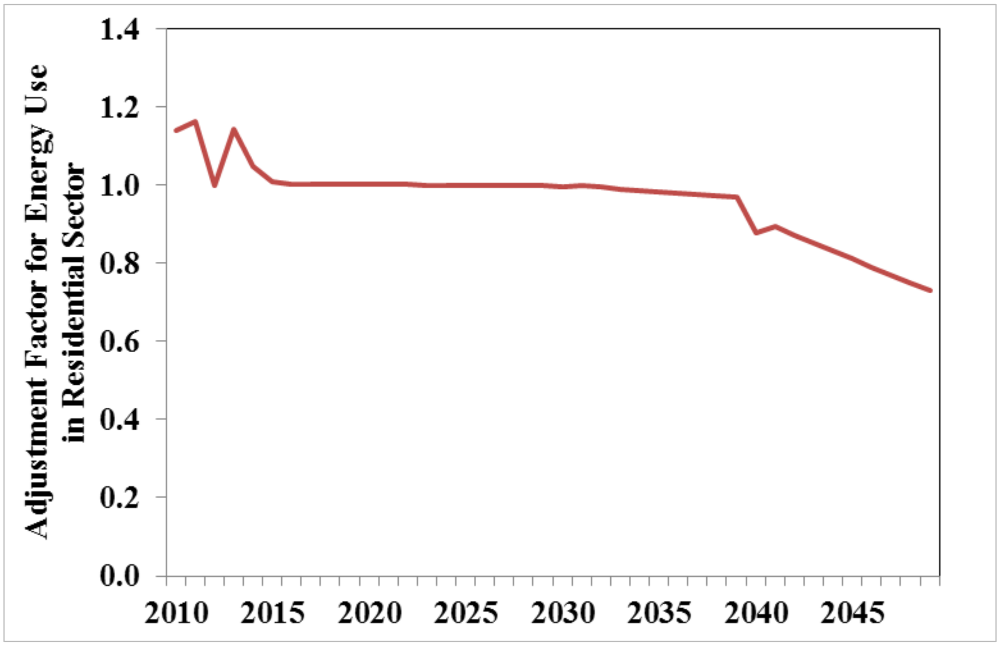

Figure 10.5.2 Combined Adjustment Factor for CPB Energy Use in Residential Sector

10.5.2 Shipments

DOE projects shipments for each equipment class under the no-new-standards case and all standards cases (see chapter 9). Several factors impact projected shipments, including total installed costs, operating cost, and equipment lifetime. As noted earlier, the increased total installed cost of more efficient equipment causes some consumers to forego equipment purchases. Consequently, shipments projected under the standards cases are lower than under the no-new-standards case. DOE believes it would be inappropriate to count energy savings that result from reduced shipments due to standards. Therefore, DOE does not calculate annual energy consumption for the no-new-standards case using the no-new-standards case shipments projection. Instead, for each comparison of a standards case with the no-new-standards case, DOE uses shipments associated with that particular standards case. As a result, all the calculated energy savings are due to higher energy efficiency in the standards case.

10.5.3 Equipment Stock

The stock of equipment in any given year depends on annual shipments and the lifetime of a given equipment class. The NIA model keeps track of the number of units shipped each year. The lifetime of a unit determines how many units shipped in previous years survive in the given year. DOE assumes that equipment has an increasing probability of retiring as it ages. The probability of survival as a function of years since purchase is termed the survival function. Refer to chapter 8 for further details on the survival functions that DOE used in its analysis.

10.5.4 Annual Energy Consumption

For each equipment class, DOE calculates the total national site (*i.e.*, the energy consumed at the household or establishment) AEC. Annual energy consumption is the product of the AEC per unit (also termed the UEC) and the number of units of each vintage. This method accounts for differences in UEC from year to year.

10.5.5 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 UEC from year to year. In determining national AEC, DOE first calculated AEC at the site, and then applied a conversion factor, described in section 10.5.6, to calculate primary energy consumption.

10.5.6 Site-to-Power Plant Energy Use Factor

DOE accounts for electricity use by commercial boilers. DOE calculates primary energy savings (power plant consumption) from site electricity savings by applying a factor to account for losses associated with the generation, transmission, and distribution of electricity. DOE derives marginal site-to-power plant factors based on the version of the National Energy Modeling System (NEMS) that corresponds to *AEO2015*. The factors change over time in response to projected changes in the types of power plants projected to provide electricity to the country. Figure 10.5.3 shows the site-to-power plant factors from 2019 to 2040. For years after 2040 (the last year in the *AEO*), DOE holds the site-to-power plant factor constant at the 2040 value.

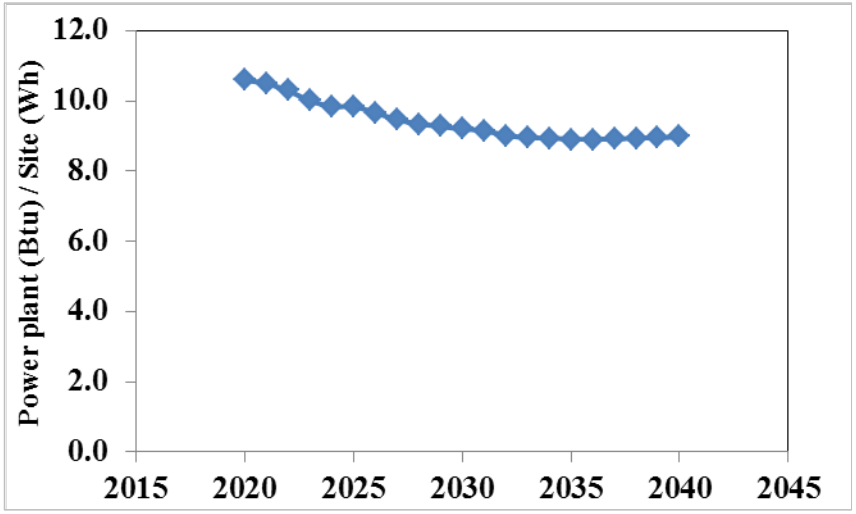

Figure 10.5.3 Primary to Site Energy Use Factor for CPB Electricity Use

10.5.7 Full-Fuel-Cycle Energy Factors

The full-fuel-cycle (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. To complete the full-fuel-cycle by encompassing the energy consumed in extracting, processing, and transporting or distributing primary fuels, which are referred to as “upstream” activities, DOE develops multipliers using the data and projections generated by the NEMS used for *AEO2015*. The *AEO* provides extensive information about the energy system, including projections of future oil, natural gas and coal supply, energy use for oil and gas field and refinery operations, and fuel consumption and emissions related to electric power production. This information can be used to define a set of parameters representing the energy intensity of energy production. The method used to calculate FFC energy multipliers is described in appendix 10B.

Table 10.5.3 shows the upstream energy multipliers used for commercial packaged boilers for selected years. The multipliers are applied to site energy. For years after 2040 (the last year in the *AEO*), DOE maintains the 2040 value.

Table 10.5.3 Upstream Energy Multipliers (Based on *AEO2015*)

	2020	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Electricity	4.4%	4.5%	4.6%	4.5%	4.5%	4.5%	4.5%
Natural Gas	12.3%	12.4%	12.3%	12.2%	12.3%	12.3%	12.3%
Petroleum Fuels	17.1%	16.9%	16.5%	16.5%	16.5%	16.5%	16.5%

10.6 NET PRESENT VALUE OF CONSUMER BENEFITS

Listed below are the inputs to DOE's calculation of the NPV of costs and savings.

- total installed cost per unit,
- annual per-unit savings in operation cost,
- shipments,
- equipment stock ($STOCK_V$),
- total annual increases in installed cost (*TIC*),
- total annual operating cost (*OCS*),
- discount factor (*DF*),
- present value of costs (*PVC*), and
- present value of savings (*PVS*).

The *total annual increase in installed cost* is equal to the annual change in the total per-unit installed cost (difference between no-new-standards case and standards case) multiplied by the shipments projected for each TSL. As with calculating energy savings, DOE does not use no-new-standards-case shipments to calculate total annual installed costs for all of the equipment classes. DOE uses the projected shipments and stock for each TSL to calculate costs.

The annual operating cost includes energy, repair, and maintenance costs. The *total annual savings in operating cost* are equal to the change in the annual operating costs (difference between no-new-standards case and standards case) per unit multiplied by the shipments projected for each TSL. As with calculating total annual installed costs, DOE uses standards-case shipments to calculate savings in operating cost.

10.6.1 Total Installed Cost per Unit

DOE describes the total per-unit installed cost for each equipment class as by efficiency level in chapter 8, Life-Cycle Cost and Payback Period Analysis. Because the total per-unit annual installed cost depends directly on efficiency, DOE uses the shipments-weighted efficiencies for the no-new-standards and standards cases, combined with the total installed cost presented in chapter 8, to estimate the shipments-weighted total per-unit average annual installed cost under the no-new-standards and standards cases. Table 10.6.1 shows the average installed cost of commercial packaged boilers in 2019 for the no-new-standards and standards cases for the eight equipment classes considered for amended standards by EL, and Table 10.6.2 presents the information by TSL. For reasons discussed in chapter 8 of this NOPR TSD, DOE uses a constant price assumption for the default projection in the NIA. The constant price trend is used for the reference, high, and low cases.

As discussed in chapter 8 in the 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.

Table 10.6.1 Average Installed Cost of Commercial Packaged Boilers in 2019 for the No-New-Standards and Standards Cases by EL (2014$)

Equipment Class	No-New-Standards Case	Efficiency Level						
		1	2	3	4	5	6	7
Small Gas-Fired Hot Water Commercial Packaged Boilers	$33,473	$33,538	$33,687	$34,651	$35,175	$40,697	$41,269	$46,572
Large Gas-Fired Hot Water Commercial Packaged Boilers	$119,648	$120,973	$123,858	$127,602	$167,357	$176,194	NA	NA
Small Oil-Fired Hot Water Commercial Packaged Boilers	$30,057	$30,414	$31,004	$31,754	$33,756	$35,496	$52,862	NA
Large Oil-Fired Hot Water Commercial Packaged Boilers	$77,036	$80,090	$89,059	$95,449	$157,396	NA	NA	NA
Small Gas-Fired Steam Commercial Packaged Boilers	$23,882	$24,221	$24,623	$25,197	$26,010	$28,107	NA	NA
Large Gas-Fired Steam Commercial Packaged Boilers	$88,710	$88,941	$89,689	$90,856	$92,798	$95,600	$101,397	NA
Small Oil-Fired Steam Commercial Packaged Boilers	$23,761	$24,522	$25,637	$28,572	NA	NA	NA	NA
Large Oil-Fired Steam Commercial Packaged Boilers	$72,190	$74,373	$79,148	$86,793	NA	NA	NA	NA

Table 10.6.2 Average Installed Cost of Commercial Packaged Boilers in 2019 for the No-New-Standards and Standards Cases by TSL (2014$)

Equipment Class	No-New-Standards Case	Trial Standard Levels				
		1	2	3	4	5
Gas-Fired Hot Water Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h	$33,473	$34,651	$35,175	$41,269	$46,572	$46,572
Gas-Fired Hot Water Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h	$119,648	$123,858	$127,602	$127,602	$176,194	$176,194
Oil-Fired Hot Water Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h	$30,057	$33,756	$33,756	$33,756	$35,496	$52,862
Oil-Fired Hot Water Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h	$77,036	$80,090	$89,059	$89,059	$95,449	$157,396
Gas-Fired Steam Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h	$23,882	$25,197	$26,010	$26,010	$28,107	$28,107
Gas-Fired Steam Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h	$88,710	$92,798	$95,600	$95,600	$101,397	$101,397
Oil-Fired Steam Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h	$23,761	$24,522	$25,637	$25,637	$28,572	$28,572
Oil-Fired Steam Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h	$72,190	$74,373	$79,148	$79,148	$86,793	$86,793

10.6.2 Annual Operating Cost per Unit

The per-unit annual operating cost includes costs for energy, repair, and maintenance. DOE determines the per-unit annual savings in energy costs by multiplying the per-unit annual savings in energy consumption developed for each equipment class by the appropriate energy price. DOE considers operating costs separately for commercial and residential boiler users.

Estimates of the per-unit annual energy consumption for the no-new-standards case and each standards case were presented in section 10.5.1. DOE projects the per-unit annual energy consumption for the no-new-standards case for all equipment classes by applying a growth trend in efficiency.

Energy prices and trends in energy prices are described in chapter 8. DOE projects energy prices based on annual changes in average commercial and residential energy prices in EIA's *AEO2015* reference case scenario.

DOE describes the total per-unit repair and maintenance costs for each equipment class by efficiency level in chapter 8. Because the per-unit repair and maintenance costs depend directly on efficiency, DOE uses the efficiencies for the no-new-standards and standards cases presented in section 10.4, combined with the repair and maintenance costs presented in chapter 8, to estimate the per-unit average repair and maintenance costs under the no-new-standards and standards cases.

Table 10.6.3 shows the average operating cost of commercial packaged boilers in 2019 for the no-new-standards and standards cases for the eight equipment classes considered for amended standards by EL, and Table 10.6.4 presents the information by TSL. The operating costs change over time, depending on change in annual energy use and energy prices.

Table 10.6.3 Average Annual Operating Cost of Commercial Packaged Boilers in 2019 for the No-New-Standards and Standards Cases by EL (2014$)

Equipment Class	No-New-Standards Case	Efficiency Level						
		1	2	3	4	5	6	7
Small Gas-Fired Hot Water Commercial Packaged Boilers	$9,981	$9,971	$9,950	$9,869	$9,820	$9,610	$9,443	$9,052
Large Gas-Fired Hot Water Commercial Packaged Boilers	$40,893	$40,759	$40,506	$40,221	$38,742	$37,390	NA	NA
Small Oil-Fired Hot Water Commercial Packaged Boilers	$16,812	$16,729	$16,605	$16,463	$16,133	$15,952	$15,160	NA
Large Oil-Fired Hot Water Commercial Packaged Boilers	$122,095	$121,144	$119,009	$117,821	$114,972	NA	NA	NA
Small Gas-Fired Steam Commercial Packaged Boilers	$9,491	$9,437	$9,379	$9,304	$9,209	$8,998	NA	NA
Large Gas-Fired Steam Commercial Packaged Boilers	$42,512	$42,455	$42,286	$42,042	$41,668	$41,274	$40,362	NA
Small Oil-Fired Steam Commercial Packaged Boilers	$23,080	$22,886	$22,652	$22,145	NA	NA	NA	NA
Large Oil-Fired Steam Commercial Packaged Boilers	$121,302	$120,146	$118,072	$115,355	NA	NA	NA	NA

Table 10.6.4 Average Annual Operating Cost of Commercial Packaged Boilers in 2019 for the No-New-Standards and Standards Cases by TSL (2014$)

Equipment Class	No-New-Standards Case	Trial Standard Levels				
		1	2	3	4	5
Gas-Fired Hot Water Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h	$9,981	$9,869	$9,820	$9,443	$9,052	$9,052
Gas-Fired Hot Water Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h	$40,893	$40,506	$40,221	$40,221	$37,390	$37,390
Oil-Fired Hot Water Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h	$16,812	$16,133	$16,133	$16,133	$15,952	$15,160
Oil-Fired Hot Water Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h	$122,095	$121,144	$119,009	$119,009	$117,821	$114,972
Gas-Fired Steam Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h	$9,491	$9,304	$9,209	$9,209	$8,998	$8,998
Gas-Fired Steam Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h	$42,512	$41,668	$41,274	$41,274	$40,362	$40,362
Oil-Fired Steam Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h	$23,080	$22,886	$22,652	$22,652	$22,145	$22,145
Oil-Fired Steam Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h	$121,302	$120,146	$118,072	$118,072	$115,355	$115,355

10.6.3 Equipment Stock

The stock of equipment in any given year depends on annual shipments and the lifetime of a given equipment class. The NIA model keeps track of the number of units shipped each year. The lifetime of a unit determines how many units shipped in previous years survive in the given year. DOE assumes that equipment have an increasing probability of retiring as they age. The probability of survival as a function of years since purchase is termed the survival function. Refer to chapter 9 for further details on the survival functions that DOE uses in its analysis.

10.6.4 Increases in Total Annual Installed Cost

The increase in total annual installed cost for equipment under any given standards case is the product of the increase in total installed cost per unit attributable to the standard and the number of units of each vintage. This method accounts for differences in total installed cost from year to year.

10.6.5 Savings in Total Annual Operating Cost

The savings in total annual operating cost for any given TSL is the product of the annual per-unit savings in operating cost attributable to the standard and the number of units of each vintage. This method accounts for the year-to-year differences in annual operating cost savings.

As previously stated, DOE does not apply a rebound effect to adjust its estimates of energy savings because it is unlikely that commercial consumers will use a higher-efficiency boiler more than a baseline one.

10.6.6 Discount Factor

DOE multiplies monetary values in future years by a discount factor to determine the present value. The discount factor (DF) is described by the equation:

$$DF = \frac{1}{(1+r)^{(y-yp)}}$$

Eq. 10.9

Where:

r = discount rate,
y = year of the monetary value, 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 packaged boilers (see chapter 8), it used national discount rates to calculate national NPV. DOE estimates 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*.[3] DOE defines the present year as 2015.

10.6.7 Present Value of Increased Installed Cost and Savings

The present value of increased installed cost is the difference between installation cost in each standards case and the no-new-standards case discounted to the present and summed throughout the period over which DOE is considering the installation of units (from the compliance date of standards, 2019, through 2048). DOE calculates annual increases in installed cost as the difference in total installed cost for new equipment purchased each year, multiplied by the shipments in the standards case.

The present value of annual savings in operating cost is the difference between the no-new-standards case and each standards case discounted to the present and summed throughout the period from the compliance date, 2019, to the time when the last unit installed in 2019–2048 is retired from service.

Savings represent decreases in operating cost (including fuel costs, repair, and maintenance) associated with the more energy efficient equipment purchased in each 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.

10.7 NATIONAL ENERGY SAVINGS AND NET PRESENT VALUE RESULTS

10.7.1 National Energy Savings

This section provides the NES that DOE calculates for each of the TSLs analyzed for commercial packaged boilers. See Table 10.7.1 for primary energy savings by EL, Table 10.7.2 for primary energy savings by TSL, Table 10.7.3 for FFC energy savings by EL, and Table 10.7.4 for FFC energy savings by TSL. DOE bases the inputs to the NIA model on weighted-average values, producing results that are discrete point values, rather than a distribution of values such as is generated by the life-cycle cost and payback period analysis.

Table 10.7.1 Primary National Energy Savings for Commercial Packaged Boilers by EL (quads)

Equipment Class	Efficiency Level						
	1	2	3	4	5	6	7
Small Gas-Fired Hot Water Commercial Packaged Boilers	0.012	0.038	0.138	0.199	0.466	0.708	1.332
Large Gas-Fired Hot Water Commercial Packaged Boilers	0.015	0.043	0.075	0.241	0.617	NA	NA
Small Oil-Fired Hot Water Commercial Packaged Boilers	0.002	0.006	0.010	0.019	0.023	0.043	NA
Large Oil-Fired Hot Water Commercial Packaged Boilers	0.004	0.012	0.017	0.029	NA	NA	NA
Small Gas-Fired Steam Commercial Packaged Boilers	0.001	0.002	0.009	0.018	0.038	NA	NA
Large Gas-Fired Steam Commercial Packaged Boilers	0.000	0.000	0.004	0.009	0.014	0.026	NA
Small Oil-Fired Steam Commercial Packaged Boilers	0.002	0.004	0.010	NA	NA	NA	NA
Large Oil-Fired Steam Commercial Packaged Boilers	0.003	0.008	0.014	NA	NA	NA	NA

Table 10.7.2 Primary National Energy Savings for Commercial Packaged Boilers by TSL (quads)

Equipment Class	Trial Standard Levels				
	1	2	3	4	5
Gas-Fired Hot Water Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h	0.138	0.199	0.708	1.332	1.332
Gas-Fired Hot Water Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h	0.043	0.075	0.075	0.617	0.617
Oil-Fired Hot Water Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h	0.019	0.019	0.019	0.023	0.043
Oil-Fired Hot Water Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h	0.004	0.012	0.012	0.017	0.029
Gas-Fired Steam Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h	0.009	0.018	0.018	0.038	0.038
Gas-Fired Steam Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h	0.009	0.014	0.014	0.026	0.026
Oil-Fired Steam Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h	0.002	0.004	0.004	0.010	0.010
Oil-Fired Steam Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h	0.003	0.008	0.008	0.014	0.014

Table 10.7.3 Full-Fuel-Cycle National Energy Savings for Commercial Packaged Boilers by EL (quads)

Equipment Class	Efficiency Level						
	1	2	3	4	5	6	7
Small Gas-Fired Hot Water Commercial Packaged Boilers	0.014	0.043	0.155	0.223	0.525	0.797	1.496
Large Gas-Fired Hot Water Commercial Packaged Boilers	0.017	0.049	0.085	0.271	0.693	NA	NA
Small Oil-Fired Hot Water Commercial Packaged Boilers	0.003	0.007	0.011	0.022	0.027	0.050	NA
Large Oil-Fired Hot Water Commercial Packaged Boilers	0.004	0.015	0.020	0.033	NA	NA	NA
Small Gas-Fired Steam Commercial Packaged Boilers	0.001	0.002	0.010	0.020	0.042	NA	NA
Large Gas-Fired Steam Commercial Packaged Boilers	0.000	0.001	0.004	0.010	0.016	0.029	NA
Small Oil-Fired Steam Commercial Packaged Boilers	0.002	0.005	0.011	NA	NA	NA	NA
Large Oil-Fired Steam Commercial Packaged Boilers	0.003	0.009	0.017	NA	NA	NA	NA

Table 10.7.4 Full-Fuel-Cycle National Energy Savings for Commercial Packaged Boilers by TSL (quads)

Equipment Class	Trial Standard Levels				
	1	2	3	4	5
Gas-Fired Hot Water Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h	0.155	0.223	0.797	1.496	1.496
Gas-Fired Hot Water Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h	0.049	0.085	0.085	0.693	0.693
Oil-Fired Hot Water Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h	0.022	0.022	0.022	0.027	0.050
Oil-Fired Hot Water Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h	0.004	0.015	0.015	0.020	0.033
Gas-Fired Steam Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h	0.010	0.020	0.020	0.042	0.042
Gas-Fired Steam Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h	0.010	0.016	0.016	0.029	0.029
Oil-Fired Steam Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h	0.002	0.005	0.005	0.011	0.011
Oil-Fired Steam Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h	0.003	0.009	0.009	0.017	0.017

10.7.2 Net Present Value of Consumer Benefit

This section provides results of calculating the NPV for each TSL considered for commercial packaged boilers. Results, which are cumulative, are shown as the discounted dollar value of the net savings. See Table 10.7.5 for NPV results with a 3-percent discount rate applied by EL, Table 10.7.6 for a 3-percent discount rate by TSL, Table 10.7.7 for a 7-percent discount rate by EL, and Table 10.7.8 for a 7-percent discount rate by TSL. DOE bases the inputs to the NIA model on weighted-average values, yielding results that are discrete point values, rather than a distribution of values such as produced by the life-cycle cost and payback period analyses. A negative NPV indicates that the costs of a standard at a given TSL exceed the savings.

Table 10.7.5 Net Present Value of Consumer Benefit for Commercial Packaged Boilers, Discounted at 3 Percent by EL (billion 2014$)

Equipment Class	Efficiency Level						
	1	2	3	4	5	6	7
Small Gas-Fired Hot Water Commercial Packaged Boilers	0.053	0.159	0.463	0.665	0.366	1.570	3.187
Large Gas-Fired Hot Water Commercial Packaged Boilers	0.048	0.129	0.208	-0.005	1.446	NA	NA
Small Oil-Fired Hot Water Commercial Packaged Boilers	0.036	0.088	0.147	0.278	0.337	0.372	NA
Large Oil-Fired Hot Water Commercial Packaged Boilers	0.063	0.199	0.271	0.331	NA	NA	NA
Small Gas-Fired Steam Commercial Packaged Boilers	0.004	0.008	0.038	0.074	0.145	NA	NA
Large Gas-Fired Steam Commercial Packaged Boilers	0.001	0.003	0.017	0.039	0.060	0.110	NA
Small Oil-Fired Steam Commercial Packaged Boilers	0.032	0.070	0.148	NA	NA	NA	NA

Equipment Class	Efficiency Level						
	1	2	3	4	5	6	7
Large Oil-Fired Steam Commercial Packaged Boilers	0.048	0.134	0.244	NA	NA	NA	NA

Table 10.7.6 Net Present Value of Consumer Benefit for Commercial Packaged Boilers, Discounted at 3 Percent by TSL (billion 2014$)

Equipment Class	Trial Standard Levels				
	1	2	3	4	5
Gas-Fired Hot Water Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h	0.463	0.665	1.570	3.187	3.187
Gas-Fired Hot Water Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h	0.129	0.208	0.208	1.446	1.446
Oil-Fired Hot Water Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h	0.278	0.278	0.278	0.337	0.372
Oil-Fired Hot Water Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h	0.063	0.199	0.199	0.271	0.331
Gas-Fired Steam Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h	0.038	0.074	0.074	0.145	0.145
Gas-Fired Steam Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h	0.039	0.060	0.060	0.110	0.110
Oil-Fired Steam Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h	0.032	0.070	0.070	0.148	0.148
Oil-Fired Steam Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h	0.048	0.134	0.134	0.244	0.244

Table 10.7.7 Net Present Value of Consumer Benefit for Commercial Packaged Boilers, Discounted at 7 Percent by EL (billion 2014$)

Equipment Class	Efficiency Level						
	1	2	3	4	5	6	7
Small Gas-Fired Hot Water Commercial Packaged Boilers	0.015	0.043	0.092	0.132	-0.323	0.052	0.209
Large Gas-Fired Hot Water Commercial Packaged Boilers	0.012	0.027	0.036	-0.298	0.089	NA	NA
Small Oil-Fired Hot Water Commercial Packaged Boilers	0.011	0.026	0.043	0.080	0.093	0.040	NA
Large Oil-Fired Hot Water Commercial Packaged Boilers	0.019	0.059	0.080	0.067	NA	NA	NA
Small Gas-Fired Steam Commercial Packaged Boilers	0.002	0.003	0.012	0.022	0.038	NA	NA
Large Gas-Fired Steam Commercial Packaged Boilers	0.000	0.001	0.006	0.013	0.020	0.035	NA
Small Oil-Fired Steam Commercial Packaged Boilers	0.010	0.021	0.044	NA	NA	NA	NA
Large Oil-Fired Steam Commercial Packaged Boilers	0.016	0.044	0.079	NA	NA	NA	NA

Table 10.7.8 Net Present Value of Consumer Benefit for Commercial Packaged Boilers, Discounted at 7 Percent by TSL (billion 2014$)

Equipment Class	Trial Standard Levels				
	1	2	3	4	5
Gas-Fired Hot Water Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h	0.092	0.132	0.052	0.209	0.209
Gas-Fired Hot Water Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h	0.027	0.036	0.036	0.089	0.089
Oil-Fired Hot Water Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h	0.080	0.080	0.080	0.093	0.040
Oil-Fired Hot Water Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h	0.019	0.059	0.059	0.080	0.067
Gas-Fired Steam Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h	0.012	0.022	0.022	0.038	0.038
Gas-Fired Steam Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h	0.013	0.020	0.020	0.035	0.035
Oil-Fired Steam Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h	0.010	0.021	0.021	0.044	0.044
Oil-Fired Steam Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h	0.016	0.044	0.044	0.079	0.079

REFERENCES

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2. U.S. Department of Energy–Energy Information Administration. *Annual Energy Outlook 2014 with Projections to 2040*. 2014. Washington, DC. DOE/EIA-0383(2014). www.eia.gov/forecasts/archive/aeo14/.

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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® spreadsheets accessible on the Internet from the U.S. Department of Energy's (DOE's) commercial packaged boiler rulemaking page: https://www1.eere.energy.gov/buildings/appliance_standards/rulemaking.aspx/ruleid/79. From that page, follow the links to the notice of proposed rulemaking phase of the rulemaking and then to the analytical tools.

10A.2 STARTUP

The National Impact Analyses (NIA) spreadsheets enable the user to examine selected national impacts attributable to each efficiency level considered for commercial packaged boilers. To use the spreadsheet, DOE assumes the user has access to a personal computer with a hardware configuration capable of running Microsoft Excel 2003, or a later version.

10A.3 DESCRIPTION OF NATIONAL IMPACT ANALYSES WORKSHEETS

The NIA spreadsheets perform calculations to project the change in national energy use and net present value of financial impacts due to revised energy efficiency standards. The energy use and associated costs for a given energy efficiency standard level are determined by calculating the shipments and then calculating the energy use and costs for all boilers shipped under that standard. The differences between the standards and no-new-standards case can then be compared and the overall energy savings and net present values determined. The NIA spreadsheets consist of the worksheets described in Table 10A.3.1.

Table 10A.3.1 Worksheets Contained in the NIA Spreadsheet

Flow Chart	Contains an introduction to each worksheet and a flow chart of spreadsheet inputs and outputs.
NIA Summary	Contains source energy savings results matrix, net present value results matrix, and shipment, equipment cost and energy use in 2019 for each equipment class.
SGHW	Contains small gas-fired hot water boiler NIA calculations.
LGHW	Contains large gas-fired Hot Water boiler NIA calculations.
SHOW	Contains small oil-fired Hot Water boiler NIA calculations.
LOHW	Contains large oil-fired Hot Water boiler NIA calculations.
SGST	Contains small gas-fired steam boiler NIA calculations.
LGST	Contains large gas-fired steam boiler NIA calculations.
SOST	Contains small oil-fired steam boiler NIA calculations.
LOST	Contains large oil-fired steam boiler NIA calculations.
Labels	Contains labels and definitions used throughout the spreadsheet – Also, worksheet where the efficiency levels (ELs) used in the analysis are defined.
LCC Output	Life-cycle cost (LCC) output contains energy use, electricity use, total installed price, annual repair, maintenance costs, energy price, electricity price, price trends, and savings for each equipment class.
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 boiler divided by a change in the relative price.
Energy Use Trend	Contains look-up tables to adjust for the climate conditions and building shell characteristics during the analysis period.
Condensing Market Share	Contains look-up table presenting the market share for condensing boilers during the analysis period.
Historical Shipments	Includes historical shipments data for each equipment class.
Fuel Prices	Contains energy prices for each equipment class by year.
AEO Building Forecast	Includes *Annual Energy Outlook* (*AEO*) forecasts of building stocks and building starts for both commercial and residential buildings.
Shipment Forecast	Contains shipment forecast.
New Saturation	Contains market saturation data for each equipment class in new buildings.
Lifetime	Includes the lifetime and the retirement function for each equipment class.
NIA TSD Tables	Contains the majority of tables reported in the notice and technical support document.
Summary Results	Contains intermediate outputs referenced from Output Data for use in downstream (ImSET) analysis.
for MIA	Contains shipment projections for export to the MIA model.
Shipments	Contains shipment projections and other intermediate results.
Output Data	Contains intermediate outputs for use in downstream (ImSET) analysis.
for ImSET	Results used as input to the ImSET analysis of employment impacts.
for NIAplus	Results used as input to the NIAplus analysis of emissions impacts.
Intermed. for NIAplus	Calculation of intermediate results feeding both the NIA Summary tables and the NIAplus downstream analysis.
Intermed2 for NIAplus	Calculation of intermediate results feeding both the NIA Summary tables and the NIAplus downstream analysis.
for NIAplus Com	Commercial sector results used as input to the NIAplus analysis of emissions impacts.
for NIAplus Res	Residential sector results used as input to the NIAplus analysis of emissions impacts.

10A.4 BASIC INSTRUCTIONS FOR OPERATING THE NATIONAL IMPACT ANALYSIS SPREADSHEET

Basic instructions for operating the NIA spreadsheet are as follows:

1) Once the NIA spreadsheet file has been downloaded from the DOE web site, 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) The user can change the parameters in the sheet “NIA Summary”. The default parameters (shown in Figure 10A.4.1) are the following:

    a) Year Standards in Effect: Set to 2019. To change value, click on cell D6 and change to desired year.

b) Analysis period: Set to 30. To change value, click on cell D7 and change to desired analysis period. The year that analysis ends (cell D8) is automatically calculated based on the year standards in effect and analysis period.

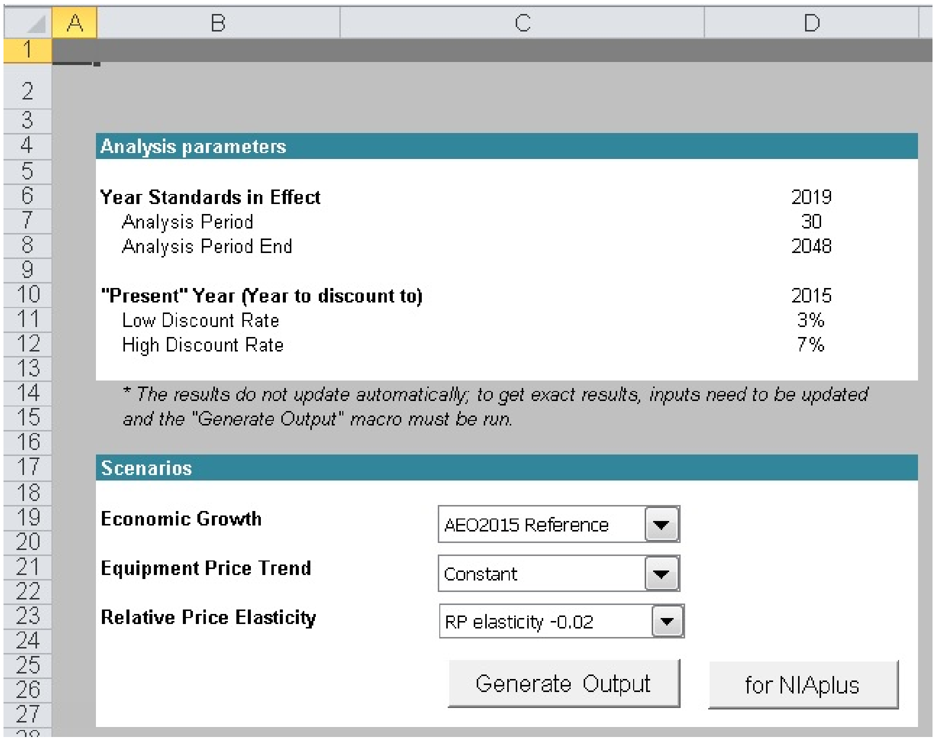
c) Discount Rates: Set to 7%. To change value, click on cell D44 in "Labels" and change to desired value (7% or 3%).

d) Discount Year: Set to 2015. To change value, click on cell D10 and change to desired year.

e) Economic Growth Scenario: Set to "AEO2015 Reference". To change value, click on the pull down menu next to cell C19 "Economic Growth Scenario" and change to desired scenario.

f) Equipment Price Trend Scenario: Set to "Constant". To change value, click on the pull down menu next to cell C21 "Equipment Price Trend" and change to desired scenario.

g) Relative Price Elasticity: Set to -0.02. To change value, click on the pull down menu next to cell C23 "Relative Price Elasticity" and change to desired elasticity.



Analysis parameters

Year Standards in Effect	2019
Analysis Period	30
Analysis Period End	2048
"Present" Year (Year to discount to)	2015
Low Discount Rate	3%
High Discount Rate	7%

** The results do not update automatically; to get exact results, inputs need to be updated and the "Generate Output" macro must be run.*

Scenarios

Economic Growth	AEO2015 Reference
Equipment Price Trend	Constant
Relative Price Elasticity	RP elasticity -0.02

Figure 10A.4.1 Default User Input Parameters

4) Choose the reporting of results by Efficiency Level (EL) or Trial Standard Level (TSL) using the pull down menu next to cell C31 "Report by EL or TSL."

5) The button “Generate Output” updates the analysis results based on user inputs: National Energy Savings by EL or TSL in cells H7 to O14 and Net Present Values by EL or TSL in cells H22 to O42.

6) The button “for NIAplus” populates the “for NIAplus” tab as input to the NIAplus model for the Reference, High Growth, and Low Growth cases.

7) Current application sector: because commercial packaged boilers 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 cell D22 in “Labels”. The annual shipment, unit energy use, equipment cost etc. of commercial packaged boilers at no-new-standards-case and higher efficiency levels under the selected application sector could be seen in the accounting worksheets named by equipment classes, namely “SGHW”, “LGHW”, “SOHW”, “LOHW”, “SGST”, “LGST”, “SOST”, and “LOST”. 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 by (shown in Figure 10A.4.2):

1) In Excel 2010 and later, go to the tab “Formulas” in the Office ribbon.

2) Click on the button “Calculation Options” and select “Automatic”.

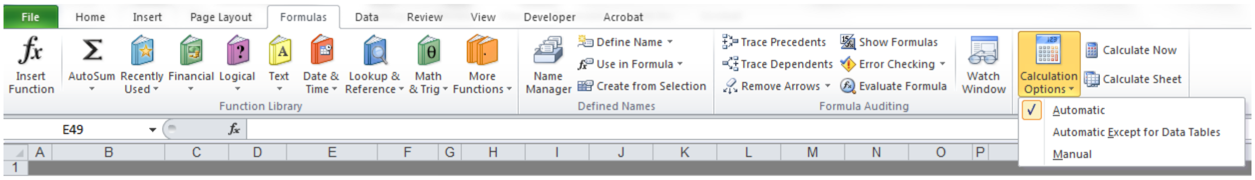


Figure 10A.4.2 Setting the Spreadsheet to Automatic Calculation Mode

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.

APPENDIX 10B. FULL-FUEL-CYCLE MULTIPLIERS

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APPENDIX 10B. FULL-FUEL-CYCLE MULTIPLIERS

10B.1 INTRODUCTION

This appendix summarizes the methods the U.S. Department of Energy (DOE) used to calculate full-fuel-cycle (FFC) energy savings expected to result from amended standards for commercial packaged boilers (CPBs). 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 losses associated with 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 FFC 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, in British thermal units (Btu), of a primary fuel used to provide an end-use service.[a] Site energy use is defined as the energy consumed at the point-of-use in a building or industrial process. Where natural gas or petroleum fuels are consumed at a site, such as in a boiler, 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).[b] In such a case, the primary energy is equal to the amount of primary energy required to generate and deliver electricity to the site.[c] 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 a FFC analysis must distinguish between electricity generated by fossil fuels and uranium, and electricity generated from renewable sources (*e.g.*, wind, solar, and hydropower). For the former, the upstream fuel cycle relates to the amount of fuel consumed at the power plant. For the latter, no fuel *per se* is used, so there is no upstream component.

10B.2 METHODOLOGY

The mathematical approach to FFC is addressed in the paper *A Mathematical Analysis of Full Fuel Cycle Energy Use*, and details about the fuel production chain analysis are presented in

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[a] A British thermal unit is the amount of energy needed to cool or heat one pound of water by one degree Fahrenheit.

[b] A kilowatt-hour is a unit of energy equivalent to one kilowatt (1 kW) of power expended for one hour. A kilowatt hour is a unit of energy equal to 1,000 watt-hours. The total energy in kilowatt-hours is the product of the power in kilowatts and the time in hours. 1 kWh = 3412 Btu.

[c] Quad is a unit of energy, short for quadrillion, where 1 quad = 10^{15} Btu or 293.1 billion kWh.

the paper *Projections of Full-Fuel-Cycle Energy and Emissions Metrics*.[2,3] The methods used to calculate FFC energy use are summarized here.

When all energy quantities are normalized to the same units, FFC energy use can be represented as the product of the primary energy use and an FFC multiplier. Mathematically, the FFC multiplier is a function of a set of parameters that represent the energy intensity and material losses at each stage of energy production. These 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 output, 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 (MMBtu/physical unit).
- z_x(s) is the emissions intensity for fuel x (mass of pollutant s per physical unit of x produced).

The parameters are calculated as a function of an annual time step; hence, for evaluating the effects of potential amended standards, a time series of annual values is used to estimate the FFC energy and emissions savings in each year of the analysis period as well as cumulatively. Fossil fuel quantities are converted to energy units using the heat content factor q_x. To convert electricity in kWh to primary energy units, on-site electricity consumption is multiplied by the site-to-primary energy use factor, described in chapter 10.

The FFC multiplier is denoted as 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 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 FFC analysis utilizes data and projections published in the *Annual Energy Outlook* (*AEO*); in the case of this rulemaking, the *AEO2015*.[4] Table 10B.2.1 summarizes the *AEO* data used as inputs to the calculation of various parameters. The column titled "*AEO* Table" gives the name of the table that provided the reference data.

Table 10B.2.1 Dependence of FFC Parameters on *AEO* Inputs

Parameter	Fuel	*AEO* Table	Variables
q_x	All	Conversion Factors	MMBtu per physical unit
a_x	All	Electricity Supply, Disposition, Prices, and Emissions	Generation by fuel type
		Energy Consumption by Sector and Source	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	Refining only energy use
		Liquid Fuels Supply and Disposition	Crude supply by source
		International Liquids Supply and Disposition	Crude oil imports
		Oil and Gas Supply	Domestic crude oil production
c_{nn}	Natural gas	Oil and Gas Supply	U.S. dry gas production
		Natural Gas Supply, Disposition and Prices	Pipeline, lease, and plant fuel
z_x	All	Electricity Supply, Disposition, Prices and Emissions	Power sector emissions

The *AEO* does not provide all the information needed to estimate total energy use in the fuel production chain. The *Projections of Full-Fuel-Cycle Energy and Emissions Metrics* paper describes the additional data sources needed to complete the analysis.[3] However, the time dependence in the FFC multipliers arises exclusively from variables taken from the *AEO*.

10B.3 FULL-FUEL-CYCLE ENERGY MULTIPLIERS

FFC energy multipliers for selected years are presented in Table 10B.3.1. The 2040 value was held constant for the analysis period beyond 2040, which is the last year in the *AEO2015* projection. The multipliers are applied to site energy. The multiplier for electricity reflects the shares of various primary fuels in total electricity generation throughout the forecast period.

Table 10B.3.1 Energy Multipliers for the Full-Fuel-Cycle (Based on *AEO2015*)

	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
Petroleum Fuels	1.171	1.169	1.165	1.165	1.165	1.165	1.165

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APPENDIX 10C. TRIAL STANDARD LEVELS

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APPENDIX 10C. TRIAL STANDARD LEVELS

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 seven higher efficiency levels within each equipment class of commercial packaged boiler (CPB) equipment as described in chapters 5–10 of this notice of proposed rulemaking (NOPR) technical support document (TSD).

Subsequently, DOE identified Trial Standard Levels (TSLs) as possible standard proposals that reflect combined efficiency levels across all classes of analyzed CPB equipment. DOE developed TSLs so that each TSL is composed of energy efficiency levels from each equipment class that exhibits similar characteristics. For example, one of the TSLs consists of the maximum technologically feasible (max-tech) efficiency levels from each equipment class being 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.

This appendix describes DOE's method for selecting TSLs for CPB equipment. The following sections describe the criteria used for TSL selection associated with each TSL.

10C.2 TRIAL STANDARD LEVEL SELECTION CRITERIA

DOE selected five TSLs for this rulemaking based on the following criteria:

1. TSL 5 corresponds to the max-tech efficiency level for each equipment class.
2. TSL 4 is composed of the efficiency levels corresponding to the maximum net present value (NPV) at a 7 percent discount rate for each equipment class.
3. TSL 3 is composed of
    - the highest condensing level with a positive NPV at a 7 percent discount rate with less than 50 percent of customers with a net cost and a positive LCC for the small gas hot water CPB equipment class;
    - the efficiency level below the maximum NPV efficiency level at a 7 percent discount rate with less than 50 percent of customers with a net cost and a positive LCC for the large gas hot water CPB equipment class;
    - the efficiency level below the highest noncondensing efficiency level for the small oil hot water CPB equipment class;
    - the efficiency level corresponding to 3 percentage points above the large gas hot water CPB TSL 3 efficiency level for the large oil hot water CPB equipment class; and

- the efficiency level below the maximum NPV efficiency level at a 7 percent discount rate for all steam CPB equipment classes.

4. TSL 2 is composed of

    - the highest noncondensing efficiency level for small gas hot water and large gas hot water CPB equipment classes;

    - the efficiency level corresponding to 2 percentage points above the small gas hot water CPB TSL 2 efficiency level for the small oil hot water CPB equipment class;

    - the efficiency level corresponding to 3 percentage points above the large gas hot water CPB TSL 2 efficiency level for the large oil hot water CPB equipment class; and

    - the efficiency level below the maximum NPV efficiency level at a 7 percent discount rate for all steam CPB equipment classes.

5. TSL 1 is composed of

    - the efficiency level corresponding to one efficiency level below the highest noncondensing efficiency level for small gas hot water and large gas hot water equipment classes;

    - the efficiency level corresponding to 3 percentage points above the small gas hot water CPB TSL 1 efficiency level for the small oil hot water CPB equipment class;

    - the efficiency level corresponding to 2 percentage points above the large gas hot water CPB TSL 1 efficiency level for the large oil hot water CPB equipment class; and

    - the efficiency level that is two efficiency level steps below the maximum NPV efficiency level at a 7 percent discount rate for all steam CPB equipment classes.

Table 10C.2.1 presents the efficiency levels within each equipment class that belong to the TSL groupings. Table 10C.2.2 presents the efficiency (thermal, E_T, or combustion, E_C, depending on product class) for each equipment product class in each TSL that DOE considered.

Table 10C.2.1 TSL and Efficiency Levels Mapping for CPB Equipment

Equipment Class	Trial Standard Level				
	1	2	3	4	5
	EL	EL	EL	EL	EL
Small Gas-Fired Hot Water Commercial Packaged Boilers	3	4	6	7	7
Large Gas-Fired Hot Water Commercial Packaged Boilers	2	3	3	5	5
Small Oil-Fired Hot Water Commercial Packaged Boilers	4	4	4	5	6
Large Oil-Fired Hot Water Commercial Packaged Boilers	1	2	2	3	4
Small Gas-Fired Steam Commercial Packaged Boilers	3	4	4	5	5
Large Gas-Fired Steam Commercial Packaged Boilers	4	5	5	6	6
Small Oil-Fired Steam Commercial Packaged Boilers	1	2	2	3	3
Large Oil-Fired Steam Commercial Packaged Boilers	1	2	2	3	3

Table 10C.2.2 Trial Standard Levels for CPB Equipment by Thermal Efficiency and Combustion Efficiency

Equipment Class	Trial Standard Level*									
	1		2		3		4		5	
	E_T	E_C	E_T	E_C	E_T	E_C	E_T	E_C	E_T	E_C
Small Gas-Fired Hot Water Commercial Packaged Boilers	84%	n/a	85%	n/a	95%	n/a	99%	n/a	99%	n/a
Large Gas-Fired Hot Water Commercial Packaged Boilers	n/a	84%	n/a	85%	n/a	85%	n/a	97%	n/a	97%
Small Oil-Fired Hot Water Commercial Packaged Boilers	87%	n/a	87%	n/a	87%	n/a	88%	n/a	97%	n/a
Large Oil-Fired Hot Water Commercial Packaged Boilers	n/a	86%	n/a	88%	n/a	88%	n/a	89%	n/a	97%
Small Gas-Fired Steam Commercial Packaged Boilers	80%	n/a	81%	n/a	81%	n/a	83%	n/a	83%	n/a
Large Gas-Fired Steam Commercial Packaged Boilers	81%	n/a	82%	n/a	82%	n/a	84%	n/a	84%	n/a
Small Oil-Fired Steam Commercial Packaged Boilers	83%	n/a	84%	n/a	84%	n/a	86%	n/a	86%	n/a
Large Oil-Fired Steam Commercial Packaged Boilers	83%	n/a	85%	n/a	85%	n/a	87%	n/a	87%	n/a

* E_T stands for thermal efficiency, and E_C stands for combustion efficiency

APPENDIX 10D. NATIONAL NET PRESENT VALUE USING ALTERNATIVE SCENARIOS: SENSITIVITY ANALYSES

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10D.1 NET PRESENT VALUE SENSITIVITY ANALYSES USING ALTERNATIVE 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 Energy Information Administration's (EIA's) *Annual Energy Outlook 2015* (*AEO2015*).[1]

10D.1.1 Description of High and Low Economic Growth Scenarios

To generate national impact analysis (NIA) results reported in chapter 10 of this technical support document (TSD), DOE uses the Reference case energy price and building stock and construction projections 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.

Starting in 2018, energy prices are higher in the High Economic Growth scenario and lower in the Low Economic Growth scenario. Figure 10D.1.1 shows the residential sector fuel price projections for the different *AEO2015* scenarios and Figure 10D.1.2 shows commercial sector fuel price projections based on the *AEO2015* scenarios.

The High and Low Economic Growth scenarios also provide different building additions and stock projections that affect the commercial packaged boiler (CPB) shipments projections. Table 10D.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 10D.1.2 shows the total building starts, by year, for commercial and residential consumer sectors, and for the Low Economic Growth, Reference, and High Economic Growth *AEO2015* cases.

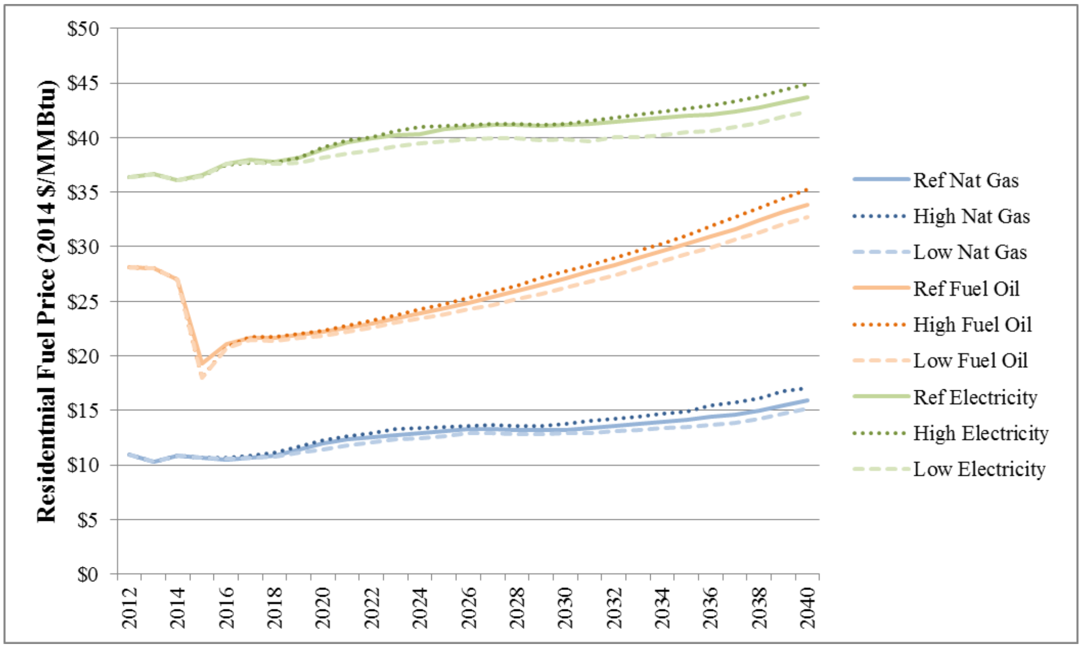

Figure 10D.1.1 Residential Sector Fuel Price Projections from *AEO2015*

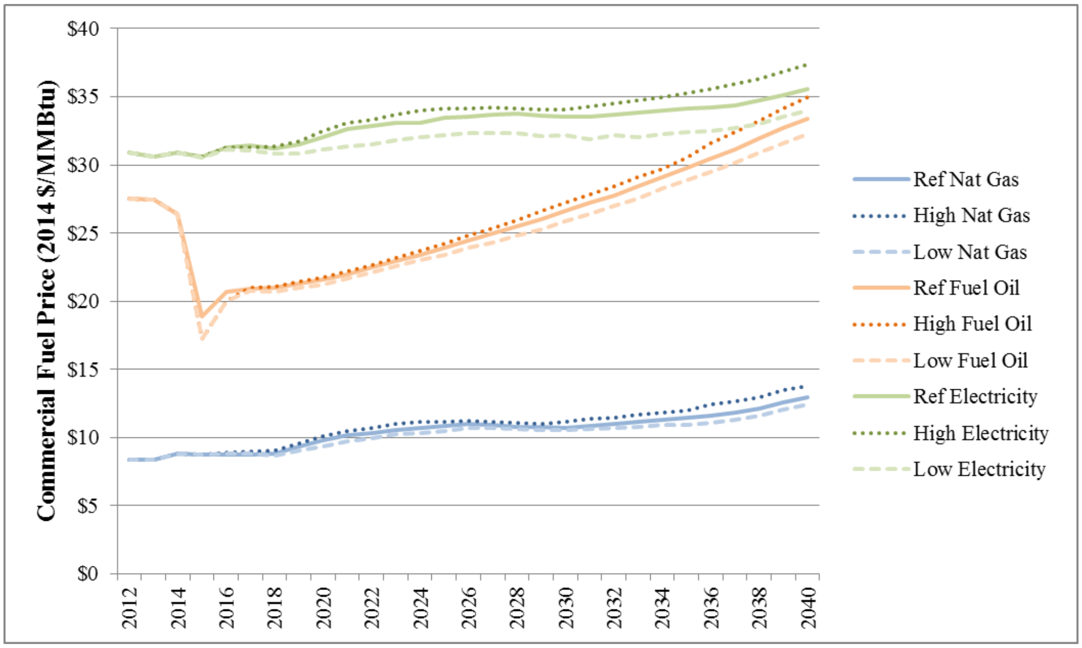

Figure 10D.1.2 Commercial Sector Fuel Price Projections from *AEO2015*

Table 10D.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 past 10 years of the AEO projections.

* Low Econ = Low Economic Growth scenario; Reference = Reference case; High Econ = High Economic Growth scenario

Table 10D.1.2 Building Start Projections from *AEO2015*

Year	Commercial Building Starts			Residential Building Starts		
	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	1,451	1,451	1,451	0.990	0.990	0.990
2014	1,546	1,546	1,546	1.062	1.062	1.062
2015	1,674	1,681	1,688	1.180	1.299	1.734
2016	1,758	1,787	1,843	1.126	1.410	2.070
2017	1,876	1,933	2,037	1.191	1.551	2.097
2018	1,915	2,014	2,102	1.184	1.629	2.187
2019	1,954	2,077	2,146	1.190	1.668	2.217
2020	1,960	2,089	2,198	1.206	1.693	2.281
2021	1,978	2,108	2,239	1.165	1.644	2.319
2022	1,980	2,106	2,256	1.146	1.638	2.341
2023	1,957	2,073	2,230	1.145	1.647	2.365
2024	1,923	2,037	2,190	1.160	1.672	2.392
2025	1,909	2,027	2,173	1.168	1.697	2.424
2026	1,890	2,007	2,138	1.161	1.699	2.464
2027	1,871	1,986	2,108	1.138	1.682	2.485
2028	1,860	1,973	2,091	1.085	1.642	2.453
2029	1,864	1,979	2,092	1.059	1.644	2.442
2030	1,864	1,987	2,105	1.046	1.661	2.443
2031	1,885	2,018	2,138	1.028	1.646	2.427
2032	1,955	2,094	2,213	1.007	1.602	2.397
2033	2,017	2,159	2,285	1.002	1.601	2.379
2034	2,077	2,220	2,362	0.978	1.608	2.383
2035	2,159	2,302	2,469	0.974	1.621	2.431
2036	2,246	2,391	2,568	0.971	1.624	2.469
2037	2,269	2,424	2,613	0.973	1.625	2.514
2038	2,273	2,437	2,638	0.973	1.625	2.534
2039	2,251	2,428	2,639	0.961	1.612	2.536
2040	2,223	2,408	2,626	0.962	1.622	2.554
2041	2,263	2,455	2,685	1.002	1.681	2.623
2042	2,303	2,503	2,745	1.006	1.693	2.654
2043	2,344	2,551	2,807	1.010	1.705	2.685
2044	2,385	2,601	2,870	1.013	1.717	2.716
2045	2,428	2,651	2,934	1.017	1.729	2.748
2046	2,471	2,703	2,999	1.021	1.741	2.781
2047	2,515	2,755	3,067	1.025	1.753	2.813
2048	2,559	2,808	3,135	1.029	1.766	2.846

Source: EIA, *AEO2015*, for 2013–2040. Commercial starts after 2040 projected by extrapolating the *AEO2015* growth over the past 10 years of the AEO projections; residential starts after 2040 projected by extrapolating the *AEO2015* growth over the past 10 years of the AEO projections and incorporating the National Energy Modeling System (NEMS) demolition rates.

[*] Low Econ = Low Economic Growth scenario; Reference = Reference case; High Econ = High Economic Growth scenario

As described in chapter 9, the no-new-standards case shipment projections were based on the commercial *AEO* Reference case. These projections were converted to high and low growth scenario projections by calculating an adjustment factor equal to the selected growth scenario commercial building starts divided by the reference case commercial building starts for each year. This yearly adjustment factor was then applied to the shipments forecast.

10D.2 SENSITIVITY ANALYSIS RESULTS

10D.2.1 High Economic Growth Scenarios

Table 10D.2.1 through Table 10D.2.4 show the resulting NPV for scenarios involving High Economic Growth case energy prices and building stock growth.

Table 10D.2.1 CPB Equipment: Net Present Value in Billions (2014$) at a 3-Percent Discount Rate by EL – High Economic Growth Scenario

Equipment Class	Efficiency Level						
	1	2	3	4	5	6	7
Small Gas-Fired Hot Water Commercial Packaged Boilers	0.061	0.182	0.540	0.776	0.540	1.913	3.857
Large Gas-Fired Hot Water Commercial Packaged Boilers	0.055	0.148	0.240	0.054	1.728	NA	NA
Small Oil-Fired Hot Water Commercial Packaged Boilers	0.041	0.101	0.169	0.320	0.389	0.451	NA
Large Oil-Fired Hot Water Commercial Packaged Boilers	0.072	0.228	0.311	0.388	NA	NA	NA
Small Gas-Fired Steam Commercial Packaged Boilers	0.004	0.009	0.043	0.083	0.166	NA	NA
Large Gas-Fired Steam Commercial Packaged Boilers	0.001	0.003	0.019	0.044	0.068	0.124	NA
Small Oil-Fired Steam Commercial Packaged Boilers	0.037	0.080	0.169	NA	NA	NA	NA
Large Oil-Fired Steam Commercial Packaged Boilers	0.055	0.152	0.277	NA	NA	NA	NA
Total	0.325	0.902	1.767	1.665	2.891	2.488	3.857

Table 10D.2.2 CPB Equipment: Net Present Value in Billions (2014$) at a 7-Percent Discount Rate by EL – High Economic Growth Scenario

Equipment Class	Efficiency Level						
	1	2	3	4	5	6	7
Small Gas-Fired Hot Water Commercial Packaged Boilers	0.017	0.050	0.110	0.157	-0.307	0.115	0.334
Large Gas-Fired Hot Water Commercial Packaged Boilers	0.013	0.032	0.044	-0.300	0.144	NA	NA
Small Oil-Fired Hot Water Commercial Packaged Boilers	0.012	0.029	0.049	0.090	0.106	0.056	NA
Large Oil-Fired Hot Water Commercial Packaged Boilers	0.022	0.067	0.090	0.080	NA	NA	NA
Small Gas-Fired Steam Commercial Packaged Boilers	0.002	0.004	0.013	0.024	0.044	NA	NA
Large Gas-Fired Steam Commercial Packaged Boilers	0.000	0.001	0.007	0.015	0.022	0.039	NA
Small Oil-Fired Steam Commercial Packaged Boilers	0.011	0.024	0.050	NA	NA	NA	NA

Equipment Class	Efficiency Level						
	1	2	3	4	5	6	7
Large Oil-Fired Steam Commercial Packaged Boilers	0.018	0.049	0.089	NA	NA	NA	NA
Total	0.095	0.256	0.451	0.067	0.009	0.210	0.334

Table 10D.2.3 CPB Equipment: Net Present Value in Billions (2014$) at a 3-Percent Discount Rate by TSL – High Economic Growth Scenario

Equipment Class	Trial Standard Level				
	1	2	3	4	5
Small Gas-Fired Hot Water Commercial Packaged Boilers	0.540	0.776	1.913	3.857	3.857
Large Gas-Fired Hot Water Commercial Packaged Boilers	0.148	0.240	0.240	1.728	1.728
Small Oil-Fired Hot Water Commercial Packaged Boilers	0.320	0.320	0.320	0.389	0.451
Large Oil-Fired Hot Water Commercial Packaged Boilers	0.072	0.228	0.228	0.311	0.388
Small Gas-Fired Steam Commercial Packaged Boilers	0.043	0.083	0.083	0.166	0.166
Large Gas-Fired Steam Commercial Packaged Boilers	0.044	0.068	0.068	0.124	0.124
Small Oil-Fired Steam Commercial Packaged Boilers	0.037	0.080	0.080	0.169	0.169
Large Oil-Fired Steam Commercial Packaged Boilers	0.055	0.152	0.152	0.277	0.277
Total	1.258	1.946	3.083	7.022	7.161

Table 10D.2.4 CPB Equipment: Net Present Value in Billions (2014$) at a 7-Percent Discount Rate by TSL – High Economic Growth Scenario

Equipment Class	Trial Standard Level				
	1	2	3	4	5
Small Gas-Fired Hot Water Commercial Packaged Boilers	0.110	0.157	0.115	0.334	0.334
Large Gas-Fired Hot Water Commercial Packaged Boilers	0.032	0.044	0.044	0.144	0.144
Small Oil-Fired Hot Water Commercial Packaged Boilers	0.090	0.090	0.090	0.106	0.056
Large Oil-Fired Hot Water Commercial Packaged Boilers	0.022	0.067	0.067	0.090	0.080
Small Gas-Fired Steam Commercial Packaged Boilers	0.013	0.024	0.024	0.044	0.044
Large Gas-Fired Steam Commercial Packaged Boilers	0.015	0.022	0.022	0.039	0.039
Small Oil-Fired Steam Commercial Packaged Boilers	0.011	0.024	0.024	0.050	0.050
Large Oil-Fired Steam Commercial Packaged Boilers	0.018	0.049	0.049	0.089	0.089
Total	0.311	0.478	0.435	0.897	0.836

10D.2.2 Low Economic Growth Scenarios

Table 10D.2.5 through

Table 10D.2.8 show the resulting NPV for scenarios involving Low Economic Growth case energy prices.

Table 10D.2.5 CPB Equipment: Net Present Value in Billions (2014$) at a 3-Percent Discount Rate by EL – Low Economic Growth Scenario

Equipment Class	Efficiency Level						
	1	2	3	4	5	6	7
Small Gas-Fired Hot Water Commercial Packaged Boilers	0.047	0.141	0.407	0.585	0.256	1.334	2.720
Large Gas-Fired Hot Water Commercial Packaged Boilers	0.043	0.116	0.186	-0.035	1.250	NA	NA
Small Oil-Fired Hot Water Commercial Packaged Boilers	0.032	0.079	0.132	0.250	0.303	0.324	NA
Large Oil-Fired Hot Water Commercial Packaged Boilers	0.057	0.180	0.245	0.296	NA	NA	NA
Small Gas-Fired Steam Commercial Packaged Boilers	0.004	0.008	0.034	0.066	0.130	NA	NA
Large Gas-Fired Steam Commercial Packaged Boilers	0.001	0.002	0.016	0.035	0.054	0.100	NA
Small Oil-Fired Steam Commercial Packaged Boilers	0.029	0.063	0.134	NA	NA	NA	NA
Large Oil-Fired Steam Commercial Packaged Boilers	0.044	0.121	0.221	NA	NA	NA	NA
Total	0.257	0.711	1.375	1.198	1.994	1.758	2.720

Table 10D.2.6 CPB Equipment: Net Present Value in Billions (2014$) at a 7-Percent Discount Rate by EL – Low Economic Growth Scenario

Equipment Class	Efficiency Level						
	1	2	3	4	5	6	7
Small Gas-Fired Hot Water Commercial Packaged Boilers	0.013	0.039	0.081	0.116	-0.321	0.021	0.142
Large Gas-Fired Hot Water Commercial Packaged Boilers	0.010	0.024	0.032	-0.287	0.061	NA	NA
Small Oil-Fired Hot Water Commercial Packaged Boilers	0.010	0.023	0.039	0.072	0.084	0.031	NA
Large Oil-Fired Hot Water Commercial Packaged Boilers	0.017	0.054	0.073	0.060	NA	NA	NA
Small Gas-Fired Steam Commercial Packaged Boilers	0.002	0.003	0.011	0.020	0.035	NA	NA
Large Gas-Fired Steam Commercial Packaged Boilers	0.000	0.001	0.006	0.012	0.018	0.032	NA
Small Oil-Fired Steam Commercial Packaged Boilers	0.009	0.020	0.040	NA	NA	NA	NA
Large Oil-Fired Steam Commercial Packaged Boilers	0.015	0.040	0.072	NA	NA	NA	NA
Total	0.077	0.205	0.353	-0.008	-0.123	0.084	0.142

Table 10D.2.7 CPB Equipment: Net Present Value in Billions (2014$) at a 3-Percent Discount Rate by TSL – Low Economic Growth Scenario

Equipment Class	Trial Standard Level				
	1	2	3	4	5
Small Gas-Fired Hot Water Commercial Packaged Boilers	0.407	0.585	1.334	2.720	2.720
Large Gas-Fired Hot Water Commercial Packaged Boilers	0.116	0.186	0.186	1.250	1.250
Small Oil-Fired Hot Water Commercial Packaged Boilers	0.250	0.250	0.250	0.303	0.324
Large Oil-Fired Hot Water Commercial Packaged Boilers	0.057	0.180	0.180	0.245	0.296
Small Gas-Fired Steam Commercial Packaged Boilers	0.034	0.066	0.066	0.130	0.130
Large Gas-Fired Steam Commercial Packaged Boilers	0.035	0.054	0.054	0.100	0.100
Small Oil-Fired Steam Commercial Packaged Boilers	0.029	0.063	0.063	0.134	0.134
Large Oil-Fired Steam Commercial Packaged Boilers	0.044	0.121	0.121	0.221	0.221
Total	0.973	1.506	2.255	5.103	5.175

Table 10D.2.8 CPB Equipment: Net Present Value in Billions (2014$) at a 7-Percent Discount Rate by TSL – Low Economic Growth Scenario

Equipment Class	Trial Standard Level				
	1	2	3	4	5
Small Gas-Fired Hot Water Commercial Packaged Boilers	0.081	0.116	0.021	0.142	0.142
Large Gas-Fired Hot Water Commercial Packaged Boilers	0.024	0.032	0.032	0.061	0.061
Small Oil-Fired Hot Water Commercial Packaged Boilers	0.072	0.072	0.072	0.084	0.031
Large Oil-Fired Hot Water Commercial Packaged Boilers	0.017	0.054	0.054	0.073	0.060
Small Gas-Fired Steam Commercial Packaged Boilers	0.011	0.020	0.020	0.035	0.035
Large Gas-Fired Steam Commercial Packaged Boilers	0.012	0.018	0.018	0.032	0.032
Small Oil-Fired Steam Commercial Packaged Boilers	0.009	0.020	0.020	0.040	0.040
Large Oil-Fired Steam Commercial Packaged Boilers	0.015	0.040	0.040	0.072	0.072
Total	0.241	0.371	0.276	0.539	0.473

10D.3 PRICE TREND SENSITIVITY ANALYSES

The NPV results presented in TSD chapter 10 reflect constant real prices for commercial packaged boiler equipment. In analyses of price trends in manufacturing costs, DOE analyzed the producer price index (PPI) that included relevant equipment (in this case, commercial packaged boiler equipment). As described in chapter 8, DOE examined the historical PPI data for cast iron water heating boilers from 1999 through 2013 and steel water heating boilers from 1980 to 2013 (discontinued between 1987 and 1993) from the Bureau of Labor Statistics (BLS).[a] The PPI data reflect nominal prices, adjusted for equipment quality changes. The inflation-adjusted (deflated) price indexes for cast iron water heating boilers and steel water heating boilers were calculated by dividing the PPI series by the Gross Domestic Equipment Chained Price Index. Given the pattern in iron and steel prices, DOE is not confident that extrapolating the trend in the PPI for cast iron water heating boilers or steel water heating boilers would provide a sound projection. Nor is DOE confident that the recent downward trend in iron and steel prices will continue in the future. 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.

10D.4 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 the Energy Policy and Conservation Act of 1975 (EPCA) for the review of certain energy conservation standards and the potential revision of and compliance with such revised standards.[b] The review timeframe established in EPCA is generally not synchronized with the equipment lifetime, equipment manufacturing cycles, or other factors specific to commercial packaged boilers. Thus, such results are presented for informational purposes only and are not indicative of any change in DOE's analytical methodology. The NPV results based on a 9-year analysis period are shown in Table 10D.4.1 through Table 10D.4.4. The impacts are counted over the lifetime of equipment purchased in 2019–2027.

Table 10D.4.1 CPB 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	Efficiency Level						
	1	2	3	4	5	6	7
Small Gas-Fired Hot Water Commercial Packaged Boilers	0.019	0.055	0.153	0.220	0.031	0.417	0.829
Large Gas-Fired Hot Water Commercial Packaged Boilers	0.025	0.066	0.105	-0.049	0.375	NA	NA
Small Oil-Fired Hot Water Commercial Packaged Boilers	0.011	0.026	0.044	0.082	0.099	0.096	NA

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[a] Cast iron heating boiler PPI series ID: PCU 3334143334141; Steel heating boiler PPI series ID: PCU 3334143334145; www.bls.gov/ppi/

[b] EPCA requires DOE to review its standards at least once every 6 years, and requires, for certain equipment, 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 commercial equipment, the compliance period is 5 years rather than 3 years.

Equipment Class	Efficiency Level						
	1	2	3	4	5	6	7
Large Oil-Fired Hot Water Commercial Packaged Boilers	0.018	0.057	0.078	0.089	NA	NA	NA
Small Gas-Fired Steam Commercial Packaged Boilers	0.004	0.008	0.022	0.038	0.071	NA	NA
Large Gas-Fired Steam Commercial Packaged Boilers	0.001	0.003	0.009	0.020	0.029	0.053	NA
Small Oil-Fired Steam Commercial Packaged Boilers	0.011	0.024	0.050	NA	NA	NA	NA
Large Oil-Fired Steam Commercial Packaged Boilers	0.017	0.046	0.084	NA	NA	NA	NA
Total	0.105	0.286	0.545	0.401	0.606	0.565	0.829

Table 10D.4.2 CPB 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	Efficiency Level						
	1	2	3	4	5	6	7
Small Gas-Fired Hot Water Commercial Packaged Boilers	0.007	0.020	0.038	0.054	-0.212	-0.044	-0.020
Large Gas-Fired Hot Water Commercial Packaged Boilers	0.007	0.015	0.020	-0.216	-0.058	NA	NA
Small Oil-Fired Hot Water Commercial Packaged Boilers	0.004	0.011	0.018	0.032	0.038	0.006	NA
Large Oil-Fired Hot Water Commercial Packaged Boilers	0.008	0.024	0.032	0.023	NA	NA	NA
Small Gas-Fired Steam Commercial Packaged Boilers	0.002	0.003	0.008	0.014	0.023	NA	NA
Large Gas-Fired Steam Commercial Packaged Boilers	0.000	0.001	0.004	0.008	0.012	0.021	NA
Small Oil-Fired Steam Commercial Packaged Boilers	0.005	0.010	0.020	NA	NA	NA	NA
Large Oil-Fired Steam Commercial Packaged Boilers	0.007	0.021	0.037	NA	NA	NA	NA
Total	0.040	0.106	0.177	-0.085	-0.198	-0.017	-0.020

Table 10D.4.3 CPB 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 Level				
	1	2	3	4	5
Small Gas-Fired Hot Water Commercial Packaged Boilers	0.153	0.220	0.417	0.829	0.829
Large Gas-Fired Hot Water Commercial Packaged Boilers	0.066	0.105	0.105	0.375	0.375
Small Oil-Fired Hot Water Commercial Packaged Boilers	0.082	0.082	0.082	0.099	0.096
Large Oil-Fired Hot Water Commercial Packaged Boilers	0.018	0.057	0.057	0.078	0.089
Small Gas-Fired Steam Commercial Packaged Boilers	0.022	0.038	0.038	0.071	0.071
Large Gas-Fired Steam Commercial	0.020	0.029	0.029	0.053	0.053

Equipment Class	Trial Standard Level				
	1	2	3	4	5
Packaged Boilers					
Small Oil-Fired Steam Commercial Packaged Boilers	0.011	0.024	0.024	0.050	0.050
Large Oil-Fired Steam Commercial Packaged Boilers	0.017	0.046	0.046	0.084	0.084
Total	0.389	0.602	0.799	1.639	1.647

Table 10D.4.4 CPB 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 Level				
	1	2	3	4	5
Small Gas-Fired Hot Water Commercial Packaged Boilers	0.038	0.054	-0.044	-0.020	-0.020
Large Gas-Fired Hot Water Commercial Packaged Boilers	0.015	0.020	0.020	-0.058	-0.058
Small Oil-Fired Hot Water Commercial Packaged Boilers	0.032	0.032	0.032	0.038	0.006
Large Oil-Fired Hot Water Commercial Packaged Boilers	0.008	0.024	0.024	0.032	0.023
Small Gas-Fired Steam Commercial Packaged Boilers	0.008	0.014	0.014	0.023	0.023
Large Gas-Fired Steam Commercial Packaged Boilers	0.008	0.012	0.012	0.021	0.021
Small Oil-Fired Steam Commercial Packaged Boilers	0.005	0.010	0.010	0.020	0.020
Large Oil-Fired Steam Commercial Packaged Boilers	0.007	0.021	0.021	0.037	0.037
Total	0.122	0.186	0.089	0.093	0.052

10D.5 PRICE ELASTICITY SENSITIVITY ANALYSES

DOE used a non-zero price elasticity of demand assumption for the default projection in the NIA described in TSD chapter 10. In order to investigate, for the considered trial standard levels (TSLs) for commercial packaged boilers, the impact of alternative price elasticities on consumers' NPV, DOE considered two relative price elasticity sensitivity analyses. As described in chapter 9, DOE assigned -0.02 as the medium, or default, scenario for commercial packaged boilers and incremented the elasticity to -0.2 (a tenfold increase) to implement a high sensitivity to price change. The low scenario assumes zero elasticity, or no impact on purchase decisions from a price change.

For the No Impact scenario, future shipments are not impacted by the decision to repair or replace; therefore, the shipment forecast for all standards cases is the same as that of the no-new-standards case (see appendix 9A).

For the High Relative Price Elasticity Scenario, the increase in elasticity increases the number of commercial consumers that choose to repair their boilers, further reducing shipments in the early years of the analysis when compared to the medium, or default, scenario. Because the elasticity is modeled as a delayed replacement of a boiler, the projections for the standards cases show a decline in the early years, but an increase in later years once the delayed replacements are finally made. DOE understands that the elasticity parameter decreases over time, so the impact of standards on shipments diminishes.

Table 10D.5.1 to Table 10D.5.4 show total projected shipments of

- gas-fired hot water commercial packaged boilers ≥300,000 Btu/h and ≤2,500,000 Btu/h,
- gas-fired hot water commercial packaged boilers >2,500,000 Btu/h and ≤10,000,000 Btu/h,
- oil-fired hot water commercial packaged boilers ≥300,000 Btu/h and ≤2,500,000 Btu/h, and
- oil-fired hot water commercial packaged boilers >2,500,000 Btu/h and ≤10,000,000 Btu/h

in the no-new-standards case and under each standards case, respectively.

Table 10D.5.1 Total Projected Shipments of Gas-Fired Hot Water Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h in the No-New-Standards Case and Each Standards Case – High Relative Price Elasticity Scenario

Year	No-New-Standards Case	TSL 1	TSL 2	TSL 3	TSL 4	TSL 5
2019	16,907	16,870	16,854	16,649	16,474	16,474
2020	17,201	17,173	17,161	17,006	16,871	16,871
2021	17,456	17,434	17,424	17,300	17,192	17,192
2022	17,804	17,785	17,776	17,670	17,576	17,576
2023	18,181	18,165	18,158	18,070	17,989	17,989
2024	18,350	18,335	18,328	18,245	18,168	18,168
2025	18,512	18,535	18,545	18,672	18,774	18,774
2026	18,643	18,658	18,665	18,747	18,813	18,813
2027	18,733	18,743	18,747	18,803	18,846	18,846
2028	18,794	18,802	18,805	18,848	18,881	18,881
2029	18,910	18,915	18,917	18,944	18,964	18,964
2030	19,066	19,070	19,072	19,096	19,113	19,113
2031	19,306	19,310	19,312	19,333	19,347	19,347
2032	19,656	19,659	19,660	19,679	19,691	19,691
2033	20,057	20,060	20,061	20,077	20,087	20,087
2034	20,506	20,508	20,509	20,523	20,532	20,532
2035	21,025	21,028	21,029	21,044	21,055	21,055
2036	21,566	21,569	21,570	21,586	21,598	21,598
2037	22,017	22,020	22,021	22,038	22,050	22,050
2038	22,403	22,406	22,408	22,425	22,438	22,438
2039	22,711	22,714	22,715	22,733	22,747	22,747
2040	22,953	22,956	22,957	22,974	22,989	22,989
2041	23,178	23,181	23,182	23,199	23,214	23,214
2042	23,454	23,457	23,458	23,475	23,490	23,490
2043	23,738	23,741	23,742	23,758	23,773	23,773

Year	No-New-Standards Case	TSL 1	TSL 2	TSL 3	TSL 4	TSL 5
2044	24,040	24,043	24,044	24,056	24,069	24,069
2045	24,363	24,366	24,367	24,379	24,392	24,392
2046	24,707	24,710	24,711	24,722	24,735	24,735
2047	25,056	25,058	25,059	25,070	25,082	25,082
2048	25,409	25,411	25,412	25,422	25,435	25,435

Table 10D.5.2 Total Projected Shipments of Gas-Fired Hot Water Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h in the No-New-Standards Case and Each Standards Case – High Relative Price Elasticity Scenario

Year	No-New-Standards Case	TSL 1	TSL 2	TSL 3	TSL 4	TSL 5
2019	2,707	2,701	2,696	2,696	2,625	2,625
2020	2,754	2,750	2,747	2,747	2,703	2,703
2021	2,794	2,792	2,789	2,789	2,755	2,755
2022	2,850	2,848	2,846	2,846	2,817	2,817
2023	2,910	2,908	2,907	2,907	2,883	2,883
2024	2,937	2,935	2,934	2,934	2,912	2,912
2025	2,963	2,967	2,971	2,971	3,022	3,022
2026	2,984	2,986	2,988	2,988	3,014	3,014
2027	2,998	3,000	3,001	3,001	3,019	3,019
2028	3,008	3,009	3,010	3,010	3,024	3,024
2029	3,027	3,027	3,028	3,028	3,038	3,038
2030	3,052	3,052	3,053	3,053	3,061	3,061
2031	3,090	3,091	3,091	3,091	3,099	3,099
2032	3,146	3,147	3,147	3,147	3,154	3,154
2033	3,210	3,211	3,211	3,211	3,217	3,217
2034	3,282	3,283	3,283	3,283	3,288	3,288
2035	3,365	3,366	3,366	3,366	3,372	3,372
2036	3,452	3,452	3,453	3,453	3,458	3,458
2037	3,524	3,525	3,525	3,525	3,530	3,530
2038	3,586	3,586	3,587	3,587	3,592	3,592
2039	3,635	3,635	3,636	3,636	3,641	3,641
2040	3,674	3,674	3,674	3,674	3,679	3,679
2041	3,710	3,710	3,710	3,710	3,715	3,715
2042	3,754	3,754	3,755	3,755	3,759	3,759
2043	3,800	3,800	3,800	3,800	3,804	3,804
2044	3,848	3,848	3,848	3,848	3,852	3,852
2045	3,900	3,900	3,900	3,900	3,903	3,903
2046	3,955	3,955	3,955	3,955	3,958	3,958
2047	4,011	4,011	4,011	4,011	4,014	4,014
2048	4,067	4,067	4,067	4,067	4,070	4,070

Table 10D.5.3 Total Projected Shipments of Oil-Fired Hot Water Commercial Packaged Boiler ≥300,000 Btu/h and ≤2,500,000 Btu/h in the No-New-Standards Case and Each Standards Case – High Relative Price Elasticity Scenario

Year	No-New-Standards Case	TSL 1	TSL 2	TSL 3	TSL 4	TSL 5
2019	868	855	855	855	843	746
2020	877	867	867	867	858	786
2021	885	878	878	878	870	815
2022	893	887	887	887	881	835
2023	899	894	894	894	889	852
2024	904	900	900	900	896	862
2025	910	919	919	919	928	993
2026	914	921	921	921	926	970
2027	919	923	923	923	927	958
2028	923	926	926	926	929	953
2029	927	930	930	930	932	948
2030	932	934	934	934	936	950
2031	937	939	939	939	941	953
2032	945	946	946	946	948	958
2033	952	953	953	953	955	964
2034	960	961	961	961	962	970
2035	969	970	970	970	971	978
2036	979	980	980	980	981	988
2037	988	989	989	989	990	997
2038	997	998	998	998	999	1,006
2039	1,006	1,006	1,006	1,006	1,007	1,013
2040	1,014	1,014	1,014	1,014	1,015	1,021
2041	1,021	1,022	1,022	1,022	1,023	1,028
2042	1,029	1,030	1,030	1,030	1,030	1,035
2043	1,037	1,037	1,037	1,037	1,038	1,043
2044	1,045	1,045	1,045	1,045	1,046	1,050
2045	1,053	1,053	1,053	1,053	1,054	1,058
2046	1,061	1,061	1,061	1,061	1,062	1,065
2047	1,068	1,069	1,069	1,069	1,070	1,073
2048	1,076	1,077	1,077	1,077	1,078	1,081

Table 10D.5.4 Total Projected Shipments of Oil-Fired Hot Water Commercial Packaged Boiler >2,500,000 Btu/h and ≤10,000,000 Btu/h in the No-New-Standards Case and Each Standards Case – High Relative Price Elasticity Scenario

Year	No-New-Standards Case	TSL 1	TSL 2	TSL 3	TSL 4	TSL 5
2019	119	119	118	118	117	106
2020	121	120	120	120	119	110
2021	122	122	121	121	120	114
2022	123	123	122	122	122	116
2023	124	124	123	123	123	118
2024	125	125	124	124	124	120
2025	125	126	126	126	127	135
2026	126	126	127	127	127	133
2027	127	127	127	127	128	131
2028	127	128	128	128	128	131
2029	128	128	128	128	129	131
2030	129	129	129	129	129	131
2031	129	129	130	130	130	131
2032	130	130	130	130	131	132
2033	131	131	131	131	131	133
2034	132	132	132	132	132	133
2035	133	133	133	133	133	134
2036	134	134	135	135	135	135
2037	136	136	136	136	136	137
2038	137	137	137	137	137	138
2039	138	138	138	138	138	139
2040	139	139	139	139	139	140
2041	140	140	140	140	140	141
2042	141	141	141	141	141	142
2043	142	142	142	142	142	143
2044	143	143	143	143	143	144
2045	144	144	144	144	144	145
2046	145	145	145	145	145	146
2047	146	146	146	146	146	147
2048	147	147	147	147	147	148

10D.5.1 No Impact Relative Price Elasticity Scenarios

Table 10D.5.5 through Table 10D.5.8 show the resulting NPV for scenarios involving No Impact Relative Price Elasticity.

Table 10D.5.5 CPB Equipment: Net Present Value in Billions (2014$) at a 3-Percent Discount Rate by EL – No Impact Relative Price Elasticity Scenario

Equipment Class	Efficiency Level						
	1	2	3	4	5	6	7
Small Gas-Fired Hot Water Commercial Packaged Boilers	0.053	0.159	0.462	0.664	0.362	1.567	3.181
Large Gas-Fired Hot Water Commercial Packaged Boilers	0.048	0.129	0.208	-0.006	1.444	NA	NA
Small Oil-Fired Hot Water Commercial Packaged Boilers	0.036	0.088	0.147	0.278	0.337	0.370	NA
Large Oil-Fired Hot Water Commercial Packaged Boilers	0.063	0.199	0.271	0.330	NA	NA	NA
Small Gas-Fired Steam Commercial Packaged Boilers	0.004	0.008	0.038	0.073	0.145	NA	NA
Large Gas-Fired Steam Commercial Packaged Boilers	0.001	0.003	0.017	0.039	0.060	0.110	NA
Small Oil-Fired Steam Commercial Packaged Boilers	0.032	0.070	0.148	NA	NA	NA	NA
Large Oil-Fired Steam Commercial Packaged Boilers	0.048	0.134	0.244	NA	NA	NA	NA
Total	0.285	0.789	1.534	1.378	2.348	2.047	3.181

Table 10D.5.6 CPB Equipment: Net Present Value in Billions (2014$) at a 7-Percent Discount Rate by EL – No Impact Relative Price Elasticity Scenario

Equipment Class	Efficiency Level						
	1	2	3	4	5	6	7
Small Gas-Fired Hot Water Commercial Packaged Boilers	0.015	0.043	0.092	0.131	-0.328	0.048	0.202
Large Gas-Fired Hot Water Commercial Packaged Boilers	0.011	0.027	0.036	-0.302	0.086	NA	NA
Small Oil-Fired Hot Water Commercial Packaged Boilers	0.011	0.026	0.043	0.079	0.092	0.037	NA
Large Oil-Fired Hot Water Commercial Packaged Boilers	0.019	0.059	0.080	0.065	NA	NA	NA
Small Gas-Fired Steam Commercial Packaged Boilers	0.002	0.003	0.012	0.021	0.038	NA	NA
Large Gas-Fired Steam Commercial Packaged Boilers	0.000	0.001	0.006	0.013	0.019	0.035	NA
Small Oil-Fired Steam Commercial Packaged Boilers	0.010	0.021	0.044	NA	NA	NA	NA
Large Oil-Fired Steam Commercial Packaged Boilers	0.016	0.044	0.079	NA	NA	NA	NA
Total	0.084	0.225	0.391	0.008	-0.093	0.120	0.202

Table 10D.5.7 CPB Equipment: Net Present Value in Billions (2014$) at a 3-Percent Discount Rate by TSL – No Impact Relative Price Elasticity Scenario

Equipment Class	Trial Standard Level				
	1	2	3	4	5
Small Gas-Fired Hot Water Commercial Packaged Boilers	0.462	0.664	1.567	3.181	3.181
Large Gas-Fired Hot Water Commercial Packaged Boilers	0.129	0.208	0.208	1.444	1.444
Small Oil-Fired Hot Water Commercial Packaged Boilers	0.278	0.278	0.278	0.337	0.370
Large Oil-Fired Hot Water Commercial Packaged Boilers	0.063	0.199	0.199	0.271	0.330
Small Gas-Fired Steam Commercial Packaged Boilers	0.038	0.073	0.073	0.145	0.145
Large Gas-Fired Steam Commercial Packaged Boilers	0.039	0.060	0.060	0.110	0.110
Small Oil-Fired Steam Commercial Packaged Boilers	0.032	0.070	0.070	0.148	0.148
Large Oil-Fired Steam Commercial Packaged Boilers	0.048	0.134	0.134	0.244	0.244
Total	1.089	1.685	2.588	5.880	5.972

Table 10D.5.8 CPB Equipment: Net Present Value in Billions (2014$) at a 7-Percent Discount Rate by TSL – No Impact Relative Price Elasticity Scenario

Equipment Class	Trial Standard Level				
	1	2	3	4	5
Small Gas-Fired Hot Water Commercial Packaged Boilers	0.092	0.131	0.048	0.202	0.202
Large Gas-Fired Hot Water Commercial Packaged Boilers	0.027	0.036	0.036	0.086	0.086
Small Oil-Fired Hot Water Commercial Packaged Boilers	0.079	0.079	0.079	0.092	0.037
Large Oil-Fired Hot Water Commercial Packaged Boilers	0.019	0.059	0.059	0.080	0.065
Small Gas-Fired Steam Commercial Packaged Boilers	0.012	0.021	0.021	0.038	0.038
Large Gas-Fired Steam Commercial Packaged Boilers	0.013	0.019	0.019	0.035	0.035
Small Oil-Fired Steam Commercial Packaged Boilers	0.010	0.021	0.021	0.044	0.044
Large Oil-Fired Steam Commercial Packaged Boilers	0.016	0.044	0.044	0.079	0.079
Total	0.268	0.411	0.328	0.655	0.586

10D.5.2 High Relative Price Elasticity Scenarios

Table 10D.5.9 through Table 10D.5.12 show the resulting NPV for scenarios involving High Relative Price Elasticity.

Table 10D.5.9 CPB Equipment: Net Present Value in Billions (2014$) at a 3-Percent Discount Rate by EL – High Relative Price Elasticity Scenario

Equipment Class	Efficiency Level						
	1	2	3	4	5	6	7
Small Gas-Fired Hot Water Commercial Packaged Boilers	0.053	0.160	0.468	0.672	0.401	1.603	3.236
Large Gas-Fired Hot Water Commercial Packaged Boilers	0.049	0.131	0.211	0.009	1.459	NA	NA
Small Oil-Fired Hot Water Commercial Packaged Boilers	0.036	0.088	0.147	0.279	0.340	0.384	NA
Large Oil-Fired Hot Water Commercial Packaged Boilers	0.063	0.200	0.273	0.339	NA	NA	NA
Small Gas-Fired Steam Commercial Packaged Boilers	0.004	0.009	0.039	0.076	0.150	NA	NA
Large Gas-Fired Steam Commercial Packaged Boilers	0.001	0.003	0.017	0.039	0.061	0.112	NA
Small Oil-Fired Steam Commercial Packaged Boilers	0.032	0.070	0.149	NA	NA	NA	NA
Large Oil-Fired Steam Commercial Packaged Boilers	0.048	0.134	0.244	NA	NA	NA	NA
Total	0.286	0.793	1.547	1.415	2.411	2.099	3.236

Table 10D.5.10 CPB Equipment: Net Present Value in Billions (2014$) at a 7-Percent Discount Rate by EL – High Relative Price Elasticity Scenario

Equipment Class	Efficiency Level						
	1	2	3	4	5	6	7
Small Gas-Fired Hot Water Commercial Packaged Boilers	0.015	0.044	0.098	0.141	-0.282	0.093	0.273
Large Gas-Fired Hot Water Commercial Packaged Boilers	0.012	0.030	0.041	-0.267	0.123	NA	NA
Small Oil-Fired Hot Water Commercial Packaged Boilers	0.011	0.027	0.044	0.082	0.099	0.066	NA
Large Oil-Fired Hot Water Commercial Packaged Boilers	0.020	0.061	0.083	0.085	NA	NA	NA
Small Gas-Fired Steam Commercial Packaged Boilers	0.002	0.004	0.013	0.024	0.044	NA	NA
Large Gas-Fired Steam Commercial Packaged Boilers	0.000	0.001	0.006	0.014	0.021	0.037	NA
Small Oil-Fired Steam Commercial Packaged Boilers	0.010	0.023	0.047	NA	NA	NA	NA
Large Oil-Fired Steam Commercial Packaged Boilers	0.016	0.044	0.080	NA	NA	NA	NA
Total	0.087	0.234	0.413	0.079	0.004	0.196	0.273

Table 10D.5.11 CPB Equipment: Net Present Value in Billions (2014$) at a 3-Percent Discount Rate by TSL – High Relative Price Elasticity Scenario

Equipment Class	**Trial Standard Level**				
	1	**2**	**3**	**4**	**5**
Small Gas-Fired Hot Water Commercial Packaged Boilers	0.468	0.672	1.603	3.236	3.236
Large Gas-Fired Hot Water Commercial Packaged Boilers	0.131	0.211	0.211	1.459	1.459
Small Oil-Fired Hot Water Commercial Packaged Boilers	0.279	0.279	0.279	0.340	0.384
Large Oil-Fired Hot Water Commercial Packaged Boilers	0.063	0.200	0.200	0.273	0.339
Small Gas-Fired Steam Commercial Packaged Boilers	0.039	0.076	0.076	0.150	0.150
Large Gas-Fired Steam Commercial Packaged Boilers	0.039	0.061	0.061	0.112	0.112
Small Oil-Fired Steam Commercial Packaged Boilers	0.032	0.070	0.070	0.149	0.149
Large Oil-Fired Steam Commercial Packaged Boilers	0.048	0.134	0.134	0.244	0.244
Total	1.100	1.702	2.634	5.962	6.073

Table 10D.5.12 CPB Equipment: Net Present Value in Billions (2014$) at a 7-Percent Discount Rate by TSL – High Relative Price Elasticity Scenario

Equipment Class	**Trial Standard Level**				
	1	**2**	**3**	**4**	**5**
Small Gas-Fired Hot Water Commercial Packaged Boilers	0.098	0.141	0.093	0.273	0.273
Large Gas-Fired Hot Water Commercial Packaged Boilers	0.030	0.041	0.041	0.123	0.123
Small Oil-Fired Hot Water Commercial Packaged Boilers	0.082	0.082	0.082	0.099	0.066
Large Oil-Fired Hot Water Commercial Packaged Boilers	0.020	0.061	0.061	0.083	0.085
Small Gas-Fired Steam Commercial Packaged Boilers	0.013	0.024	0.024	0.044	0.044
Large Gas-Fired Steam Commercial Packaged Boilers	0.014	0.021	0.021	0.037	0.037
Small Oil-Fired Steam Commercial Packaged Boilers	0.010	0.023	0.023	0.047	0.047
Large Oil-Fired Steam Commercial Packaged Boilers	0.016	0.044	0.044	0.080	0.080
Total	0.283	0.437	0.389	0.786	0.756

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 10E. RISC & OIRA CONSOLIDATED INFORMATION SYSTEM (ROCIS) TABLES

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10E.1 INTRODUCTION

The net present value (NPV) of the monetized benefits associated with emissions reductions can be viewed as a complement to the NPV of the customer savings calculated for each trial standard level (TSL) considered in this notice of public rulemaking (NOPR) for commercial packaged boiler (CPB) equipment. Table 10E.1.1 through Table 10E.1.10 present the 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 customer savings calculated for each TSL considered in this NOPR, at both a 3-percent and 7-percent discount rate.

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 commercial packaged boilers shipped in 2019–2048.

The CO_2 reduction is a benefit that 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,[a] the SCC values in future years reflect future CO_2-emissions impacts that continue beyond 2100 through 2300.

The benefits and costs of the considered standard levels, for products sold in 2019 through 2048, also can be expressed in terms of annualized values. The annualized monetary values shown in Table 10E.1.1 through Table 10E.1.10 present the sum of (1) the annualized national economic value, expressed in 2014 dollars (2014$), of the benefits from customer operation of products that meet the considered standard levels (consisting primarily of operating cost savings from using less energy, minus increases in equipment purchase and installation costs, which is another way of representing customer NPV) and (2) the annualized monetary value of the benefits of emission reductions, including CO_2 emission reductions.

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[a] 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,'" J. Geophys. Res. 110. pp. D14105 (2005).

Table 10E.1.1 Cumulative and Annualized Benefits and Costs of Considered Standard Levels for CPB Equipment Shipped in the Period 2019–2048 (TSL 1, 3-Percent Discount Rate)[*]

	Units	**SGHW**	**LGHW**	**SOHW**	**LOHW**	**SGST**	**LGST**	**SOST**	**LOST**	**Total**
Cumulative Results										
Energy Savings										
Full-Fuel Cycle (total)	*quads*	0.15	0.05	0.02	0.00	0.01	0.01	0.00	0.00	0.25
Economic Impacts										
Incremental Equipment Cost	*billion 2014$*	0.34	0.11	0.06	0.01	0.02	0.01	0.00	0.00	0.55
Operating Cost Savings	*billion 2014$*	0.80	0.24	0.34	0.07	0.05	0.05	0.04	0.05	1.64
NPV	*billion 2014$*	0.46	0.13	0.28	0.06	0.04	0.04	0.03	0.05	1.09
Emissions Savings (physical)										
Full-Fuel Cycle (total)										
CO_2	*million metric ton*	8.38	2.64	1.65	0.34	0.53	0.53	0.18	0.25	14.50
NO_X	*thousand ton*	27.29	8.60	43.43	9.01	1.74	1.73	4.74	6.54	103.09
Hg	*ton*	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0002
N_2O	*thousand ton*	0.02	0.01	0.03	0.01	0.00	0.00	0.00	0.00	0.07
N_2O	*thousand ton CO_2eq*	4.67	1.45	8.67	1.80	0.30	0.29	0.95	1.30	19.42
CH_4	*thousand ton*	101.50	32	3	1	6	6	0	0	151
CH_4	*thousand ton CO_2eq*	2842	896	87	18	181	180	9	13	4227
SO_2	*thousand ton*	0.08	0.02	0.83	0.17	0.00	0.00	0.09	0.13	1.32
Emissions Savings (monetized)										
Full-Fuel Cycle (total)										
CO_2 (global)										
5% dr, average	*million 2014$*	49	17	10	2	4	3	1	1	87
3% dr, average	*million 2014$*	241	81	47	10	16	16	5	7	423
2.5% dr, average	*million 2014$*	388	129	76	16	26	26	8	12	680
3% dr, 95th perc	*million 2014$*	735	245	143	29	50	49	16	22	1288
NO_X										
At 3% dr	*million 2014$*	75	26	117	24	5	5	13	18	284
NPV										
Consumer & Emissions Value										
Consumers + CO_2 (1st) + NO_X (3%)	*billion 2014$*	0.59	0.17	0.40	0.09	0.05	0.05	0.05	0.07	1.46
Consumers + CO_2 (2nd) + NO_X (3%)	*billion 2014$*	0.78	0.24	0.44	0.10	0.06	0.06	0.05	0.07	1.80
Consumers + CO_2 (3rd) + NO_X (3%)	*billion 2014$*	0.93	0.28	0.47	0.10	0.07	0.07	0.05	0.08	2.05
Consumers + CO_2 (4th) + NO_X (3%)	*billion 2014$*	1.27	0.40	0.54	0.12	0.09	0.09	0.06	0.09	2.66

	Units	SGHW	LGHW	SOHW	LOHW	SGST	LGST	SOST	LOST	Total
Annualized Results										
Economic Impacts										
Incremental Equipment Cost	*billion 2014$*	0.019	0.006	0.003	0.000	0.001	0.001	0.000	0.000	0.031
Operating Cost Savings	*billion 2014$*	0.044	0.013	0.019	0.004	0.003	0.003	0.002	0.003	0.091
NPV	*billion 2014$*	0.026	0.007	0.015	0.004	0.002	0.002	0.002	0.003	0.061
Emissions Savings (monetized)										
Full-Fuel Cycle (total)										
CO_2 (global)										
5% dr, average	*million 2014$*	3.711	1.293	0.715	0.147	0.266	0.255	0.080	0.110	6.577
3% dr, average	*million 2014$*	13.428	4.489	2.612	0.539	0.916	0.891	0.289	0.398	23.561
2.5% dr, average	*million 2014$*	19.981	6.615	3.894	0.804	1.349	1.316	0.430	0.592	34.982
3% dr, 95th perc	*million 2014$*	40.949	13.672	7.967	1.644	2.789	2.714	0.882	1.214	71.830
NO_X										
At 3% dr	*million 2014$*	4.185	1.477	6.499	1.338	0.304	0.290	0.728	1.004	15.825
NPV										
Consumer & Emissions Value										
Consumers + CO_2 (1st) + NO_X (3%)	*billion 2014$*	0.034	0.010	0.023	0.005	0.003	0.003	0.003	0.004	0.083
Consumers + CO_2 (2nd) + NO_X (3%)	*billion 2014$*	0.043	0.013	0.025	0.005	0.003	0.003	0.003	0.004	0.100
Consumers + CO_2 (3rd) + NO_X (3%)	*billion 2014$*	0.050	0.015	0.026	0.006	0.004	0.004	0.003	0.004	0.112
Consumers + CO_2 (4th) + NO_X (3%)	*billion 2014$*	0.071	0.022	0.030	0.006	0.005	0.005	0.003	0.005	0.148

* Values in parentheses are negative numbers. The CPB equipment abbreviations are SGHW = Small Gas-fired Hot Water, LGHW = Large Gas-fired Hot Water, SHOW = Small Oil-fired Hot Water, LOHW = Large Oil-fired Hot Water, SGST = Small Gas-fired Steam, LGST = Large Gas-fired Steam, SOST = Small Oil-fired Steam, and LOST = Large Oil-fired Steam.

Table 10E.1.2 Cumulative and Annualized Benefits and Costs of Considered Standard Levels for CPB Equipment Shipped in the Period 2019–2048 (TSL 2, 3-Percent Discount Rate)*

	Units	**SGHW**	**LGHW**	**SOHW**	**LOHW**	**SGST**	**LGST**	**SOST**	**LOST**	**Total**
Cumulative Results										
Energy Savings										
Full-Fuel Cycle (total)	*quads*	0.22	0.08	0.02	0.01	0.02	0.02	0.01	0.01	0.39
Economic Impacts										
Incremental Equipment Cost	*billion 2014$*	0.49	0.21	0.06	0.03	0.04	0.02	0.01	0.01	0.86
Operating Cost Savings	*billion 2014$*	1.15	0.42	0.34	0.23	0.11	0.08	0.08	0.14	2.55
NPV	*billion 2014$*	0.66	0.21	0.28	0.20	0.07	0.06	0.07	0.13	1.69
Emissions Savings (physical)										
Full-Fuel Cycle (total)										
CO_2	*million metric ton*	12.09	4.59	1.65	1.11	1.08	0.85	0.40	0.69	22.46
NO_X	*thousand metric ton*	39.36	14.96	43.43	29.26	3.53	2.77	10.46	18.29	162.06
Hg	*ton*	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0003
N_2O	*thousand metric ton*	0.03	0.01	0.03	0.02	0.00	0.00	0.01	0.01	0.12
N_2O	*thousand metric ton* CO_2*eq*	6.73	2.52	8.67	5.83	0.60	0.47	2.09	3.65	30.55
CH_4	*thousand metric ton*	146.35	56	3	2	13	10	1	1	233
CH_4	*thousand metric ton* CO_2*eq*	4098	1558	87	58	367	289	21	36	6515
SO_2	*thousand metric ton*	0.11	0.03	0.83	0.56	0.01	0.01	0.20	0.35	2.10
Emissions Savings (monetized)										
Full-Fuel Cycle (total)										
CO_2 (global)										
5% dr, average	*million 2014$*	71	30	10	6	7	5	2	4	136
3% dr, average	*million 2014$*	347	140	47	31	33	26	11	20	655
2.5% dr, average	*million 2014$*	560	224	76	51	52	41	18	32	1054
3% dr, 95th perc	*million 2014$*	1059	427	143	96	100	78	35	61	1998
NO_X										
At 3% dr	*million 2014$*	108	46	117	78	11	8	29	50	447
NPV										
Consumer & Emissions Value										
Consumers + CO_2 (1st) + NO_X (3%)	*billion 2014$*	0.84	0.28	0.40	0.28	0.09	0.07	0.10	0.19	2.27
Consumers + CO_2 (2nd) + NO_X (3%)	*billion 2014$*	1.12	0.39	0.44	0.31	0.12	0.09	0.11	0.20	2.79
Consumers + CO_2 (3rd) + NO_X (3%)	*billion 2014$*	1.33	0.48	0.47	0.33	0.14	0.11	0.12	0.22	3.19
Consumers + CO_2 (4th) + NO_X (3%)	*billion 2014$*	1.83	0.68	0.54	0.37	0.18	0.15	0.13	0.24	4.13

	Units	SGHW	LGHW	SOHW	LOHW	SGST	LGST	SOST	LOST	Total
Annualized Results										
Economic Impacts										
Incremental Equipment Cost	*billion 2014$*	0.027	0.012	0.003	0.002	0.002	0.001	0.001	0.001	0.048
Operating Cost Savings	*billion 2014$*	0.064	0.023	0.019	0.013	0.006	0.004	0.005	0.008	0.142
NPV	*billion 2014$*	0.037	0.012	0.015	0.011	0.004	0.003	0.004	0.007	0.094
Emissions Savings (monetized)										
Full-Fuel Cycle (total)										
CO_2 (global)										
5% dr, average	*million 2014$*	5.352	2.249	0.715	0.478	0.526	0.406	0.177	0.308	10.210
3% dr, average	*million 2014$*	19.362	7.808	2.612	1.749	1.831	1.424	0.638	1.112	36.536
2.5% dr, average	*million 2014$*	28.811	11.507	3.894	2.610	2.701	2.104	0.949	1.655	54.232
3% dr, 95th perc	*million 2014$*	59.047	23.782	7.967	5.336	5.575	4.339	1.946	3.392	111.384
NO_X										
At 3% dr	*million 2014$*	6.035	2.569	6.499	4.343	0.599	0.463	1.608	2.806	24.922
NPV										
Consumer & Emissions Value										
Consumers + CO_2 (1st) + NO_X (3%)	*billion 2014$*	0.048	0.016	0.023	0.016	0.005	0.004	0.006	0.011	0.129
Consumers + CO_2 (2nd) + NO_X (3%)	*billion 2014$*	0.062	0.022	0.025	0.017	0.007	0.005	0.006	0.011	0.156
Consumers + CO_2 (3rd) + NO_X (3%)	*billion 2014$*	0.072	0.026	0.026	0.018	0.007	0.006	0.006	0.012	0.173
Consumers + CO_2 (4th) + NO_X (3%)	*billion 2014$*	0.102	0.038	0.030	0.021	0.010	0.008	0.007	0.014	0.230

* Values in parentheses are negative numbers. The CPB equipment abbreviations are SGHW = Small Gas-fired Hot Water, LGHW = Large Gas-fired Hot Water, SHOW = Small Oil-fired Hot Water, LOHW = Large Oil-fired Hot Water, SGST = Small Gas-fired Steam, LGST = Large Gas-fired Steam, SOST = Small Oil-fired Steam, and LOST = Large Oil-fired Steam.

Table 10E.1.3 Cumulative and Annualized Benefits and Costs of Considered Standard Levels for CPB Equipment Shipped in the Period 2019–2048 (TSL 3, 3-Percent Discount Rate)*

	Units	SGHW	LGHW	SOHW	LOHW	SGST	LGST	SOST	LOST	Total
Cumulative Results										
Energy Savings										
Full-Fuel Cycle (total)	*quads*	0.80	0.08	0.02	0.01	0.02	0.02	0.01	0.01	0.97
Economic Impacts										
Incremental Equipment Cost	*billion 2014$*	2.27	0.21	0.06	0.03	0.04	0.02	0.01	0.01	2.65
Operating Cost Savings	*billion 2014$*	3.84	0.42	0.34	0.23	0.11	0.08	0.08	0.14	5.24
NPV	*billion 2014$*	1.57	0.21	0.28	0.20	0.07	0.06	0.07	0.13	2.59
Emissions Savings (physical)										
Full-Fuel Cycle (total)										
CO_2	*million metric ton*	43.08	4.59	1.65	1.11	1.08	0.85	0.40	0.69	53.45
NO_X	*thousand metric ton*	142.14	14.96	43.43	29.26	3.53	2.77	10.46	18.29	264.84
Hg	*ton*	(0.0022)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	(0.0021)
N_2O	*thousand metric ton*	0.08	0.01	0.03	0.02	0.00	0.00	0.01	0.01	0.17
N_2O	*thousand metric ton CO_2eq*	20.56	2.52	8.67	5.83	0.60	0.47	2.09	3.65	44.39
CH_4	*thousand metric ton*	531.58	56	3	2	13	10	1	1	618
CH_4	*thousand metric ton CO_2eq*	14884	1558	87	58	367	289	21	36	17301
SO_2	*thousand metric ton*	(0.35)	0.03	0.83	0.56	0.01	0.01	0.20	0.35	1.63
Emissions Savings (monetized)										
Full-Fuel Cycle (total)										
CO_2 (global)										
5% dr, average	*million 2014$*	251	30	10	6	7	5	2	4	316
3% dr, average	*million 2014$*	1232	140	47	31	33	26	11	20	1540
2.5% dr, average	*million 2014$*	1989	224	76	51	52	41	18	32	2483
3% dr, 95th perc	*million 2014$*	3759	427	143	96	100	78	35	61	4697
NO_X										
At 3% dr	*million 2014$*	388	46	117	78	11	8	29	50	727
NPV										
Consumer & Emissions Value										
Consumers + CO_2 (1st) + NO_X (3%)	*billion 2014$*	2.21	0.28	0.40	0.28	0.09	0.07	0.10	0.19	3.64
Consumers + CO_2 (2nd) + NO_X (3%)	*billion 2014$*	3.19	0.39	0.44	0.31	0.12	0.09	0.11	0.20	4.86
Consumers + CO_2 (3rd) + NO_X (3%)	*billion 2014$*	3.95	0.48	0.47	0.33	0.14	0.11	0.12	0.22	5.80
Consumers + CO_2 (4th) + NO_X (3%)	*billion 2014$*	5.72	0.68	0.54	0.37	0.18	0.15	0.13	0.24	8.02

	Units	SGHW	LGHW	SOHW	LOHW	SGST	LGST	SOST	LOST	Total
Annualized Results										
Economic Impacts										
Incremental Equipment Cost	*billion 2014$*	0.127	0.012	0.003	0.002	0.002	0.001	0.001	0.001	0.148
Operating Cost Savings	*billion 2014$*	0.214	0.023	0.019	0.013	0.006	0.004	0.005	0.008	0.292
NPV	*billion 2014$*	0.088	0.012	0.015	0.011	0.004	0.003	0.004	0.007	0.145
Emissions Savings (monetized)										
Full-Fuel Cycle (total)										
CO_2 (global)										
5% dr, average	*million 2014$*	18.929	2.249	0.715	0.478	0.526	0.406	0.177	0.308	23.787
3% dr, average	*million 2014$*	68.706	7.808	2.612	1.749	1.831	1.424	0.638	1.112	85.881
2.5% dr, average	*million 2014$*	102.313	11.507	3.894	2.610	2.701	2.104	0.949	1.655	127.734
3% dr, 95th perc	*million 2014$*	209.548	23.782	7.967	5.336	5.575	4.339	1.946	3.392	261.885
NO_X										
At 3% dr	*million 2014$*	21.622	2.569	6.499	4.343	0.599	0.463	1.608	2.806	40.509
NPV										
Consumer & Emissions Value										
Consumers + CO_2 (1st) + NO_X (3%)	*billion 2014$*	0.128	0.016	0.023	0.016	0.005	0.004	0.006	0.011	0.209
Consumers + CO_2 (2nd) + NO_X (3%)	*billion 2014$*	0.178	0.022	0.025	0.017	0.007	0.005	0.006	0.011	0.271
Consumers + CO_2 (3rd) + NO_X (3%)	*billion 2014$*	0.211	0.026	0.026	0.018	0.007	0.006	0.006	0.012	0.313
Consumers + CO_2 (4th) + NO_X (3%)	*billion 2014$*	0.319	0.038	0.030	0.021	0.010	0.008	0.007	0.014	0.447

* Values in parentheses are negative numbers. The CPB equipment abbreviations are SGHW = Small Gas-fired Hot Water, LGHW = Large Gas-fired Hot Water, SHOW = Small Oil-fired Hot Water, LOHW = Large Oil-fired Hot Water, SGST = Small Gas-fired Steam, LGST = Large Gas-fired Steam, SOST = Small Oil-fired Steam, and LOST = Large Oil-fired Steam.

Table 10E.1.4 Cumulative and Annualized Benefits and Costs of Considered Standard Levels for CPB Equipment Shipped in the Period 2019–2048 (TSL 4, 3-Percent Discount Rate)*

	Units	**SGHW**	**LGHW**	**SOHW**	**LOHW**	**SGST**	**LGST**	**SOST**	**LOST**	**Total**
Cumulative Results										
Energy Savings										
Full-Fuel Cycle (total)	*quads*	1.50	0.69	0.03	0.02	0.04	0.03	0.01	0.02	2.34
Economic Impacts										
Incremental Equipment Cost	*billion 2014$*	4.17	1.75	0.09	0.04	0.08	0.04	0.03	0.02	6.23
Operating Cost Savings	*billion 2014$*	7.36	3.19	0.43	0.32	0.23	0.15	0.18	0.27	12.12
NPV	*billion 2014$*	3.19	1.45	0.34	0.27	0.15	0.11	0.15	0.24	5.89
Emissions Savings (physical)										
Full-Fuel Cycle (total)										
CO_2	*million metric ton*	81.00	37.51	2.08	1.54	2.29	1.59	0.87	1.28	128.17
NO_X	*thousand metric ton*	265.49	122.69	54.74	40.53	7.48	5.18	22.84	33.69	552.63
Hg	*ton*	(0.0015)	(0.0003)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	(0.0016)
N_2O	*thousand metric ton*	0.16	0.08	0.04	0.03	0.00	0.00	0.02	0.03	0.36
N_2O	*thousand metric ton* CO_2*eq*	41.99	19.96	10.93	8.08	1.27	0.87	4.56	6.72	94.37
CH_4	*thousand metric ton*	990.01	457	4	3	28	19	2	2	1505
CH_4	*thousand metric ton* CO_2*eq*	27720	12796	109	81	778	540	46	67	42137
SO_2	*thousand metric ton*	0.05	0.13	1.05	0.77	0.02	0.01	0.44	0.64	3.12
Emissions Savings (monetized)										
Full-Fuel Cycle (total)										
CO_2 (global)										
5% dr, average	*million 2014$*	467	226	12	9	15	10	5	8	751
3% dr, average	*million 2014$*	2301	1093	59	43	69	48	25	37	3675
2.5% dr, average	*million 2014$*	3718	1758	95	70	111	76	40	59	5928
3% dr, 95th perc	*million 2014$*	7020	3331	180	133	210	145	76	112	11208
NO_X										
At 3% dr	*million 2014$*	715	346	147	108	22	15	63	93	1,510
NPV										
Consumer & Emissions Value										
Consumers + CO_2 (1st) + NO_X (3%)	*billion 2014$*	4.37	2.02	0.50	0.39	0.18	0.14	0.22	0.34	8.15
Consumers + CO_2 (2nd) + NO_X (3%)	*billion 2014$*	6.20	2.88	0.54	0.42	0.24	0.17	0.24	0.37	11.07
Consumers + CO_2 (3rd) + NO_X (3%)	*billion 2014$*	7.62	3.55	0.58	0.45	0.28	0.20	0.25	0.40	13.33
Consumers + CO_2 (4th) + NO_X (3%)	*billion 2014$*	10.92	5.12	0.66	0.51	0.38	0.27	0.29	0.45	18.61

	Units	SGHW	LGHW	SOHW	LOHW	SGST	LGST	SOST	LOST	Total
Annualized Results										
Economic Impacts										
Incremental Equipment Cost	*billion 2014$*	0.233	0.097	0.005	0.002	0.005	0.002	0.002	0.001	0.347
Operating Cost Savings	*billion 2014$*	0.410	0.178	0.024	0.018	0.013	0.008	0.010	0.015	0.676
NPV	*billion 2014$*	0.178	0.081	0.019	0.015	0.008	0.006	0.008	0.014	0.328
Emissions Savings (monetized)										
Full-Fuel Cycle (total)										
CO_2 (global)										
5% dr, average	*million 2014$*	35.173	16.996	0.902	0.662	1.100	0.756	0.386	0.567	56.542
3% dr, average	*million 2014$*	128.307	60.910	3.294	2.423	3.852	2.655	1.393	2.049	204.884
2.5% dr, average	*million 2014$*	191.283	90.441	4.911	3.615	5.689	3.925	2.073	3.049	304.985
3% dr, 95th perc	*million 2014$*	391.376	185.700	10.047	7.392	11.733	8.091	4.249	6.250	624.838
NO_X										
At 3% dr	*million 2014$*	39.843	19.307	8.200	6.017	1.252	0.861	3.511	5.170	84.161
NPV										
Consumer & Emissions Value										
Consumers + CO_2 (1st) + NO_X (3%)	*billion 2014$*	0.253	0.117	0.028	0.022	0.010	0.008	0.012	0.019	0.469
Consumers + CO_2 (2nd) + NO_X (3%)	*billion 2014$*	0.346	0.161	0.030	0.024	0.013	0.010	0.013	0.021	0.617
Consumers + CO_2 (3rd) + NO_X (3%)	*billion 2014$*	0.409	0.190	0.032	0.025	0.015	0.011	0.014	0.022	0.717
Consumers + CO_2 (4th) + NO_X (3%)	*billion 2014$*	0.609	0.286	0.037	0.029	0.021	0.015	0.016	0.025	1.037

* Values in parentheses are negative numbers. The CPB equipment abbreviations are SGHW = Small Gas-fired Hot Water, LGHW = Large Gas-fired Hot Water, SHOW = Small Oil-fired Hot Water, LOHW = Large Oil-fired Hot Water, SGST = Small Gas-fired Steam, LGST = Large Gas-fired Steam, SOST = Small Oil-fired Steam, and LOST = Large Oil-fired Steam.

Table 10E.1.5 Cumulative and Annualized Benefits and Costs of Considered Standard Levels for CPB Equipment Shipped in the Period 2019–2048 (TSL 5, 3-Percent Discount Rate)*

	Units	**SGHW**	**LGHW**	**SOHW**	**LOHW**	**SGST**	**LGST**	**SOST**	**LOST**	**Total**
Cumulative Results										
Energy Savings										
Full-Fuel Cycle (total)	*quads*	1.50	0.69	0.05	0.03	0.04	0.03	0.01	0.02	2.37
Economic Impacts										
Incremental Equipment Cost	*billion 2014$*	4.17	1.75	0.39	0.19	0.08	0.04	0.03	0.02	6.67
Operating Cost Savings	*billion 2014$*	7.36	3.19	0.76	0.53	0.23	0.15	0.18	0.27	12.66
NPV	*billion 2014$*	3.19	1.45	0.37	0.33	0.15	0.11	0.15	0.24	5.98
Emissions Savings (physical)										
Full-Fuel Cycle (total)										
CO_2	*million metric ton*	81.00	37.51	3.87	2.57	2.29	1.59	0.87	1.28	130.99
NO_X	*thousand metric ton*	265.49	122.69	103.56	68.82	7.48	5.18	22.84	33.69	629.75
Hg	*ton*	(0.0015)	(0.0003)	(0.0001)	(0.0001)	0.0000	0.0000	0.0000	0.0000	(0.0017)
N_2O	*thousand metric ton*	0.16	0.08	0.08	0.05	0.00	0.00	0.02	0.03	0.41
N_2O	*thousand metric ton CO_2eq*	41.99	19.96	20.47	13.58	1.27	0.87	4.56	6.72	109.42
CH_4	*thousand metric ton*	990.01	457	7	5	28	19	2	2	1510
CH_4	*thousand metric ton CO_2eq*	27720	12796	199	131	778	540	46	67	42277
SO_2	*thousand metric ton*	0.05	0.13	1.94	1.29	0.02	0.01	0.44	0.64	4.53
Emissions Savings (monetized)										
Full-Fuel Cycle (total)										
CO_2 (global)										
5% dr, average	*million 2014$*	467	226	22	15	15	10	5	8	767
3% dr, average	*million 2014$*	2301	1093	110	73	69	48	25	37	3755
2.5% dr, average	*million 2014$*	3718	1758	178	117	111	76	40	59	6057
3% dr, 95th perc	*million 2014$*	7020	3331	336	222	210	145	76	112	11452
NO_X										
At 3% dr	*million 2014$*	715	346	279	184	22	15	63	93	1,718
NPV										
Consumer & Emissions Value										
Consumers + CO_2 (1st) + NO_X (3%)	*billion 2014$*	4.37	2.02	0.67	0.53	0.18	0.14	0.22	0.34	8.47
Consumers + CO_2 (2nd) + NO_X (3%)	*billion 2014$*	6.20	2.88	0.76	0.59	0.24	0.17	0.24	0.37	11.46
Consumers + CO_2 (3rd) + NO_X (3%)	*billion 2014$*	7.62	3.55	0.83	0.63	0.28	0.20	0.25	0.40	13.76
Consumers + CO_2 (4th) + NO_X (3%)	*billion 2014$*	10.92	5.12	0.99	0.74	0.38	0.27	0.29	0.45	19.15

	Units	**SGHW**	**LGHW**	**SOHW**	**LOHW**	**SGST**	**LGST**	**SOST**	**LOST**	**Total**
Annualized Results										
Economic Impacts										
Incremental Equipment Cost	*billion 2014$*	0.233	0.097	0.022	0.011	0.005	0.002	0.002	0.001	0.372
Operating Cost Savings	*billion 2014$*	0.410	0.178	0.042	0.029	0.013	0.008	0.010	0.015	0.706
NPV	*billion 2014$*	0.178	0.081	0.021	0.018	0.008	0.006	0.008	0.014	0.334
Emissions Savings (monetized)										
Full-Fuel Cycle (total)										
CO_2 (global)										
5% dr, average	*million 2014$*	35.173	16.996	1.684	1.108	1.100	0.756	0.386	0.567	57.769
3% dr, average	*million 2014$*	128.307	60.910	6.139	4.050	3.852	2.655	1.393	2.049	209.356
2.5% dr, average	*million 2014$*	191.283	90.441	9.151	6.041	5.689	3.925	2.073	3.049	311.650
3% dr, 95th perc	*million 2014$*	391.376	185.700	18.724	12.354	11.733	8.091	4.249	6.250	638.477
NO_X										
At 3% dr	*million 2014$*	39.843	19.307	15.562	10.257	1.252	0.861	3.511	5.170	95.763
NPV										
Consumer & Emissions Value										
Consumers + CO_2 (1st) + NO_X (3%)	*billion 2014$*	0.253	0.117	0.038	0.030	0.010	0.008	0.012	0.019	0.487
Consumers + CO_2 (2nd) + NO_X (3%)	*billion 2014$*	0.346	0.161	0.042	0.033	0.013	0.010	0.013	0.021	0.639
Consumers + CO_2 (3rd) + NO_X (3%)	*billion 2014$*	0.409	0.190	0.045	0.035	0.015	0.011	0.014	0.022	0.741
Consumers + CO_2 (4th) + NO_X (3%)	*billion 2014$*	0.609	0.286	0.055	0.041	0.021	0.015	0.016	0.025	1.068

* Values in parentheses are negative numbers. The CPB equipment abbreviations are SGHW = Small Gas-fired Hot Water, LGHW = Large Gas-fired Hot Water, SHOW = Small Oil-fired Hot Water, LOHW = Large Oil-fired Hot Water, SGST = Small Gas-fired Steam, LGST = Large Gas-fired Steam, SOST = Small Oil-fired Steam, and LOST = Large Oil-fired Steam.

Table 10E.1.6 Cumulative and Annualized Benefits and Costs of Considered Standard Levels for CPB Equipment Shipped in the Period 2019–2048 (TSL 1, 7-Percent Discount Rate)*

	Units	**SGHW**	**LGHW**	**SOHW**	**LOHW**	**SGST**	**LGST**	**SOST**	**LOST**	**Total**
Cumulative Results										
Energy Savings										
Full-Fuel Cycle (total)	*quads*	0.15	0.05	0.02	0.00	0.01	0.01	0.00	0.00	0.25
Economic Impacts										
Incremental Equipment Cost	*billion 2014$*	0.19	0.07	0.03	0.00	0.01	0.01	0.00	0.00	0.32
Operating Cost Savings	*billion 2014$*	0.28	0.10	0.11	0.02	0.02	0.02	0.01	0.02	0.59
NPV	*billion 2014$*	0.09	0.03	0.08	0.02	0.01	0.01	0.01	0.02	0.27
Emissions Savings (physical)										
Full-Fuel Cycle (total)										
CO_2	*million metric ton*	8.38	2.64	1.65	0.34	0.53	0.53	0.18	0.25	14.50
NO_X	*thousand metric ton*	27.29	8.60	43.43	9.01	1.74	1.73	4.74	6.54	103.09
Hg	*ton*	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0002
N_2O	*thousand metric ton*	0.02	0.01	0.03	0.01	0.00	0.00	0.00	0.00	0.07
N_2O	*thousand metric ton* CO_2eq	4.67	1.45	8.67	1.80	0.30	0.29	0.95	1.30	19.42
CH_4	*thousand metric ton*	101.50	32	3	1	6	6	0	0	151
CH_4	*thousand metric ton* CO_2eq	2842	896	87	18	181	180	9	13	4227
SO_2	*thousand metric ton*	0.08	0.02	0.83	0.17	0.00	0.00	0.09	0.13	1.32
Emissions Savings (monetized)										
Full-Fuel Cycle (total)										
CO_2 (global)										
5% dr, average	*million 2014$*	49	17	10	2	4	3	1	1	87
3% dr, average	*million 2014$*	241	81	47	10	16	16	5	7	423
2.5% dr, average	*million 2014$*	388	129	76	16	26	26	8	12	680
3% dr, 95th perc	*million 2014$*	735	245	143	29	50	49	16	22	1288
NO_X										
At 7% dr	*million 2014$*	26	10	40	8	2	2	5	6	100
NPV										
Consumer & Emissions Value										
Consumers + CO_2 (1st) + NO_X (7%)	*billion 2014$*	0.17	0.05	0.13	0.03	0.02	0.02	0.02	0.02	0.46
Consumers + CO_2 (2nd) + NO_X (7%)	*billion 2014$*	0.36	0.12	0.17	0.04	0.03	0.03	0.02	0.03	0.79
Consumers + CO_2 (3rd) + NO_X (7%)	*billion 2014$*	0.51	0.17	0.20	0.04	0.04	0.04	0.02	0.03	1.05
Consumers + CO_2 (4th) + NO_X (7%)	*billion 2014$*	0.85	0.28	0.26	0.06	0.06	0.06	0.03	0.04	1.66

	Units	**SGHW**	**LGHW**	**SOHW**	**LOHW**	**SGST**	**LGST**	**SOST**	**LOST**	**Total**
Annualized Results										
Economic Impacts										
Incremental Equipment Cost	*billion 2014$*	0.019	0.007	0.003	0.000	0.001	0.001	0.000	0.000	0.032
Operating Cost Savings	*billion 2014$*	0.028	0.010	0.011	0.002	0.002	0.002	0.001	0.002	0.059
NPV	*billion 2014$*	0.009	0.003	0.008	0.002	0.001	0.001	0.001	0.002	0.027
Emissions Savings (monetized)										
Full-Fuel Cycle (total)										
CO_2 (global)										
5% dr, average	*million 2014$*	3.711	1.293	0.715	0.147	0.266	0.255	0.080	0.110	6.577
3% dr, average	*million 2014$*	13.428	4.489	2.612	0.539	0.916	0.891	0.289	0.398	23.561
2.5% dr, average	*million 2014$*	19.981	6.615	3.894	0.804	1.349	1.316	0.430	0.592	34.982
3% dr, 95th perc	*million 2014$*	40.949	13.672	7.967	1.644	2.789	2.714	0.882	1.214	71.830
NO_X										
At 7% dr	*million 2014$*	2.607	1.035	3.930	0.801	0.220	0.200	0.455	0.625	9.873
NPV										
Consumer & Emissions Value										
Consumers + CO_2 (1st) + NO_X (7%)	*billion 2014$*	0.015	0.005	0.012	0.003	0.002	0.002	0.002	0.002	0.043
Consumers + CO_2 (2nd) + NO_X (7%)	*billion 2014$*	0.025	0.008	0.014	0.003	0.002	0.002	0.002	0.003	0.060
Consumers + CO_2 (3rd) + NO_X (7%)	*billion 2014$*	0.032	0.010	0.016	0.003	0.003	0.003	0.002	0.003	0.071
Consumers + CO_2 (4th) + NO_X (7%)	*billion 2014$*	0.053	0.017	0.020	0.004	0.004	0.004	0.002	0.003	0.108

* Values in parentheses are negative numbers. The CPB equipment abbreviations are SGHW = Small Gas-fired Hot Water, LGHW = Large Gas-fired Hot Water, SHOW = Small Oil-fired Hot Water, LOHW = Large Oil-fired Hot Water, SGST = Small Gas-fired Steam, LGST = Large Gas-fired Steam, SOST = Small Oil-fired Steam, and LOST = Large Oil-fired Steam.

Table 10E.1.7 Cumulative and Annualized Benefits and Costs of Considered Standard Levels for CPB Equipment Shipped in the Period 2019–2048 (TSL 2, 7-Percent Discount Rate)[*]

	Units	**SGHW**	**LGHW**	**SOHW**	**LOHW**	**SGST**	**LGST**	**SOST**	**LOST**	**Total**
Cumulative Results										
Energy Savings										
Full-Fuel Cycle (total)	*quads*	0.22	0.08	0.02	0.01	0.02	0.02	0.01	0.01	0.39
Economic Impacts										
Incremental Equipment Cost	*billion 2014$*	0.28	0.13	0.03	0.02	0.02	0.01	0.01	0.01	0.51
Operating Cost Savings	*billion 2014$*	0.41	0.17	0.11	0.08	0.04	0.03	0.03	0.05	0.93
NPV	*billion 2014$*	0.13	0.04	0.08	0.06	0.02	0.02	0.02	0.04	0.41
Emissions Savings (physical)										
Full-Fuel Cycle (total)										
CO_2	*million metric ton*	12.09	4.59	1.65	1.11	1.08	0.85	0.40	0.69	22.46
NO_X	*thousand metric ton*	39.36	14.96	43.43	29.26	3.53	2.77	10.46	18.29	162.06
Hg	*ton*	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0003
N_2O	*thousand metric ton*	0.03	0.01	0.03	0.02	0.00	0.00	0.01	0.01	0.12
N_2O	*thousand metric ton* CO_2*eq*	6.73	2.52	8.67	5.83	0.60	0.47	2.09	3.65	30.55
CH_4	*thousand metric ton*	146.35	56	3	2	13	10	1	1	233
CH_4	*thousand metric ton* CO_2*eq*	4098	1558	87	58	367	289	21	36	6515
SO_2	*thousand metric ton*	0.11	0.03	0.83	0.56	0.01	0.01	0.20	0.35	2.10
Emissions Savings (monetized)										
Full-Fuel Cycle (total)										
CO_2 (global)										
5% dr, average	*million 2014$*	71	30	10	6	7	5	2	4	136
3% dr, average	*million 2014$*	347	140	47	31	33	26	11	20	655
2.5% dr, average	*million 2014$*	560	224	76	51	52	41	18	32	1054
3% dr, 95th perc	*million 2014$*	1059	427	143	96	100	78	35	61	1998
NO_X										
At 7% dr	*million 2014$*	38	18	40	26	4	3	10	18	158
NPV										
Consumer & Emissions Value										
Consumers + CO_2 (1st) + NO_X (7%)	*billion 2014$*	0.24	0.08	0.13	0.09	0.03	0.03	0.03	0.07	0.71
Consumers + CO_2 (2nd) + NO_X (7%)	*billion 2014$*	0.52	0.19	0.17	0.12	0.06	0.05	0.04	0.08	1.23
Consumers + CO_2 (3rd) + NO_X (7%)	*billion 2014$*	0.73	0.28	0.20	0.14	0.08	0.06	0.05	0.09	1.63
Consumers + CO_2 (4th) + NO_X (7%)	*billion 2014$*	1.23	0.48	0.26	0.18	0.13	0.10	0.07	0.12	2.57

	Units	SGHW	LGHW	SOHW	LOHW	SGST	LGST	SOST	LOST	Total
Annualized Results										
Economic Impacts										
Incremental Equipment Cost	*billion 2014$*	0.027	0.013	0.003	0.002	0.002	0.001	0.001	0.001	0.051
Operating Cost Savings	*billion 2014$*	0.040	0.017	0.011	0.007	0.004	0.003	0.003	0.005	0.091
NPV	*billion 2014$*	0.013	0.004	0.008	0.006	0.002	0.002	0.002	0.004	0.041
Emissions Savings (monetized)										
Full-Fuel Cycle (total)										
CO_2 (global)										
5% dr, average	*million 2014$*	5.352	2.249	0.715	0.478	0.526	0.406	0.177	0.308	10.210
3% dr, average	*million 2014$*	19.362	7.808	2.612	1.749	1.831	1.424	0.638	1.112	36.536
2.5% dr, average	*million 2014$*	28.811	11.507	3.894	2.610	2.701	2.104	0.949	1.655	54.232
3% dr, 95th perc	*million 2014$*	59.047	23.782	7.967	5.336	5.575	4.339	1.946	3.392	111.384
NO_X										
At 7% dr	*million 2014$*	3.759	1.800	3.930	2.602	0.420	0.317	1.005	1.749	15.581
NPV										
Consumer & Emissions Value										
Consumers + CO_2 (1st) + NO_X (7%)	*billion 2014$*	0.022	0.008	0.012	0.009	0.003	0.003	0.003	0.006	0.067
Consumers + CO_2 (2nd) + NO_X (7%)	*billion 2014$*	0.036	0.013	0.014	0.010	0.004	0.004	0.004	0.007	0.093
Consumers + CO_2 (3rd) + NO_X (7%)	*billion 2014$*	0.046	0.017	0.016	0.011	0.005	0.004	0.004	0.008	0.111
Consumers + CO_2 (4th) + NO_X (7%)	*billion 2014$*	0.076	0.029	0.020	0.014	0.008	0.007	0.005	0.009	0.168

* Values in parentheses are negative numbers. The CPB equipment abbreviations are SGHW = Small Gas-fired Hot Water, LGHW = Large Gas-fired Hot Water, SHOW = Small Oil-fired Hot Water, LOHW = Large Oil-fired Hot Water, SGST = Small Gas-fired Steam, LGST = Large Gas-fired Steam, SOST = Small Oil-fired Steam, and LOST = Large Oil-fired Steam.

Table 10E.1.8 Cumulative and Annualized Benefits and Costs of Considered Standard Levels for CPB Equipment Shipped in the Period 2019–2048 (TSL 3, 7-Percent Discount Rate)[*]

	Units	**SGHW**	**LGHW**	**SOHW**	**LOHW**	**SGST**	**LGST**	**SOST**	**LOST**	**Total**
Cumulative Results										
Energy Savings										
Full-Fuel Cycle (total)	*quads*	0.80	0.08	0.02	0.01	0.02	0.02	0.01	0.01	0.97
Economic Impacts										
Incremental Equipment Cost	*billion 2014$*	1.29	0.13	0.03	0.02	0.02	0.01	0.01	0.01	1.53
Operating Cost Savings	*billion 2014$*	1.34	0.17	0.11	0.08	0.04	0.03	0.03	0.05	1.86
NPV	*billion 2014$*	0.05	0.04	0.08	0.06	0.02	0.02	0.02	0.04	0.33
Emissions Savings (physical)										
Full-Fuel Cycle (total)										
CO_2	*million metric ton*	43.08	4.59	1.65	1.11	1.08	0.85	0.40	0.69	53.45
NO_X	*thousand metric ton*	142.14	14.96	43.43	29.26	3.53	2.77	10.46	18.29	264.84
Hg	*ton*	(0.002)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	(0.002)
N_2O	*thousand metric ton*	0.08	0.01	0.03	0.02	0.00	0.00	0.01	0.01	0.17
N_2O	*thousand metric ton* CO_2*eq*	20.56	2.52	8.67	5.83	0.60	0.47	2.09	3.65	44.39
CH_4	*thousand metric ton*	531.58	56	3	2	13	10	1	1	618
CH_4	*thousand metric ton* CO_2*eq*	14884	1558	87	58	367	289	21	36	17301
SO_2	*thousand metric ton*	(0.35)	0.03	0.83	0.56	0.01	0.01	0.20	0.35	1.63
Emissions Savings (monetized)										
Full-Fuel Cycle (total)										
CO_2 (global)										
5% dr, average	*million 2014$*	251	30	10	6	7	5	2	4	316
3% dr, average	*million 2014$*	1232	140	47	31	33	26	11	20	1540
2.5% dr, average	*million 2014$*	1989	224	76	51	52	41	18	32	2483
3% dr, 95th perc	*million 2014$*	3759	427	143	96	100	78	35	61	4697
NO_X										
At 7% dr	*million 2014$*	135	18	40	26	4	3	10	18	255
NPV										
Consumer & Emissions Value										
Consumers + CO_2 (1st) + NO_X (7%)	*billion 2014$*	0.44	0.08	0.13	0.09	0.03	0.03	0.03	0.07	0.90
Consumers + CO_2 (2nd) + NO_X (7%)	*billion 2014$*	1.42	0.19	0.17	0.12	0.06	0.05	0.04	0.08	2.13
Consumers + CO_2 (3rd) + NO_X (7%)	*billion 2014$*	2.18	0.28	0.20	0.14	0.08	0.06	0.05	0.09	3.07
Consumers + CO_2 (4th) + NO_X (7%)	*billion 2014$*	3.95	0.48	0.26	0.18	0.13	0.10	0.07	0.12	5.29

	Units	SGHW	LGHW	SOHW	LOHW	SGST	LGST	SOST	LOST	Total
Annualized Results										
Economic Impacts										
Incremental Equipment Cost	*billion 2014$*	0.128	0.013	0.003	0.002	0.002	0.001	0.001	0.001	0.151
Operating Cost Savings	*billion 2014$*	0.133	0.017	0.011	0.007	0.004	0.003	0.003	0.005	0.184
NPV	*billion 2014$*	0.005	0.004	0.008	0.006	0.002	0.002	0.002	0.004	0.033
Emissions Savings (monetized)										
Full-Fuel Cycle (total)										
CO_2 (global)										
5% dr, average	*million 2014$*	18.929	2.249	0.715	0.478	0.526	0.406	0.177	0.308	23.787
3% dr, average	*million 2014$*	68.706	7.808	2.612	1.749	1.831	1.424	0.638	1.112	85.881
2.5% dr, average	*million 2014$*	102.313	11.507	3.894	2.610	2.701	2.104	0.949	1.655	127.734
3% dr, 95th perc	*million 2014$*	209.548	23.782	7.967	5.336	5.575	4.339	1.946	3.392	261.885
NO_X										
At 7% dr	*million 2014$*	13.344	1.800	3.930	2.602	0.420	0.317	1.005	1.749	25.167
NPV										
Consumer & Emissions Value										
Consumers + CO_2 (1st) + NO_X (7%)	*billion 2014$*	0.037	0.008	0.012	0.009	0.003	0.003	0.003	0.006	0.082
Consumers + CO_2 (2nd) + NO_X (7%)	*billion 2014$*	0.087	0.013	0.014	0.010	0.004	0.004	0.004	0.007	0.144
Consumers + CO_2 (3rd) + NO_X (7%)	*billion 2014$*	0.121	0.017	0.016	0.011	0.005	0.004	0.004	0.008	0.186
Consumers + CO_2 (4th) + NO_X (7%)	*billion 2014$*	0.228	0.029	0.020	0.014	0.008	0.007	0.005	0.009	0.320

* Values in parentheses are negative numbers. The CPB equipment abbreviations are SGHW = Small Gas-fired Hot Water, LGHW = Large Gas-fired Hot Water, SHOW = Small Oil-fired Hot Water, LOHW = Large Oil-fired Hot Water, SGST = Small Gas-fired Steam, LGST = Large Gas-fired Steam, SOST = Small Oil-fired Steam, and LOST = Large Oil-fired Steam.

Table 10E.1.9 Cumulative and Annualized Benefits and Costs of Considered Standard Levels for CPB Equipment Shipped in the Period 2019–2048 (TSL 4, 7-Percent Discount Rate)[*]

	Units	**SGHW**	**LGHW**	**SOHW**	**LOHW**	**SGST**	**LGST**	**SOST**	**LOST**	**Total**
Cumulative Results										
Energy Savings										
Full-Fuel Cycle (total)	*quads*	1.50	0.69	0.03	0.02	0.04	0.03	0.01	0.02	2.34
Economic Impacts										
Incremental Equipment Cost	*billion 2014$*	2.33	1.08	0.05	0.02	0.05	0.02	0.02	0.01	3.59
Operating Cost Savings	*billion 2014$*	2.53	1.17	0.14	0.10	0.09	0.06	0.06	0.09	4.26
NPV	*billion 2014$*	0.21	0.09	0.09	0.08	0.04	0.04	0.04	0.08	0.67
Emissions Savings (physical)										
Full-Fuel Cycle (total)										
CO_2	*million metric ton*	81.00	37.51	2.08	1.54	2.29	1.59	0.87	1.28	128.17
NO_X	*thousand metric ton*	265.49	122.69	54.74	40.53	7.48	5.18	22.84	33.69	552.63
Hg	*ton*	(0.0015)	(0.0003)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	(0.0016)
N_2O	*thousand metric ton*	0.16	0.08	0.04	0.03	0.00	0.00	0.02	0.03	0.36
N_2O	*thousand metric ton* CO_2eq	41.99	19.96	10.93	8.08	1.27	0.87	4.56	6.72	94.37
CH_4	*thousand metric ton*	990.01	457	4	3	28	19	2	2	1505
CH_4	*thousand metric ton* CO_2eq	27720	12796	109	81	778	540	46	67	42137
SO_2	*thousand metric ton*	0.05	0.13	1.05	0.77	0.02	0.01	0.44	0.64	3.12
Emissions Savings (monetized)										
Full-Fuel Cycle (total)										
CO_2 (global)										
5% dr, average	*million 2014$*	467	226	12	9	15	10	5	8	751
3% dr, average	*million 2014$*	2301	1093	59	43	69	48	25	37	3675
2.5% dr, average	*million 2014$*	3718	1758	95	70	111	76	40	59	5928
3% dr, 95th perc	*million 2014$*	7020	3331	180	133	210	145	76	112	11208
NO_X										
At 7% dr	*million 2014$*	245	126	50	37	9	6	22	33	527
NPV										
Consumer & Emissions Value										
Consumers + CO_2 (1st) + NO_X (7%)	*billion 2014$*	0.92	0.44	0.16	0.13	0.06	0.05	0.07	0.12	1.95
Consumers + CO_2 (2nd) + NO_X (7%)	*billion 2014$*	2.76	1.31	0.20	0.16	0.12	0.09	0.09	0.15	4.87
Consumers + CO_2 (3rd) + NO_X (7%)	*billion 2014$*	4.17	1.97	0.24	0.19	0.16	0.12	0.11	0.17	7.12
Consumers + CO_2 (4th) + NO_X (7%)	*billion 2014$*	7.47	3.55	0.32	0.25	0.26	0.19	0.14	0.22	12.40

	Units	SGHW	LGHW	SOHW	LOHW	SGST	LGST	SOST	LOST	Total
Annualized Results										
Economic Impacts										
Incremental Equipment Cost	*billion 2014$*	0.230	0.106	0.005	0.002	0.005	0.002	0.002	0.001	0.354
Operating Cost Savings	*billion 2014$*	0.250	0.115	0.014	0.010	0.009	0.006	0.006	0.009	0.420
NPV	*billion 2014$*	0.021	0.009	0.009	0.008	0.004	0.003	0.004	0.008	0.066
Emissions Savings (monetized)										
Full-Fuel Cycle (total)										
CO_2 (global)										
5% dr, average	*million 2014$*	35.173	16.996	0.902	0.662	1.100	0.756	0.386	0.567	56.542
3% dr, average	*million 2014$*	128.307	60.910	3.294	2.423	3.852	2.655	1.393	2.049	204.884
2.5% dr, average	*million 2014$*	191.283	90.441	4.911	3.615	5.689	3.925	2.073	3.049	304.985
3% dr, 95th perc	*million 2014$*	391.376	185.700	10.047	7.392	11.733	8.091	4.249	6.250	624.838
NO_X										
At 7% dr	*million 2014$*	24.196	12.391	4.965	3.606	0.861	0.585	2.197	3.224	52.025
NPV										
Consumer & Emissions Value										
Consumers + CO_2 (1st) + NO_X (7%)	*billion 2014$*	0.080	0.038	0.015	0.012	0.006	0.005	0.007	0.012	0.175
Consumers + CO_2 (2nd) + NO_X (7%)	*billion 2014$*	0.173	0.082	0.017	0.014	0.009	0.007	0.008	0.013	0.323
Consumers + CO_2 (3rd) + NO_X (7%)	*billion 2014$*	0.236	0.112	0.019	0.015	0.010	0.008	0.009	0.014	0.423
Consumers + CO_2 (4th) + NO_X (7%)	*billion 2014$*	0.436	0.207	0.024	0.019	0.016	0.012	0.011	0.017	0.743

* Values in parentheses are negative numbers. The CPB equipment abbreviations are SGHW = Small Gas-fired Hot Water, LGHW = Large Gas-fired Hot Water, SHOW = Small Oil-fired Hot Water, LOHW = Large Oil-fired Hot Water, SGST = Small Gas-fired Steam, LGST = Large Gas-fired Steam, SOST = Small Oil-fired Steam, and LOST = Large Oil-fired Steam.

Table 10E.1.10 Cumulative and Annualized Benefits and Costs of Considered Standard Levels for CPB Equipment Shipped in the Period 2019–2048 (TSL 5, 7-Percent Discount Rate)[*]

	Units	SGHW	LGHW	SOHW	LOHW	SGST	LGST	SOST	LOST	Total
Cumulative Results										
Energy Savings										
Full-Fuel Cycle (total)	*quads*	1.50	0.69	0.05	0.03	0.04	0.03	0.01	0.02	2.37
Economic Impacts										
Incremental Equipment Cost	*billion 2014$*	2.33	1.08	0.21	0.11	0.05	0.02	0.02	0.01	3.83
Operating Cost Savings	*billion 2014$*	2.53	1.17	0.25	0.17	0.09	0.06	0.06	0.09	4.44
NPV	*billion 2014$*	0.21	0.09	0.04	0.07	0.04	0.04	0.04	0.08	0.60
Emissions Savings (physical)										
Full-Fuel Cycle (total)										
CO_2	*million metric ton*	81.00	37.51	3.87	2.57	2.29	1.59	0.87	1.28	130.99
NO_X	*thousand metric ton*	265.49	122.69	103.56	68.82	7.48	5.18	22.84	33.69	629.75
Hg	*ton*	(0.0015)	(0.0003)	(0.0001)	(0.0001)	0.0000	0.0000	0.0000	0.0000	(0.0017)
N_2O	*thousand metric ton*	0.16	0.08	0.08	0.05	0.00	0.00	0.02	0.03	0.41
N_2O	*thousand metric ton* CO_2*eq*	41.99	19.96	20.47	13.58	1.27	0.87	4.56	6.72	109.42
CH_4	*thousand metric ton*	990.01	457	7	5	28	19	2	2	1510
CH_4	*thousand metric ton* CO_2*eq*	27720	12796	199	131	778	540	46	67	42277
SO_2	*thousand metric ton*	0.05	0.13	1.94	1.29	0.02	0.01	0.44	0.64	4.53
Emissions Savings (monetized)										
Full-Fuel Cycle (total)										
CO_2 (global)										
5% dr, average	*million 2014$*	467	226	22	15	15	10	5	8	767
3% dr, average	*million 2014$*	2301	1093	110	73	69	48	25	37	3755
2.5% dr, average	*million 2014$*	3718	1758	178	117	111	76	40	59	6057
3% dr, 95th perc	*million 2014$*	7020	3331	336	222	210	145	76	112	11452
NO_X										
At 7% dr	*million 2014$*	245	126	96	63	9	6	22	33	599
NPV										
Consumer & Emissions Value										
Consumers + CO_2 (1st) + NO_X (7%)	*billion 2014$*	0.92	0.44	0.16	0.14	0.06	0.05	0.07	0.12	1.97
Consumers + CO_2 (2nd) + NO_X (7%)	*billion 2014$*	2.76	1.31	0.25	0.20	0.12	0.09	0.09	0.15	4.96
Consumers + CO_2 (3rd) + NO_X (7%)	*billion 2014$*	4.17	1.97	0.31	0.25	0.16	0.12	0.11	0.17	7.26
Consumers + CO_2 (4th) + NO_X (7%)	*billion 2014$*	7.47	3.55	0.47	0.35	0.26	0.19	0.14	0.22	12.65

	Units	**SGHW**	**LGHW**	**SOHW**	**LOHW**	**SGST**	**LGST**	**SOST**	**LOST**	**Total**
Annualized Results										
Economic Impacts										
Incremental Equipment Cost	*billion 2014$*	0.230	0.106	0.021	0.011	0.005	0.002	0.002	0.001	0.378
Operating Cost Savings	*billion 2014$*	0.250	0.115	0.025	0.017	0.009	0.006	0.006	0.009	0.438
NPV	*billion 2014$*	0.021	0.009	0.004	0.007	0.004	0.003	0.004	0.008	0.060
Emissions Savings (monetized)										
Full-Fuel Cycle (total)										
CO_2 (global)										
5% dr, average	*million 2014$*	35.173	16.996	1.684	1.108	1.100	0.756	0.386	0.567	57.769
3% dr, average	*million 2014$*	128.307	60.910	6.139	4.050	3.852	2.655	1.393	2.049	209.356
2.5% dr, average	*million 2014$*	191.283	90.441	9.151	6.041	5.689	3.925	2.073	3.049	311.650
3% dr, 95th perc	*million 2014$*	391.376	185.700	18.724	12.354	11.733	8.091	4.249	6.250	638.477
NO_X										
At 7% dr	*million 2014$*	24.196	12.391	9.476	6.190	0.861	0.585	2.197	3.224	59.120
NPV										
Consumer & Emissions Value										
Consumers + CO_2 (1st) + NO_X (7%)	*billion 2014$*	0.080	0.038	0.015	0.014	0.006	0.005	0.007	0.012	0.176
Consumers + CO_2 (2nd) + NO_X (7%)	*billion 2014$*	0.173	0.082	0.020	0.017	0.009	0.007	0.008	0.013	0.328
Consumers + CO_2 (3rd) + NO_X (7%)	*billion 2014$*	0.236	0.112	0.023	0.019	0.010	0.008	0.009	0.014	0.430
Consumers + CO_2 (4th) + NO_X (7%)	*billion 2014$*	0.436	0.207	0.032	0.025	0.016	0.012	0.011	0.017	0.757

* Values in parentheses are negative numbers. The CPB equipment abbreviations are SGHW = Small Gas-fired Hot Water, LGHW = Large Gas-fired Hot Water, SHOW = Small Oil-fired Hot Water, LOHW = Large Oil-fired Hot Water, SGST = Small Gas-fired Steam, LGST = Large Gas-fired Steam, SOST = Small Oil-fired Steam, and LOST = Large Oil-fired Steam.

CHAPTER 11. COMMERCIAL CUSTOMER SUBGROUP ANALYSIS

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CHAPTER 11. COMMERCIAL CUSTOMER SUBGROUP ANALYSIS

11.1 METHODOLOGY

The commercial customer subgroup analysis evaluates impacts on any identifiable groups of commercial customers who may be disproportionately affected by a national energy conservation standard. DOE conducted this analysis as one of the analyses for the notice of proposed rulemaking (NOPR). DOE accomplished this, in part, by analyzing the life-cycle costs (LCCs) and payback periods (PBPs) for those commercial customers that fall into any identifiable groups. DOE evaluated 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 customer subpopulations. To the extent possible, DOE obtained estimates of each input parameter's variability and considered this variability in its calculation of commercial customer impacts.

DOE determined the impact on commercial customer 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 (TSD)) focuses on the commercial customers that use commercial packaged boilers (CPBs). DOE can use the LCC Spreadsheet Model to analyze the LCC for any subgroup by sampling only that subgroup. Chapter 8 explains in detail the inputs to the model used in determining LCC and PBPs.

11.2 SUBGROUP ANALYSIS FOR RESIDENTIAL APPLICATIONS

In general, consumers in the lower income groups tend to discount the future stream of benefits at a higher rate when compared to consumers in higher income brackets. Therefore, DOE used all residential users as an entire subgroup by itself, and evaluated the influence of proposed standards on that group by using the discount rate for the lowest income group (0 percent–20 percent income level). Figure 11.2.1 presents the distribution of real discount rates of the income group that was used in the low income residential subgroup analysis.

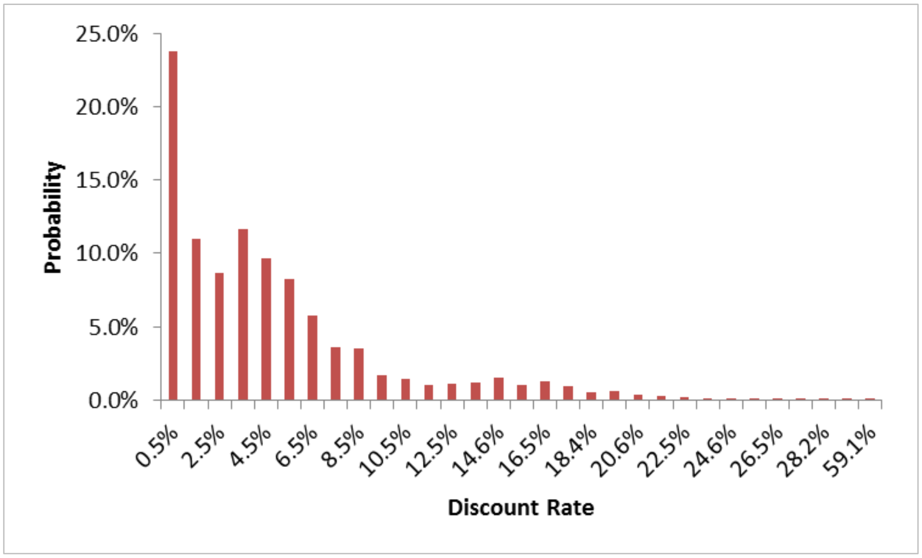

Figure 11.2.1 Distribution of Real Discount Rates for Low Income Residential Subgroup

11.3 SUBGROUP FOR COMMERCIAL APPLICATIONS

DOE developed a subgroup analysis for small businesses by modeling all commercial buildings in the CBECS sample, but developing a higher discount rate to be used in the LCC subgroup analysis. The discount rate used represents a weighted average cost of capital that was higher than that for the commercial building samples as a whole. This discount rate was developed by examining the Damodaran data for only those businesses with a low market capitalization that qualified as small businesses. An equity premium based on size premium data from Ibbotson Associates was used to develop the weighted average cost of capital (WACC) for these small businesses, and overall discount rates for the small business were developed to be applied to the sampled buildings in the Commercial Buildings Energy Consumption Survey (CBECS) dataset.[1] Separate distributions are constructed for each major sector. Figure 11.3.1 through Figure 11.3.10 show the probability distributions of commercial discount rates by sectors for the sub group analysis. The addition of the equity premium adds approximately 2.1 percent (on average) to the WACC for small businesses for all sectors except educational, state, local government and federal government categories and this was used in the small business subgroup analysis.[2]

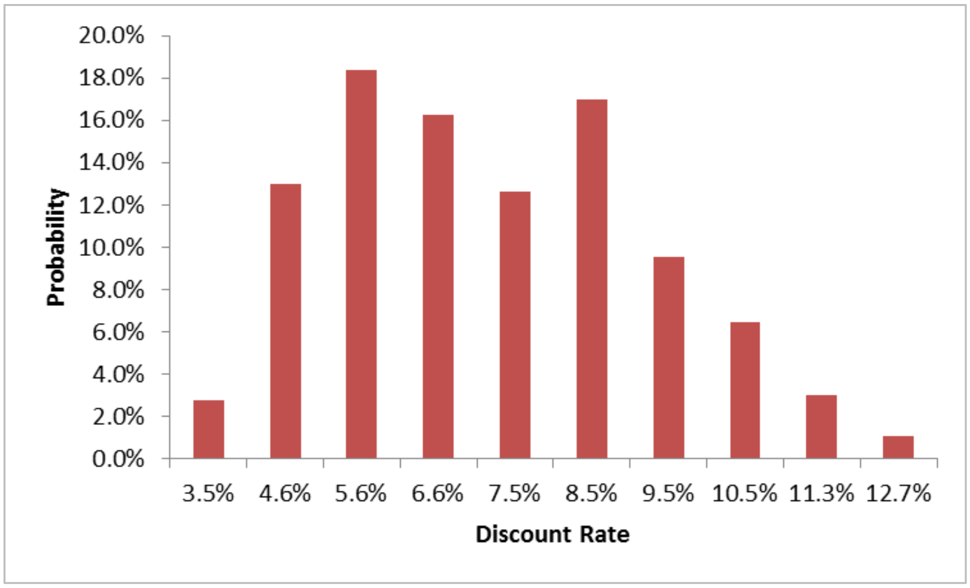

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Figure 11.3.1 Distribution of Commercial Discount Rates: Retail

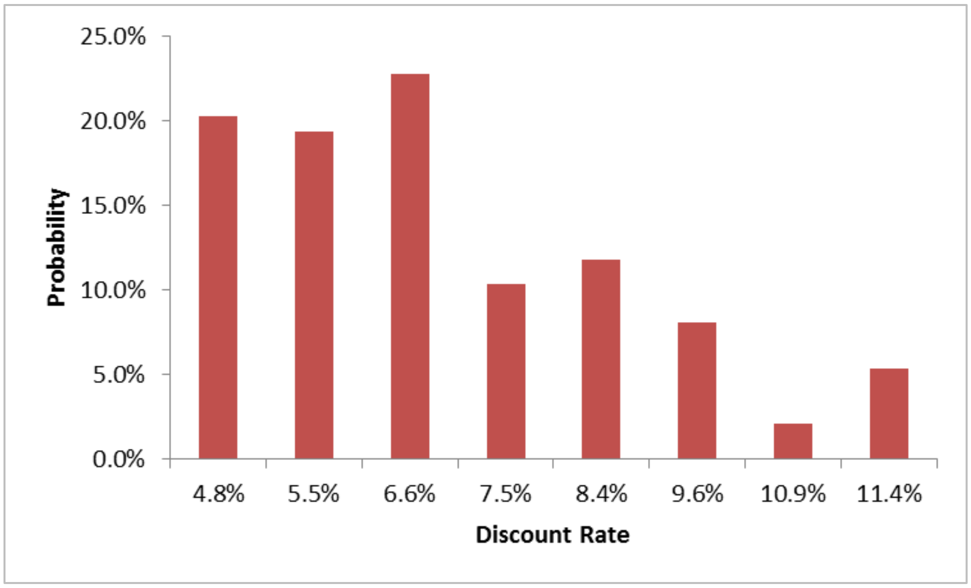

Figure 11.3.2 Distribution of Commercial Discount Rates: Property

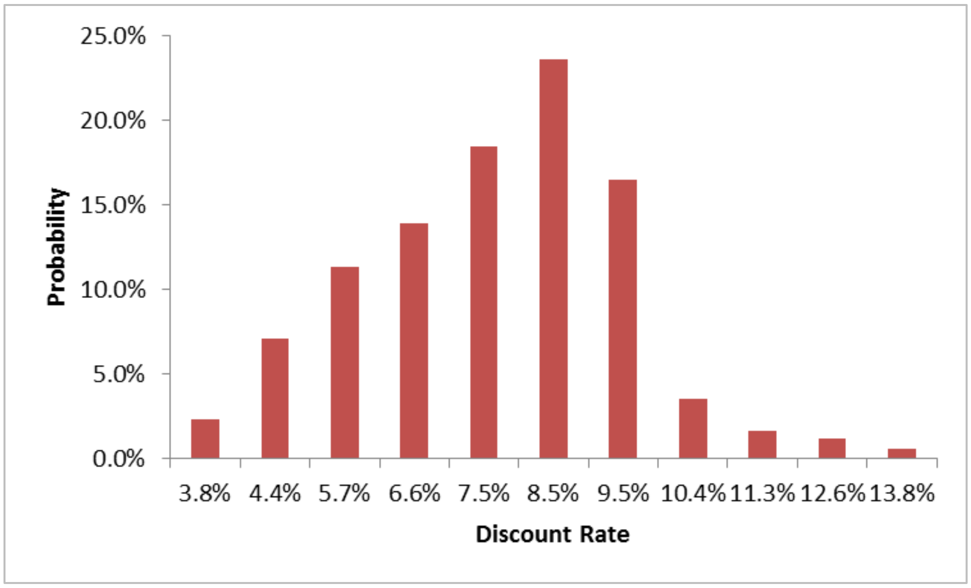

Figure 11.3.3 Distribution of Commercial Discount Rates: Medical

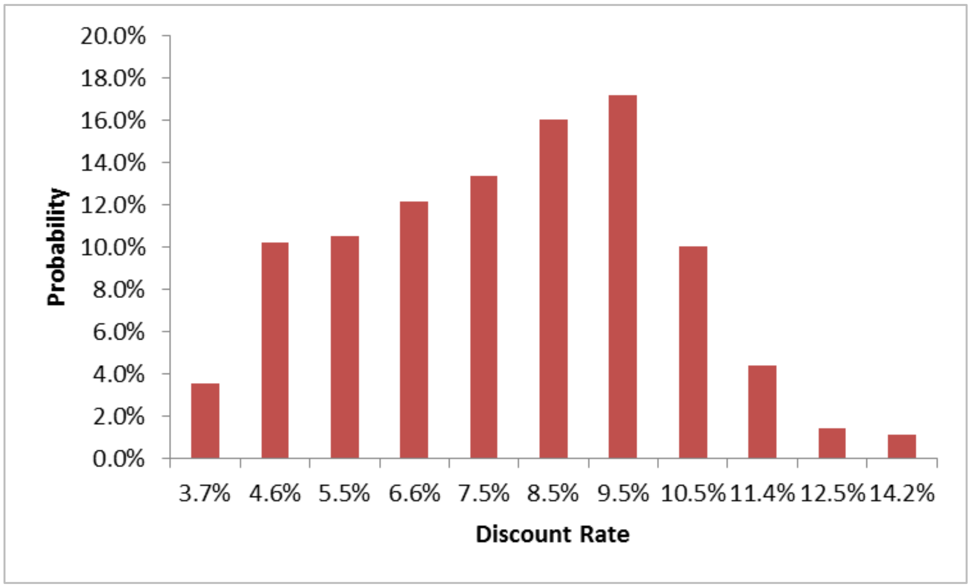

Figure 11.3.4 Distribution of Commercial Discount Rates: Industrial

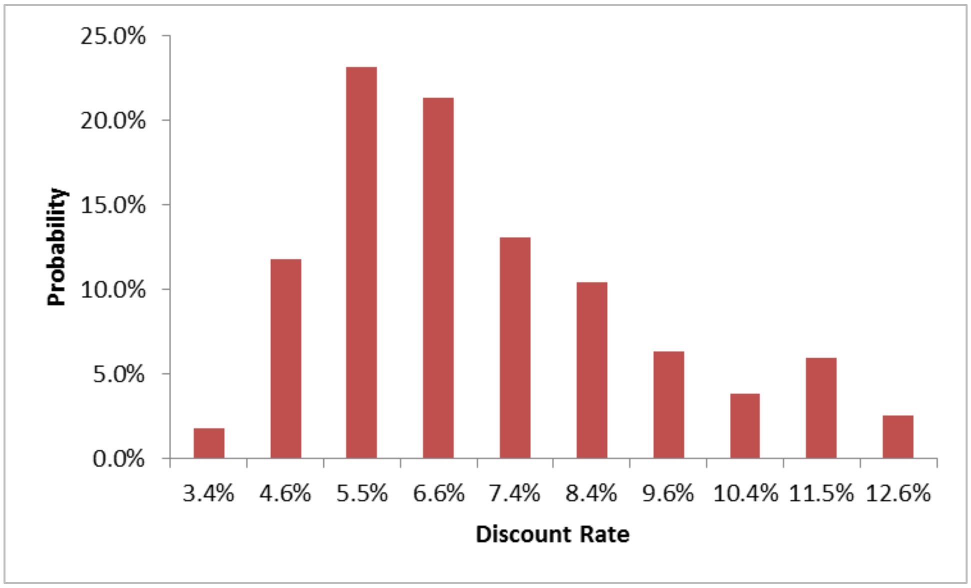

Figure 11.3.5 Distribution of Commercial Discount Rates: Hotels

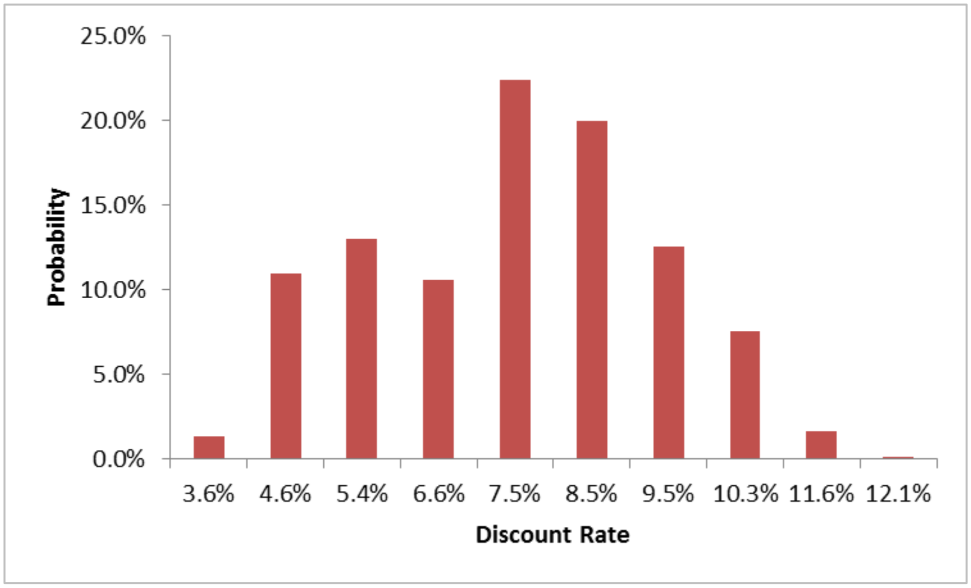

Figure 11.3.6 Distribution of Commercial Discount Rates: Food Service

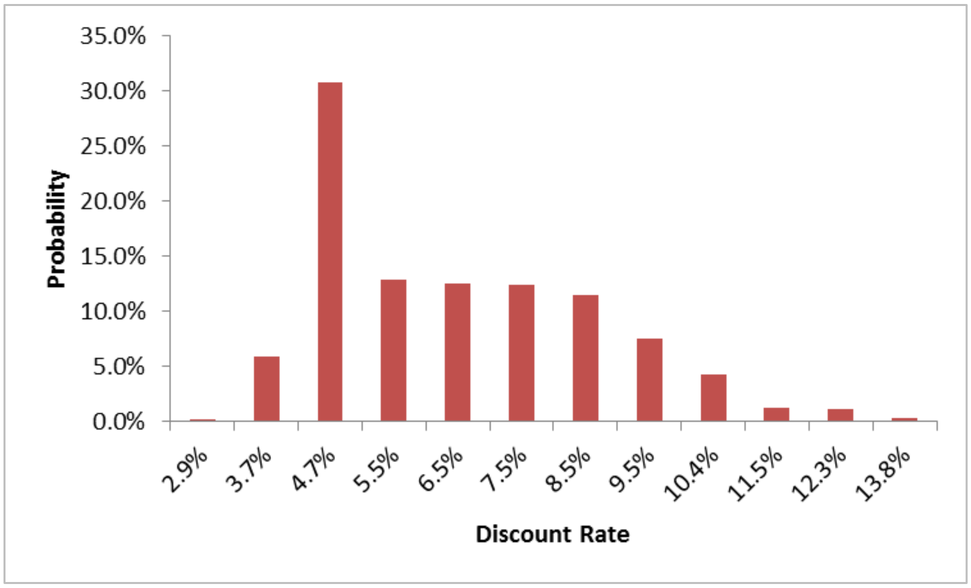

Figure 11.3.7 Distribution of Commercial Discount Rates: Office

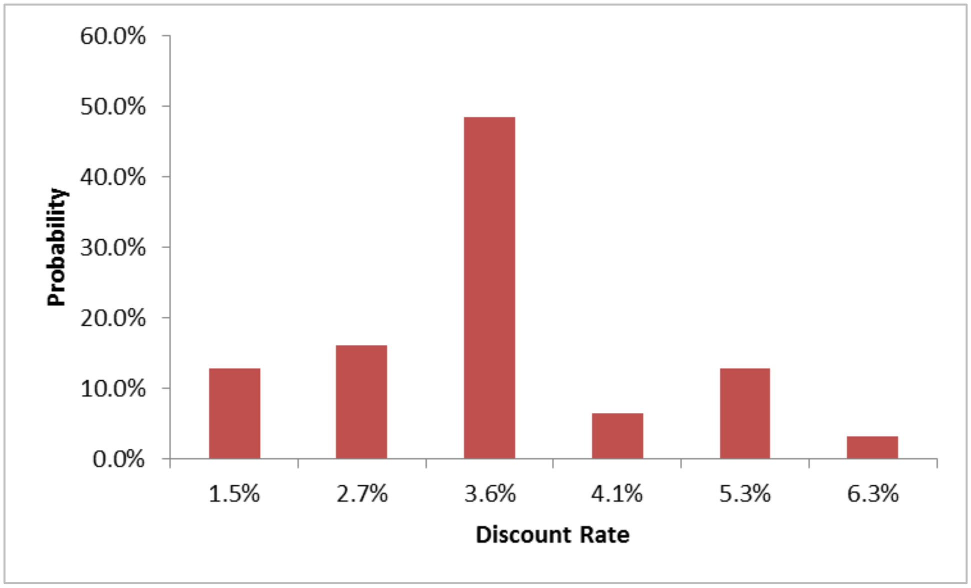

Figure 11.3.8 Distribution of Commercial Discount Rates: Education, State, and Local Government

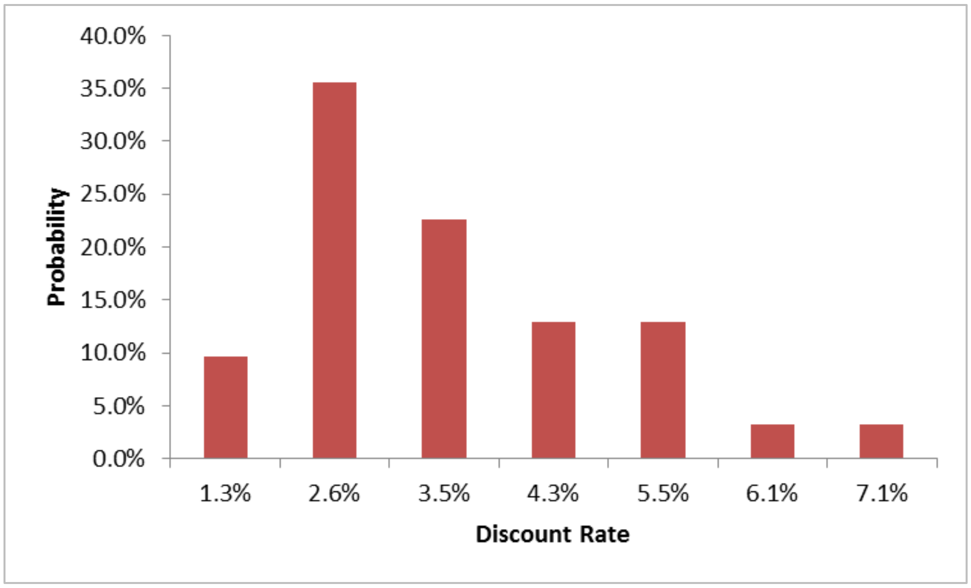

Figure 11.3.9 Distribution of Commercial Discount Rates: Federal Government

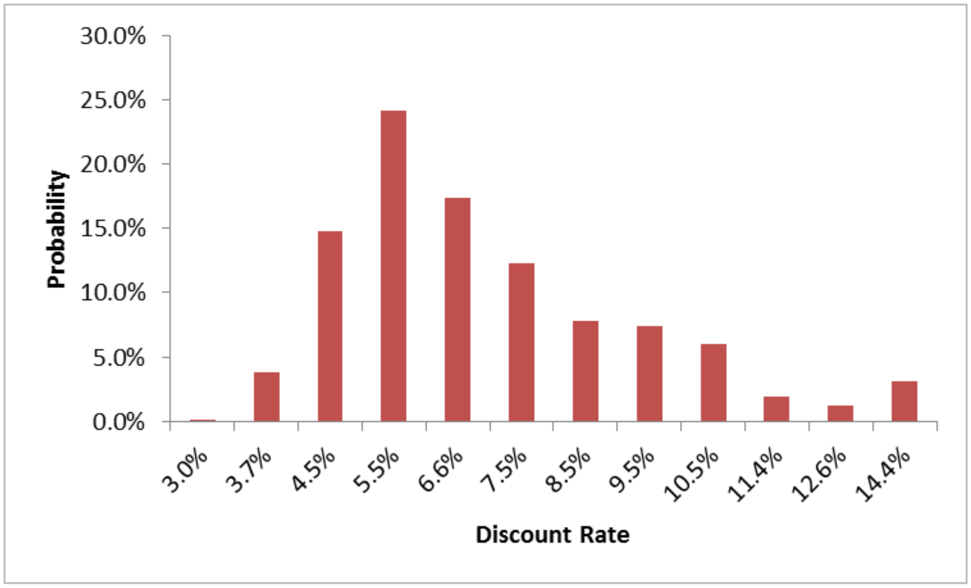

Figure 11.3.10 Distribution of Commercial Discount Rates: Other

11.4 RESULTS

Table 11.4.1 and Table 11.4.2 summarize the LCC and PBP results for the residential application and small business commercial subgroups, respectively. Table 11.4.3 through Table 11.4.10 compare average LCC savings for the consumer subgroups with the overall (i.e., National) results for CPB equipment by equipment product class.

Table 11.4.1 LCC and PBP Results for Residential Subgroup for CPB Equipment*

Product Class	Efficiency Level	Life-Cycle Cost 2014$*			Life-Cycle Cost Savings				Median Payback Period *years*
						% of Consumers with			
		Average Installed Price	Average Lifetime Operating Cost	Average LCC	Average Savings *2014$*	Net Cost	No Impact	Net Benefit	
SGHW	Baseline	$21,928	$291,698	$313,626	-	0%	100%	0%	-
	1	$22,593	$288,649	$311,243	$185	0%	92%	7%	4.2
	2	$23,311	$285,676	$308,987	$549	1%	84%	15%	4.4
	3	$25,719	$279,951	$305,669	$1,126	13%	67%	20%	6.2
	4	$26,707	$277,191	$303,897	$1,839	13%	58%	28%	6.3
	5	$33,593	$271,588	$305,181	$1,011	36%	40%	24%	11.0
	6	$34,169	$266,465	$300,634	$4,554	27%	22%	51%	9.2
	7	$38,448	$256,955	$295,403	$9,657	32%	2%	66%	9.0
LGHW	Baseline	$84,574	$1,032,898	$1,117,472	-	0%	100%	0%	-
	1	$89,538	$1,020,966	$1,110,505	$1,634	3%	76%	21%	7.9
	2	$95,095	$1,009,354	$1,104,449	$4,456	8%	53%	39%	8.5
	3	$101,314	$998,050	$1,099,364	$7,172	12%	46%	43%	9.1
	4	$150,261	$962,293	$1,112,554	-$2,683	48%	28%	24%	17.1
	5	$158,310	$932,542	$1,090,851	$18,622	34%	2%	64%	13.6
SOHW	Baseline	$24,901	$534,104	$559,005	-	0%	100%	0%	-
	1	$25,710	$528,114	$553,824	$2,045	0%	61%	39%	2.7
	2	$26,581	$522,268	$548,849	$5,065	1%	39%	60%	2.8
	3	$27,517	$516,562	$544,079	$8,466	1%	29%	70%	3.0
	4	$29,606	$505,550	$535,155	$16,048	2%	15%	84%	3.3
	5	$32,012	$500,234	$532,246	$18,773	8%	5%	87%	4.2
	6	$47,513	$481,207	$528,719	$22,248	29%	2%	70%	8.4
LOHW	Baseline	$59,164	$2,502,592	$2,561,757	-	0%	100%	0%	-
	1	$66,867	$2,448,779	$2,515,646	$16,193	0%	65%	35%	2.9
	2	$76,519	$2,397,308	$2,473,827	$50,146	1%	19%	81%	3.3
	3	$82,509	$2,372,407	$2,454,915	$67,827	1%	6%	92%	3.6
	4	$139,444	$2,334,739	$2,474,183	$49,517	32%	5%	63%	9.5
SGST	Baseline	$20,890	$298,469	$319,359	-	0%	100%	0%	-
	1	$21,563	$295,592	$317,155	$930	5%	57%	39%	4.5
	2	$22,289	$292,790	$315,080	$1,897	6%	52%	42%	4.8
	3	$23,075	$290,060	$313,135	$3,084	8%	37%	55%	5.0
	4	$23,925	$287,398	$311,323	$4,556	12%	18%	70%	5.3
	5	$25,836	$282,273	$308,109	$7,591	17%	5%	78%	5.9
LGST	Baseline	$73,000	$956,892	$1,029,892	-	0%	100%	0%	-
	1	$74,990	$946,364	$1,021,354	$877	0%	90%	10%	3.6
	2	$77,095	$936,105	$1,013,201	$3,433	0%	68%	31%	3.8
	3	$79,321	$926,107	$1,005,428	$6,930	1%	55%	44%	3.9
	4	$81,674	$916,360	$998,034	$12,169	2%	29%	69%	4.1
	5	$84,856	$906,854	$991,710	$16,849	3%	23%	73%	4.5
	6	$90,269	$888,533	$978,802	$28,667	4%	9%	87%	4.8
SOST	Baseline	$21,817	$511,247	$533,064	-	0%	100%	0%	-
	1	$23,897	$500,006	$523,903	$3,135	1%	66%	33%	3.7
	2	$25,115	$494,590	$519,705	$6,704	4%	15%	81%	4.0
	3	$27,974	$484,145	$512,119	$13,943	6%	4%	89%	4.5

Product Class	Efficiency Level	Life-Cycle Cost 2014$*			Life-Cycle Cost Savings				Median Payback Period *years*
					Average Savings *2014$*	% of Consumers with			
		Average Installed Price	Average Lifetime Operating Cost	Average LCC		Net Cost	No Impact	Net Benefit	
LOST	Baseline	$59,234	$2,430,467	$2,489,701	-	0%	100%	0%	-
	1	$64,033	$2,373,298	$2,437,331	$19,961	0%	62%	38%	1.7
	2	$69,606	$2,318,847	$2,388,453	$54,869	0%	29%	71%	1.9
	3	$76,078	$2,266,927	$2,343,005	$100,020	0%	1%	99%	2.1

* The CPB equipment abbreviations are SGHW = Small Gas-fired Hot Water, LGHW = Large Gas-fired Hot Water, SOHW = Small Oil-fired Hot Water, LOHW = Large Oil-fired Hot Water, SGST = Small Gas-fired Steam, LGST = Large Gas-fired Steam, SOST = Small Oil-fired Steam, and LOST = Large Oil-fired Steam.

Table 11.4.2 LCC and PBP Results for Small Business Subgroup for CPB Equipment*

Product Class	Efficiency Level	Life-Cycle Cost 2014$*			Life-Cycle Cost Savings				Median Payback Period *years*
					Average Savings *2014$*	% of Consumers with			
		Average Installed Price	Average Lifetime Operating Cost	Average LCC		Net Cost	No Impact	Net Benefit	
SGHW	Baseline	$25,916	$193,170	$219,086	-	0%	100%	0%	-
	1	$26,791	$191,146	$217,937	$86	2%	92%	6%	6.9
	2	$27,734	$189,173	$216,907	$252	4%	84%	12%	7.2
	3	$30,737	$185,377	$216,114	-$27	21%	67%	12%	9.8
	4	$32,036	$183,547	$215,583	$152	25%	58%	17%	10.1
	5	$41,595	$178,938	$220,534	-$2,933	49%	40%	11%	16.6
	6	$42,352	$175,622	$217,975	-$960	47%	22%	32%	14.3
	7	$47,979	$169,546	$217,525	-$532	63%	2%	34%	14.3
LGHW	Baseline	$94,192	$746,083	$840,275	-	0%	100%	0%	-
	1	$99,849	$737,190	$837,039	$671	11%	76%	13%	9.5
	2	$106,181	$728,539	$834,719	$1,639	23%	53%	24%	10.2
	3	$113,268	$720,119	$833,387	$2,265	29%	46%	25%	11.0
	4	$169,847	$690,435	$860,282	-$17,455	59%	28%	12%	19.1
	5	$179,019	$668,772	$847,791	-$5,178	59%	2%	39%	15.7
SOHW	Baseline	$28,685	$219,064	$247,750	-	0%	100%	0%	-
	1	$29,610	$216,716	$246,326	$562	12%	61%	27%	6.5
	2	$30,605	$214,424	$245,029	$1,355	19%	39%	41%	6.8
	3	$31,674	$212,188	$243,862	$2,189	24%	29%	48%	7.1
	4	$34,061	$207,874	$241,935	$3,832	30%	15%	55%	7.9
	5	$35,778	$205,792	$241,570	$4,172	37%	5%	58%	8.8
	6	$53,798	$199,275	$253,073	-$7,130	73%	2%	25%	19.2
LOHW	Baseline	$66,662	$1,601,716	$1,668,378	-	0%	100%	0%	-
	1	$75,661	$1,567,538	$1,643,199	$8,602	2%	65%	33%	4.3
	2	$86,935	$1,534,858	$1,621,793	$25,900	6%	19%	75%	4.9
	3	$93,916	$1,519,052	$1,612,967	$34,104	8%	6%	85%	5.3
	4	$160,762	$1,481,076	$1,641,839	$6,596	54%	5%	41%	12.5
SGST	Baseline	$22,628	$191,715	$214,343	-	0%	100%	0%	-
	1	$23,424	$189,711	$213,135	$503	12%	57%	31%	6.5
	2	$24,285	$187,758	$212,043	$1,004	14%	52%	33%	6.8
	3	$25,215	$185,856	$211,072	$1,597	21%	37%	42%	7.2
	4	$26,222	$184,003	$210,224	$2,277	31%	18%	52%	7.6
	5	$28,485	$180,435	$208,920	$3,507	41%	5%	54%	8.4

Product Class	Efficiency Level	Life-Cycle Cost 2014$*			Life-Cycle Cost Savings				Median Payback Period *years*
						% of Consumers with			
		Average Installed Price	Average Lifetime Operating Cost	Average LCC	Average Savings *2014$*	Net Cost	No Impact	Net Benefit	
LGST	Baseline	$82,623	$847,349	$929,973	-	0%	100%	0%	-
	1	$84,999	$837,345	$922,343	$795	1%	90%	9%	3.8
	2	$87,510	$827,598	$915,108	$3,161	5%	68%	26%	3.9
	3	$90,165	$818,099	$908,265	$6,308	8%	55%	37%	4.1
	4	$92,973	$808,840	$901,813	$10,892	13%	29%	58%	4.3
	5	$96,680	$799,810	$896,491	$14,792	17%	23%	59%	4.7
	6	$103,138	$782,410	$885,548	$24,796	21%	9%	70%	5.0
SOST	Baseline	$21,938	$333,353	$355,292	-	0%	100%	0%	-
	1	$24,196	$326,011	$350,208	$1,687	5%	66%	29%	5.2
	2	$25,518	$322,475	$347,993	$3,577	15%	15%	70%	5.5
	3	$28,621	$315,655	$344,276	$7,123	20%	4%	75%	6.3
LOST	Baseline	$68,112	$1,572,779	$1,640,891	-	0%	100%	0%	-
	1	$73,984	$1,535,825	$1,609,809	$11,806	0%	62%	38%	2.5
	2	$80,804	$1,500,634	$1,581,438	$32,079	1%	29%	71%	2.8
	3	$88,723	$1,467,085	$1,555,809	$57,562	1%	1%	98%	3.1

* The CPB equipment abbreviations are SGHW = Small Gas-fired Hot Water, LGHW = Large Gas-fired Hot Water, SOHW = Small Oil-fired Hot Water, LOHW = Large Oil-fired Hot Water, SGST = Small Gas-fired Steam, LGST = Large Gas-fired Steam, SOST = Small Oil-fired Steam, and LOST = Large Oil-fired Steam.

Table 11.4.3 Comparison of Impacts for Consumer Subgroups with All Consumers, Small Gas-Fired Hot Water Commercial Packaged Boilers

Thermal Efficiency (E_T) Level	Average LCC Savings *2014$*			Simple Payback Period *years*		
	Residential Low-Income	Commercial Small Business	All	Residential Low-Income	Commercial Small Business	All
1	$185	$86	$106	4.2	6.9	6.5
2	$549	$252	$318	4.4	7.2	6.9
3	$1,126	-$27	$223	6.2	9.8	9.4
4	$1,839	$152	$521	6.3	10.1	9.6
5	$1,011	-$2,933	-$2,031	11.0	16.6	15.9
6	$4,554	-$960	$302	9.2	14.3	13.6
7	$9,657	-$532	$1,656	9.0	14.3	13.6

Table 11.4.4 Comparison of Impacts for Consumer Subgroups with All Consumers, Large Gas-Fired Hot Water Commercial Packaged Boilers

Combustion Efficiency (E_C) Level	Average LCC Savings *2014$*			Simple Payback Period *years*		
	Residential Low-Income	**Commercial Small Business**	**All**	**Residential Low-Income**	**Commercial Small Business**	**All**
1	$1,634	$671	$924	7.9	9.5	9.5
2	$4,456	$1,639	$2,419	8.5	10.2	10.2
3	$7,172	$2,265	$3,647	9.1	11.0	11.0
4	-$2,683	-$17,455	-$13,074	17.1	19.1	19.0
5	$18,622	-$5,178	$2,062	13.6	15.7	15.6

Table 11.4.5 Comparison of Impacts for Consumer Subgroups with All Consumers, Small Oil-Fired Hot Water Commercial Packaged Boilers

Thermal Efficiency (E_T) Level	Average LCC Savings *2014$*			Simple Payback Period *years*		
	Residential Low-Income	**Commercial Small Business**	**All**	**Residential Low-Income**	**Commercial Small Business**	**All**
1	$2,045	$562	$1,040	2.7	6.5	4.7
2	$5,065	$1,355	$2,544	2.8	6.8	4.9
3	$8,466	$2,189	$4,208	3.0	7.2	5.2
4	$16,048	$3,832	$7,799	3.3	7.9	5.7
5	$18,773	$4,172	$8,939	4.2	8.8	6.6
6	$22,248	-$7,130	$2,333	8.4	19.2	14.3

Table 11.4.6 Comparison of Impacts for Consumer Subgroups with All Consumers, Large Oil-Fired Hot Water Commercial Packaged Boilers

Combustion Efficiency (E_C) Level	Average LCC Savings *2014$*			Simple Payback Period *years*		
	Residential Low-Income	**Commercial Small Business**	**All**	**Residential Low-Income**	**Commercial Small Business**	**All**
1	$16,193	$8,602	$10,108	2.9	4.3	4.1
2	$50,146	$25,900	$30,834	3.3	4.9	4.7
3	$67,827	$34,104	$40,983	3.6	5.3	5.2
4	$49,517	$6,596	$17,076	9.5	12.5	12.2

Table 11.4.7 Comparison of Impacts for Consumer Subgroups with All Consumers, Small Gas-Fired Steam Commercial Packaged Boilers

Thermal Efficiency (E_T) Level	Average LCC Savings *2014$*			Simple Payback Period *years*		
	Residential Low-Income	Commercial Small Business	All	Residential Low-Income	Commercial Small Business	All
1	$930	$503	$600	4.5	6.5	6.3
2	$1,897	$1,004	$1,205	4.8	6.8	6.6
3	$3,084	$1,597	$1,933	5.0	7.2	7.0
4	$4,556	$2,277	$2,782	5.3	7.6	7.4
5	$7,591	$3,507	$4,383	5.9	8.4	8.2

Table 11.4.8 Comparison of Impacts for Consumer Subgroups with All Consumers, Large Gas-Fired Steam Commercial Packaged Boilers

Thermal Efficiency (E_T) Level	Average LCC Savings *2014$*			Simple Payback Period *years*		
	Residential Low-Income	Commercial Small Business	All	Residential Low-Income	Commercial Small Business	All
1	$877	$795	$880	3.6	3.8	3.8
2	$3,433	$3,161	$3,528	3.8	3.9	3.9
3	$6,930	$6,308	$7,059	3.9	4.1	4.1
4	$12,169	$10,892	$12,255	4.1	4.3	4.3
5	$16,849	$14,792	$16,802	4.5	4.7	4.7
6	$28,667	$24,796	$28,295	4.8	5.0	5.0

Table 11.4.9 Comparison of Impacts for Consumer Subgroups with All Consumers, Small Oil-Fired Steam Commercial Packaged Boilers

Thermal Efficiency (E_T) Level	Average LCC Savings *2014$*			Simple Payback Period *years*		
	Residential Low-Income	Commercial Small Business	All	Residential Low-Income	Commercial Small Business	All
1	$3,135	$1,687	$1,985	3.7	5.2	5.0
2	$6,704	$3,577	$4,256	4.0	5.5	5.3
3	$13,943	$7,123	$8,637	4.5	6.3	6.1

Table 11.4.10 Comparison of Impacts for Consumer Subgroups with All Consumers, Large Oil-Fired Steam Commercial Packaged Boilers

Thermal Efficiency (E_T) Level	Average LCC Savings *2014$*			Simple Payback Period *years*		
	Residential Low-Income	Commercial Small Business	All	Residential Low-Income	Commercial Small Business	All
1	$19,961	$11,806	$13,243	1.7	2.5	2.5
2	$54,869	$32,079	$36,128	1.9	2.8	2.8
3	$100,020	$57,562	$65,128	2.1	3.1	3.1

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CHAPTER 12. MANUFACTURER IMPACT ANALYSIS

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CHAPTER 12. MANUFACTURER IMPACT ANALYSIS

12.1 INTRODUCTION

In determining whether a standard is economically justified, the U.S. Department of Energy (DOE) is required to consider the economic impact of the standard on the manufacturers and on the consumers of the products subject to such a standard. (42 U.S.C. 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 packaged boilers (CPBs), 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 each product 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 product by comparing changes in INPV between a no-new-standards case and the various trial standard levels (TSLs) in the standards case. The qualitative part of the MIA addresses product characteristics, manufacturer characteristics, market and product trends, as well as the impact of standards on 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 CPB industry, including data on sales volumes, pricing, employment, and financial structure. In Phase II, "Industry Cash Flow," DOE used the GRIM to assess the potential impacts of amended energy conservation standards on manufacturers. DOE also developed interview guides to gather information on the potential impacts on these manufacturers. In Phase III, "Subgroup Impact Analysis," DOE interviewed manufacturers representing a broad cross-section of the CPB industry. Using information from Phase II, DOE refined its analysis in the GRIM, developed additional analyses for subgroups that required special consideration, and incorporated qualitative data from interviews into its analysis.

12.2.1 Phase I: Industry Profile

In Phase I of the MIA, DOE prepared a profile of the CPB industry that built on the market and technology assessment prepared for this rulemaking (refer to chapter 3 of this technical support document (TSD). Before initiating the detailed impact studies, DOE collected information on the present and past structure and market characteristics of the CPB industry. This information included shipments, manufacturer markups, and the cost structures of various manufacturers. The industry profile includes: (1) further detail on the overall market and product characteristics; (2) estimated manufacturer market shares; (3) financial parameters such as net plant, property, and products; selling, general, and administrative (SG&A) expenses; cost of goods sold, etc.; and (4) trends in the number of firms, market, and product characteristics. The industry profile included a top-down cost analysis of CPB manufacturers that DOE used to derive the preliminary financial inputs for the GRIM (*e.g.*, revenues, depreciation, SG&A, and research and development (R&D) expenses).

DOE also used public information to further calibrate its initial characterization of the industry, including Securities and Exchange Commission (SEC) 10-K reports,[1] Standard & Poor's (S&P's) stock reports,[2] market research tools (*i.e.*, Hoovers[3]), corporate annual reports, the U.S. Census Bureau's 2013 Annual Survey of Manufacturers (ASM),[4] the Air-Conditioning, Heating and Refrigeration Institute trade association (AHRI),[5] and the American Boiler Manufacturers Association trade association (ABMA).[6] DOE also characterized these industries using information from its engineering analysis and the life-cycle cost (LCC) analysis.

12.2.2 Phase II: Industry Cash-Flow Analysis and Interview Guide

Phase II focused on the financial impacts of potential amended energy conservation standards on manufacturers of commercial packaged boilers. More-stringent energy conservation standards can affect manufacturer cash flows in three distinct ways, as it can (1) create a need for increased investment, (2) raise production costs per unit, and (3) alter 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 CPB industry. In performing these analyses, DOE used the financial values derived during Phase I and the shipment scenarios used in the national impact analysis (NIA). In Phase II, DOE performed these preliminary industry cash-flow analyses and prepared written guides for manufacturer interviews.

12.2.2.1 Industry Cash-Flow Analysis

The GRIM uses several factors to determine a series of annual cash flows from the announcement year of amended energy conservation standards until 30 years after the standards' compliance date. These factors include annual expected revenues, costs of goods sold, SG&A, taxes, and capital expenditures related to the amended standards. Inputs to the GRIM include manufacturer production costs, markup assumptions, and shipments forecasts developed in other analyses. DOE derived the manufacturing costs from the engineering analysis and information provided by the industry. It estimated typical manufacturer markups from public 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 this TSD, provided the basis for the shipment projections in the GRIM. The financial parameters were developed using publicly available manufacturer data and were revised with information submitted confidentially during manufacturer interviews. The GRIM results are compared to no-new-standards case projections for the industry. The financial impact of amended energy conservation standards is the difference between the discounted annual cash flows in the no-new-standards case and standards case at each TSL.

12.2.2.2 Interview Guides

During Phase II of the MIA, DOE interviewed manufacturers to gather information on the effects of amended energy conservation standards on revenues and finances, direct employment, capital assets, and industry competitiveness. Before the interviews, DOE distributed an interview guide to interviewees. The interview guide provided a starting point for identifying relevant issues and impacts of amended energy conservation standards on individual manufacturers or subgroups of manufacturers. Most of the information received from these meetings is protected by non-disclosure agreements and resides with DOE's contractors. The MIA interview topics (1) key issues, (2) models offered, (3) shipments data, (4) pricing data, (5) commercial packaged boiler components, (6) company overview and organizational characteristics, (7) markups and profitability, (8) financial parameters, (9) product mix, (10) distribution channels, (11) conversion costs, (12) cumulative regulatory burden, (13) direct employment, (14) capacity/outsourcing/foreign competition, (15) consolidation, (16) impacts on small businesses, (17) test procedure issues, and (18) other issues. The interview guide is presented in appendix 12-A.

12.2.3 Phase III: Subgroup Analysis

For its GRIM analysis, DOE presented the impacts on gas-fired and oil-fired CPB equipment. DOE sought to obtain feedback from industry on the approaches used in the GRIM and to isolate key issues and concerns. During interviews, DOE defined one manufacturer subgroup, small manufacturers, that could be disproportionately impacted by amended energy conservation standards.

12.2.3.1 Manufacturing Interviews

The information gathered in Phase I and the cash-flow analysis performed in Phase II are supplemented with information gathered from manufacturer interviews in Phase III. The interview process provides an opportunity for manufacturers to express their views on important issues privately, allowing confidential or sensitive information to be considered in the rulemaking process. DOE sought to obtain feedback from industry on the approaches used in the GRIMs and to isolate key issues and concerns.

DOE used these interviews to tailor the GRIM to reflect financial characteristics unique to the CPB industry. Interviews were scheduled well in advance to provide every opportunity for key individuals to be available for comment. Although a written response to the questionnaire was acceptable, DOE sought interactive interviews, which help clarify responses and identify additional issues. The resulting information provides valuable inputs to the GRIM developed for the products classes.

12.2.3.2 Revised Industry Cash-Flow Analysis

In Phase II of the MIA, DOE provided manufacturers with preliminary GRIM input financial figures for review and evaluation. During the interviews, DOE requested comments on the values it selected for the parameters. DOE revised its industry cash-flow model based on this feedback. Section 12.4.3 provides more information on how DOE calculated the parameters.

12.2.3.3 Manufacturer Subgroup Analysis

Using average cost assumptions to develop an industry cash-flow estimate may not adequately assess differential impacts of amended energy conservation standards among manufacturer subgroups. For example, small manufacturers, niche players, or manufacturers exhibiting a cost structure that largely differs from the industry average could be more negatively affected. To address this possible impact, DOE used the results of the industry characterization analysis in Phase I to group manufacturers that exhibit similar characteristics.

During the interviews, DOE discussed the potential subgroups and subgroup members it identified for the analysis. DOE asked manufacturers and other interested parties to suggest what subgroups or characteristics are the most appropriate to analyze. As described in section 12.2.3, DOE presents the industry impacts on CPB manufacturers as a whole because most of the product classes represent the same market served by the same manufacturers. However, as discussed below, DOE identified one manufacturer subgroup that warranted a separate impact analysis: small manufacturers.

12.2.3.4 Small-Business Manufacturer Subgroup

DOE investigated whether small business manufacturers should be analyzed as a manufacturer subgroup. DOE used the Small Business Administration (SBA) small business size standards effective on November 5, 2010, 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.[7] For the products classes under review, the SBA bases its small business definition on the total number of employees for a business, 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
Heating Equipment (except Warm Air Furnaces) Manufacturing	N/A	500	333414

DOE used publicly available and proprietary information to identify potential small manufacturers. DOE's research involved industry trade association membership directories (including Compliance Certification Management System (CCMS[a]), individual company websites, and market research tools (*e.g.*, Hoovers reports[b]) to create a list of companies that manufacture or sell commercial packaged boilers covered by this rulemaking. DOE also asked industry representatives if they were aware of any other small manufacturers during manufacturer interviews. DOE reviewed publicly available data and contacted companies on its list, as necessary, to determine whether they met the SBA's definition of a small business manufacturer of covered commercial packaged boilers. DOE screened out companies that do not offer products covered by this rulemaking, do not meet the definition of a "small business," or are foreign-owned and operated. DOE was able to determine that 30 manufacturers meet the SBA's definition of a "small business" and manufacture products covered by this rulemaking. DOE reports the potential impact of this rulemaking on small CPB manufacturers in section 12.6.

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[a] Based on listings in the CCMS directory. Available at www.regulations.doe.gov/certification-data/.
[b] Hoovers Company Information, Industry Information, Lists, D&B. 2014. Available at www.hoovers.com/.

12.2.3.1 Employment

The impact of amended energy conservation standards on employment is an important consideration in the rulemaking process. To assess how domestic direct employment patterns might be affected, the interviews explored current employment trends in the CPB industry. The interviews also solicited manufacturer views on changes in employment patterns that may result from more stringent standards. The employment section of the interview guide focused on current employment levels associated with manufacturers at each production facility, expected future employment levels with and without amended energy conservation standards, and differences in workforce skills and issues related to the retraining of employees. The employment impacts are reported in section 12.7.1.

12.2.3.2 Manufacturing Capacity Impact

One significant outcome of amended energy conservation standards could be the obsolescence of existing manufacturing assets, including tooling and investment. The manufacturer interview guides have a series of questions to help identify impacts of amended standards on manufacturing capacity, specifically capacity utilization and plant location decisions in the United States, with and without amended standards; the ability of manufacturers to upgrade or remodel existing facilities to accommodate the new requirements; the nature and value of any stranded assets; and estimates for any one-time changes to existing plant, property, and equipment (PPE). DOE's estimates of the one-time capital changes and stranded assets that affect the cash flow estimates in the GRIM can be found in section 12.7.2.

12.2.3.3 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 other Federal regulations that impact other products made by the CPB 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 the energy conservation standard rulemaking?" This question prompts manufacturers to identify the issues they think DOE should explore and discuss further during the interview. The following sections describe the most significant issues identified by manufacturers. These summaries are provided in aggregate to protect manufacturer confidentiality.

12.3.1 Testing Burden

Several manufacturers expressed concern regarding the testing burden associated with amended energy conservation standards. Manufacturers noted that amended standards and an altered test procedure will result in them having to retest all of their equipment, which they pointed out is a costly and logistically challenging process due to the large size of the equipment and the fact that a lot of commercial packaged boilers are customized for particular customers.

Manufacturers stated that retesting all of their models would put a strain on their lab resources and would be financially burdensome.

12.3.2 Condensing Boilers are Not Appropriate for Many Commercial Applications

Several manufacturers expressed concern that they would only be able to meet certain efficiency levels with condensing technology in gas-fired hot water equipment. They argued that this technology would not be effective in many commercial applications. Several manufacturers pointed out that condensing boilers will not operate in condensing mode in larger applications. As a result, they will not realize any efficiency gains when buildings and heat distribution systems are not designed around condensing technology. Manufacturers noted that it is very difficult to sell condensing boilers in the replacement market (which, according to manufacturers, comprises about 90 percent of boiler sales) because customers would have to make expensive retrofit changes to venting and distribution systems.

Manufacturers also pointed out that condensing boilers may not save money in commercial applications, even if they were to operate in condensing mode. Several manufacturers argued that condensing equipment requires higher pump force power and higher horsepower blower motors, and thus it consumes more electricity. They noted that even if the boiler were operating in condensing mode, the fuel savings could be partially offset by higher electricity use.

12.3.3 Not Many American Companies Produce Condensing Heat Exchangers

Several manufacturers expressed concern that if DOE were to mandate efficiency levels that could only be achieved with condensing technology for gas-fired hot water equipment, companies would likely face high conversion costs. While many companies in the United States currently produce condensing equipment, most condensing heat exchangers are sources from European or Asian companies. American companies would have to decide whether to develop their own condensing heat exchanger production capacity or assemble a baseline product around a condensing heat exchanger. Developing condensing heat exchanger production capacity would require large capital investments in new production lines and new equipment to handle the different metals that are required. Companies that are currently heavily invested in lower-efficiency products may not be able to make these investments. The other option would be for companies to drop their noncondensing equipment and assemble equipment around a sourced heat exchanger. In this scenario, companies would lose a significant piece of the value chain.

12.3.4 Reduced Product Durability and Reliability

Several manufacturers commented that higher-efficiency condensing boilers on the market have not demonstrated the same level of durability and reliability as lower-efficiency products. Manufacturers stated that condensing products require more upkeep and maintenance and generally do not last as long as non-condensing products. Several manufacturers pointed out that they generally incur large after-sale costs with their condensing products because of additional warranty claims. Maintenance calls for these boilers require more skilled technicians and occur more frequently than they do with non-condensing boilers.

12.4 GRIM INPUTS AND ASSUMPTIONS

The GRIM serves as the main tool for assessing the impacts on industry due to amended energy conservation standards. DOE relies on several sources to obtain inputs for the GRIM. Data and assumptions from these sources are then fed into an accounting model that calculates the industry cash flow both with and without amended energy conservation standards.

12.4.1 Overview of the GRIM

The basic structure of the GRIM, illustrated in Figure 12.4.1, is an annual cash flow analysis that uses manufacturer production costs, manufacturer selling prices, industry shipments, and industry financial parameters as inputs, and accepts a set of regulatory conditions such as changes in costs, investments, and associated margins. The GRIM spreadsheet uses a number of inputs to arrive at a series of annual cash flows, beginning with the base 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]

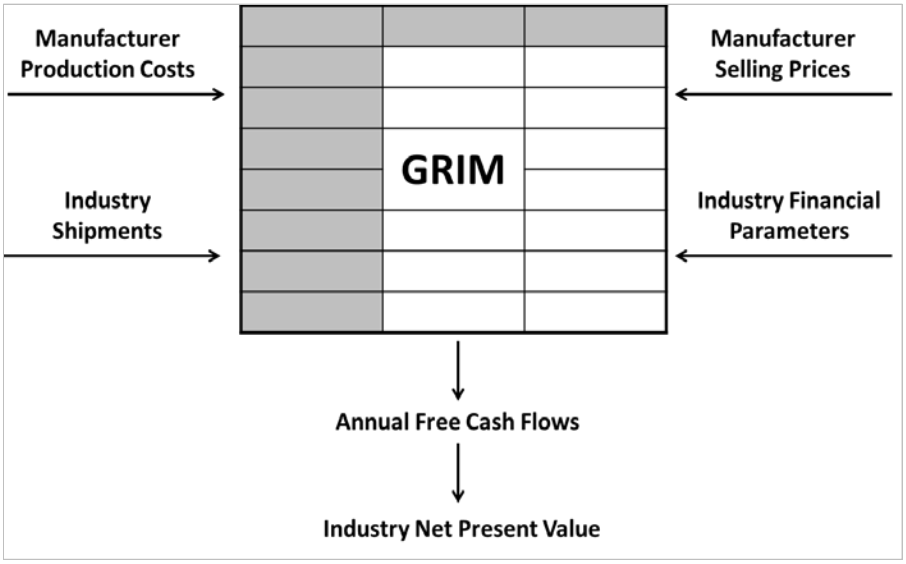

Figure 12.4.1 Using the GRIM to Calculate Cash Flow

The GRIM projects cash flows using standard accounting principles and compares changes in INPV between the no-new-standards case scenario and the standard-case scenario induced by amended energy conservation standards. The difference in INPV between the no-new-standards case and the standard case(s) represents the estimated financial impact of the amended energy conservation standard on manufacturers. Appendix 12B 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 company profiles, census data, financial metrics, the shipments model, the engineering analysis, and the 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 freely 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 manufacturers that manufacture commercial packaged boilers. Since these companies do not provide detailed information about their individual product lines, DOE used the financial information for the entire companies as its initial estimates of the financial parameters in the GRIM analysis. These figures were later revised using feedback from interviews to be representative of manufacturing for each product grouping. 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

The GRIM used no-new-standards case and standards case shipment projections derived from DOE's shipments model in the NIA. Chapter 9 of this TSD describes the methodology and analytical model DOE used to forecast shipments.

12.4.2.4 Engineering Analysis

The engineering analysis establishes the relationship between manufacturer selling price (MSP) and energy efficiency for the products covered in this rulemaking. DOE adopted an efficiency-level approach combined with a cost-assessment approach to develop cost-efficiency curves in its engineering analysis. DOE began its analysis by conducting industry research to select products classes to directly analyze, develop baseline unit specifications, and select representative commercial packaged boilers for further analysis. Next, DOE determined efficiency levels representative of either the most common efficiency levels available on the market or efficiency levels where major technological changes occur for each products class modeled. To develop cost estimates, DOE conducted a price analysis, based upon physical teardowns of selected units, cost estimates from publicly available sources, and price quotes from manufacturers. DOE then developed a cost model to determine manufacturer production costs (MPCs). By applying derived manufacturer markups to the MPC, DOE calculated the MSP and constructed industry cost-efficiency curves. See Chapter 5 for a complete discussion of the engineering analysis.

12.4.2.5 Manufacturer Interviews

During the course of the MIA, DOE conducted interviews with a representative cross-section of manufacturers. DOE also interviewed manufacturers representing a significant portion of sales in every products class. During these discussions, DOE obtained information to determine and verify GRIM input assumptions in each industry. Key topics discussed during the interviews and reflected in the GRIM include:

- Capital conversion costs (one-time investments in PPE)
- Financial metrics
- Product conversion costs (one-time investments in research, product development, testing, and marketing)
- Product cost structure, or the portion of the MPCs related to materials, labor, overhead, and depreciation costs
- MPCs estimated in the engineering analysis
- Possible profitability impacts.

12.4.3 Financial Parameters

Table 12.4.1 provides financial parameters for three public companies engaged in manufacturing and selling commercial packaged boilers. The values listed are averages over a 7-year period (2008 to 2014).

Table 12.4.1 Financial Parameters Used for Commercial Packaged Boilers in GRIM

Parameter	Industry-Weighted Average	Manufacturers		
		A	B	C
Tax Rate (% of Taxable Income)	26.3	30.1	24.5	34.7
Working Capital (% of Revenue)	21.4	27.8	18.9	22.5
SG&A (% of Revenue)	20.9	22.4	20.5	17.8
R&D (% of Revenues)	1.5	2.5	1.2	0.0
Depreciation (% of Revenues)	2.2	2.7	2.0	2.3
Capital Expenditures (% of Revenues)	2.3	3.5	1.9	1.6
Net Property, Plant, and Equipment (% of Revenues)	15.2	19.6	13.2	24.1

While most of these companies also manufacture products not covered by this rulemaking, DOE used these parameters as initial estimates. During interviews, manufacturers were asked to provide their own figures for the parameters listed in Table 12.4.1. Where applicable, DOE adjusted the parameters in the GRIM using manufacturer feedback and market share information.

In addition to these parameters, DOE used financial information sourced from SEC filings for the six public manufacturers to determine an average manufacturer markup.

Table 12.4.2 Financial Parameters Used to Determine No-New-Standards Case Markup

	Manufacturer		
	A	**B**	**C**
Average Net Revenues ($Million)	56,611.29	202.52	3,164.29
Corporate Gross Margin (%)	31.5	28.6	23.2
Markup	1.46	1.40	1.30

Table 12.4.2 lists the average net revenues, estimated corporate gross margin, and estimated manufacturer markup for the years 2008 to 2014 for the three manufacturers. The weighted average of the estimated manufacturer markup based on public filings by these six companies is 1.37. To further refine the no-new-standards case markup, DOE solicited feedback from manufacturers on this value in confidential interviews. Based on manufacturer feedback, DOE adjusted its estimate manufacturer markup and applied the values listed in Table 12.4.3 for covered equipment.

Table 12.4.3 No-New-Standards Case Manufacturer Markups

Equipment	**Markup**
Small Gas-Fired Hot Water	1.41
Small Gas-Fired Steam	1.41
Small Oil-Fired Hot Water	1.40
Small Oil-Fired Steam	1.38
Large Gas-Fired Hot Water	1.41
Large Gas-Fired Steam	1.37
Large Oil-Fired Hot Water	1.41
Large Oil-Fired Steam	1.37

12.4.4 Corporate Discount Rate

DOE used the weighted-average cost of capital (WACC) as the discount rate to calculate the INPV. A company's assets are financed by a combination of debt and equity. The WACC is the total cost of debt and equity weighted by their respective proportions in the capital structure of the industry. DOE estimated the WACC for the CPB industry based on six representative companies, using the following formula:

$$\text{WACC} = \text{After-Tax Cost of Debt} \times (\text{Debt Ratio}) + \text{Cost of Equity} \times (\text{Equity Ratio})$$

Eq. 12.1

The cost of equity is the rate of return that equity investors (including, potentially, the company) expect to earn on a company's stock. These expectations are reflected in the market price of the company's stock. The Capital Asset Pricing Model (CAPM) provides one widely used means to estimate the cost of equity. According to the CAPM, the cost of equity (expected return) is:

$$\text{Cost of Equity} = \text{Riskless Rate of Return} + \beta \times \text{Risk Premium}$$

Eq. 12.2

Where:

Riskless Rate of Return = the rate of return on a "safe" benchmark investment, typically considered the short-term Treasury Bill (T-Bill) yield,
Risk Premium = the difference between the expected return on stocks and the riskless rate, and
Beta (β) = the correlation between the movement in the price of the stock and that of the broader market. In this case, Beta equals one if the stock is perfectly correlated with the S&P 500 market index. A Beta lower than one means the stock is less volatile than the market index.

DOE calculated that the industry average cost of equity for the CPB industry is 13.9 percent (Table 12.4.4).

Table 12.4.4 Cost of Equity Calculation

Parameter	Industry Weighted Average	A	B	C
(1) Average Beta	1.4	1.2	1.6	0.5
(2) Average Yield on 10-Year Bonds (1928–2012) (%)	5.2			
(3) Market Risk Premium (%)	6.1			
Cost of Equity (2)+[(1)×(3)](%)	13.9			
Equity/Total Capital (%)	68.8	86.8	61.1	88.1

Bond ratings are a tool to measure default risk and arrive at a cost of debt. Each bond rating is associated with a particular spread. One way of estimating a company's cost of debt is to treat it as a spread (usually expressed in basis points) over the risk-free rate. DOE used this method to calculate the cost of debt for six public manufacturers by using S&P ratings and estimated credit worthiness and adding the relevant spread to the risk-free rate.

In practice, investors use a variety of different maturity Treasury bonds to estimate the risk-free rate. DOE used the 10-year Treasury bond rate because it captures long-term inflation expectations and is less volatile than short-term rates. The risk-free rate is estimated to be approximately 5.2 percent, which is the average 10-year Treasury bond rate between 1929 and 2014.

For the cost of debt, DOE used bond ratings from S&P's Credit Services to calculate an average spread of corporate bonds.[c] DOE added these spreads to the estimated risk-free rate of 5.2 percent to determine the gross cost of debt for each company. It then calculated an industry weighted average gross cost of debt of 13.2 percent. Since proceeds from debt issuance are tax deductible, DOE adjusted the gross cost of debt by the industry average tax rate to determine the net cost of debt for the industry. Table 12.4.5 presents the derivation of the cost of debt and the capital structure of the industry (*i.e.*, the debt ratio (debt/total capital)).

Table 12.4.5 Cost of Debt Calculation

Parameter	Industry Weighted Average	A	B	C
S&P Bond Rating		CCC	CCC	CCC
(1) Avg. Yield on 10-Yr Bonds (1928–2014) (%)	5.2			
(2) Gross Cost of Debt (%)	13.2	13.2	13.2	13.2
(3) Tax Rate (%)	26.3	30.1	24.6	34.7
Net Cost of Debt (2)×[1-(3)] (%)	9.7			
Debt/Total Capital (%)	31.1	13.2	38.9	11.9

Using public information for these six companies, the initial estimate for the industry's nominal WACC was approximately 12.6 percent. Subtracting an inflation rate of 3.08 percent over the analysis period used in the initial estimate, the inflation-adjusted WACC and the initial estimate of the discount rate used in the straw-man GRIM is 9.51 percent. DOE also asked for feedback on the discount rate during manufacturer interviews. Based on this feedback, DOE used a discount rate of 9.5 percent in the GRIM.

12.4.5 Trial Standard Levels

DOE developed a number of efficiency levels for each type of products class. TSLs were then developed by selecting likely groupings of efficiency levels for all products types. Table 12.4.6 presents the TSLs used for energy efficiency analysis in the GRIM.

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[c] For one of the six manufacturers, S&P bond ratings were not available. In this cases, DOE estimated the company's synthetic bond ratings based on the interest coverage ratio. The interest coverage ratio is calculated as the ratio of earnings before interest and taxes (EBIT) to current interest expenses, with the present value of operating leases reclassified as debt. The estimated synthetic bond ratings are based on a valuation method available through the NYU Stern School of Business and may be found at www.stern.nyu.edu/~adamodar/pc/ratings.xls

Table 12.4.6 Trial Standard Levels for Energy Efficiency Analysis of Commercial Packaged Boilers

Equipment Class	Trial Standard Level				
	1	2	3	4	5
	EL	EL	EL	EL	EL
Small Gas-Fired Hot Water Commercial Packaged Boilers	3	4	6	7	7
Large Gas-Fired Hot Water Commercial Packaged Boilers	2	3	3	5	5
Small Oil-Fired Hot Water Commercial Packaged Boilers	4	4	4	5	6
Large Oil-Fired Hot Water Commercial Packaged Boilers	1	2	2	3	4
Small Gas-Fired Steam Commercial Packaged Boilers	3	4	4	5	5
Large Gas-Fired Steam Commercial Packaged Boilers	4	5	5	6	6
Small Oil-Fired Steam Commercial Packaged Boilers	1	2	2	3	3
Large Oil-Fired Steam Commercial Packaged Boilers	1	2	2	3	3

The proposed standard, TSL 2, represents adopting efficiency level at EL 4 (85 percent) for small gas-fired hot water boilers, EL 3 (85 percent) for large gas-fired hot water boilers, EL 4 (87 percent) for small oil-fired hot water boilers, EL 2 (88 percent) for large oil-fired hot water, EL 4 (81 percent) for small gas-fired steam boilers, EL 5 (82 percent) for large gas-fired steam boilers, EL 2 (84 percent) for small oil-fired steam boilers, and EL 2 (85 percent) for large oil-fired steam boilers. Approximately 48.0 percent of current industry equipment listings meet the 2019 standard levels.

12.4.6 NIA Shipments

The GRIM estimates manufacturer revenues based on total-unit-shipment forecasts and the distribution of these values by efficiency level. Changes in the efficiency mix at each TSL are a key driver of manufacturer finances. For this analysis, the GRIM applied the NIA shipments forecasts.

As part of the shipments analysis, DOE estimated the no-new-standards case shipment distribution by efficiency level for each products class. In the standards case, DOE determined efficiency distributions for cases in which a potential standard applies for 2019 and beyond. The NIA assumes that product efficiencies in the no-new-standards case that do not meet the energy conservation standard in the standards case either “roll up” to meet the amended standard or switch to another product such as a heat pump or electric furnace. Consumers in the no-new-standards case who purchase units above the standard level are not affected as they are assumed to continue to purchase the same no-new-standards case unit in the standards case. See chapter 9 of this TSD for more information on the CPB standards-case shipments.

12.4.7 Production Costs

Changes in production costs affect revenues and gross profits. Products that are more efficient typically cost more to produce than baseline products (as shown in chapter 5 of this TSD). For the MIA, DOE used the MPCs derived in the engineering analysis.

Manufacturing a higher efficiency product is typically more expensive than manufacturing a baseline product. MPCs increase at higher efficiency levels due to the use of more raw material and more complex components, which are more costly than baseline components. These changes in MPC can affect the revenues, gross margins, and cash flow of the industry, making these product cost data key GRIM inputs for DOE's analysis.

To calculate baseline MSP, DOE used the MPCs from the engineering analysis and applied a manufacturer markup, which varies with the markup scenario (discussed in detail in section 12.4.9), to the MPCs. DOE estimates MSPs for each efficiency level within each equipment class using the following formula:

$$\text{Manufacturing Selling Price} = (\text{Manufacturer Production Cost} \times \text{Markup}) \quad \textbf{Eq. 12.3}$$

Table 12.4.7 through Table 12.4.14 show the production cost estimates used in the GRIM for each analyzed equipment class.

Table 12.4.7 Manufacturer Production Cost Breakdown (2014$) for Small Gas-Fired Hot Water CBPs

Efficiency Level	Materials ($)	Labor ($)	Depreciation ($)	Overhead ($)	MPC ($)	Markup	MSP ($)
Baseline	3,543.75	462.27	190.64	716.49	4,913.15	1.41	6,927.54
EL 1	3,791.43	498.59	196.93	760.68	5,247.63	1.41	7,399.16
EL 2	4,057.08	537.81	203.22	807.69	5,605.80	1.41	7,904.17
EL 3	4,988.81	671.80	231.53	977.81	6,869.95	1.41	9,686.63
EL 4	5,410.88	734.29	241.21	1,052.24	7,438.62	1.41	10,488.46
EL 5	9,636.84	776.82	249.85	1,360.82	12,024.32	1.41	16,954.29
EL 6	10,019.19	769.43	197.49	1,369.52	12,355.62	1.41	17,421.43
EL 7	12,202.92	876.74	142.12	1,596.43	14,818.21	1.41	20,893.68

Table 12.4.8 Manufacturer Production Cost Breakdown (2014$) for Large Gas-Fired Hot Water CPBs

Efficiency Level	Materials ($)	Labor ($)	Depreciation ($)	Overhead ($)	MPC ($)	Markup	MSP ($)
Baseline	9,215.97	2,032.47	552.50	3,265.70	15,066.63	1.41	21,243.95
EL 1	10,358.57	2,288.31	591.49	3,625.26	16,863.63	1.41	23,777.72
EL 2	11,642.09	2,577.92	631.75	4,023.20	18,874.96	1.41	26,613.70
EL 3	13,084.72	2,903.14	673.30	4,465.02	21,126.18	1.41	29,787.91
EL 4	27,374.34	3,532.09	843.26	6,576.55	38,326.24	1.41	54,040.00
EL 5	29,791.09	3,837.37	745.22	6,866.04	41,239.72	1.41	58,148.00

Table 12.4.9 Manufacturer Production Cost Breakdown (2014$) for Small Oil-Fired Hot Water CPBs

Efficiency Level	Materials ($)	Labor ($)	Depreciation ($)	Overhead ($)	MPC ($)	Markup	MSP ($)
Baseline	4,558.35	405.51	197.00	842.26	6,003.12	1.40	8,404.36
EL 1	4,900.15	442.38	201.77	911.39	6,455.68	1.40	9,037.95
EL 2	5,303.90	470.67	193.42	974.38	6,942.37	1.40	9,719.31
EL 3	5,713.37	509.52	192.42	1,050.43	7,465.74	1.40	10,452.04
EL 4	6,543.62	625.31	215.90	1,249.00	8,633.83	1.40	12,087.37
EL 5	7,034.29	681.50	217.67	1,351.26	9,284.72	1.40	12,998.61
EL 6	14,526.67	1,484.03	338.07	2,287.66	18,636.43	1.40	26,091.00

Table 12.4.10 Manufacturer Production Cost Breakdown (2014$) for Large Oil-Fired Hot Water CPBs

Efficiency Level	Materials ($)	Labor ($)	Depreciation ($)	Overhead ($)	MPC ($)	Markup	MSP ($)
Baseline	8,852.36	1,306.14	397.20	2,859.44	13,415.14	1.41	18,915.35
EL 1	11,055.04	1,681.94	445.88	3,626.16	16,809.01	1.41	23,700.71
EL 2	13,805.64	2,164.28	493.77	4,597.81	21,061.50	1.41	29,696.71
EL 3	15,429.19	2,453.30	517.51	5,175.60	23,575.60	1.41	33,241.60
EL 4	33,590.96	5,411.35	863.23	8,955.74	48,821.28	1.41	68,838.00

Table 12.4.11 Manufacturer Production Cost Breakdown (2014$) for Small Gas-Fired Steam CBPs

Efficiency Level	Materials ($)	Labor ($)	Depreciation ($)	Overhead ($)	MPC ($)	Markup	MSP ($)
Baseline	2,756.26	965.09	99.35	901.73	4,722.42	1.41	6,658.61
EL 1	3,120.44	904.28	171.58	909.33	5,105.63	1.41	7,198.93
EL 2	3,532.73	847.31	222.89	917.01	5,519.93	1.41	7,783.10
EL 3	4,020.29	762.63	269.77	915.16	5,967.86	1.41	8,414.68
EL 4	4,544.37	736.92	238.29	932.55	6,452.13	1.41	9,097.50
EL 5	5,543.09	756.69	218.72	1,023.26	7,541.75	1.41	10,633.87

Table 12.4.12 Manufacturer Production Cost Breakdown (2014$) for Large Gas-Fired Steam CPBs

Efficiency Level	Materials ($)	Labor ($)	Depreciation ($)	Overhead ($)	MPC ($)	Markup	MSP ($)
Baseline	8,369.87	1,918.72	568.55	3,100.44	13,957.58	1.37	19,121.88
EL 1	8,884.55	2,041.82	579.64	3,252.13	14,758.14	1.37	20,218.65
EL 2	9,430.73	2,172.72	590.14	3,411.03	15,604.62	1.37	21,378.33
EL 3	10,010.34	2,311.93	599.93	3,577.45	16,499.65	1.37	22,604.52
EL 4	10,625.41	2,459.96	608.90	3,751.75	17,446.01	1.37	23,901.04
EL 5	11,295.23	2,611.19	611.26	3,928.99	18,446.66	1.37	25,271.93
EL 6	12,731.61	2,953.51	620.98	4,317.33	20,623.43	1.37	28,254.09

Table 12.4.13 Manufacturer Production Cost Breakdown (2014$) for Small Oil-Fired Steam CPBs

Efficiency Level	Materials ($)	Labor ($)	Depreciation ($)	Overhead ($)	MPC ($)	Markup	MSP ($)
Baseline	4,034.44	372.59	151.58	726.68	5,285.29	1.38	7,293.70
EL 1	4,984.76	466.95	177.87	903.54	6,533.13	1.38	9,015.71
EL 2	5,577.82	513.82	173.86	998.02	7,263.52	1.38	10,023.66
EL 3	6,905.91	639.19	197.12	1,236.18	8,978.41	1.38	12,390.20

Table 12.4.14 Manufacturer Production Cost Breakdown (2014$) for Large Oil-Fired Steam CPBs

Efficiency Level	Materials ($)	Labor ($)	Depreciation ($)	Overhead ($)	MPC ($)	Markup	MSP ($)
Baseline	9,054.06	1,362.72	402.53	2,831.95	13,651.26	1.37	18,702.23
EL 1	10,493.68	1,605.41	445.22	3,309.25	15,853.55	1.37	21,719.37
EL 2	12,148.67	1,905.42	476.90	3,880.14	18,411.13	1.37	25,223.24
EL 3	14,070.42	2,250.07	521.88	4,538.93	21,381.30	1.37	29,292.38

12.4.8 Conversion Costs

Amended energy conservation standards typically cause manufacturers to incur one-time conversion costs to bring their production facilities and product designs into compliance with amended regulations. For the MIA, DOE classified these one-time conversion costs into two major groups: capital conversion costs and product conversion costs. Capital conversion costs are one-time investments in plant, property, and products 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 one-time investments in research, development, testing, marketing, and other costs to make product designs comply with amended energy conservation standards.

12.4.8.1 Capital Conversion Costs

To estimate capital conversion costs, DOE used a top-down approach that began by interviewing manufacturers and learning what each manufacturer estimated to be the expected level of investment to meet each proposed efficiency level. Once DOE had capital conversion cost estimates at the various efficiency levels from the interviewed manufacturers, the estimates were scaled to represent the entire industry. DOE used the product listing database to estimate the percentage of product listings represented by the interviewed manufacturers and used this to scale up to the entire industry. For steam products, DOE did not have sufficient product data to use the same methodology. Therefore, manufacturer feedback was scaled by the number of manufacturers producing steam products found in the equipment listings database.

Table 12.4.15 through Table 12.4.22 show the industry cumulative capital conversion costs associated with each efficiency level analyzed separated by product class. Table 12.4.23 represents industry cumulative capital conversion costs associated with each TSL analyzed.

Table 12.4.15 Small Gas-Fired Hot Water Industry Manufacturer Cumulative Capital Conversion Costs by Efficiency Level

Efficiency Level	Cumulative Capital Conversion Cost (2014$ M)
EL 1	-
EL 2	0.6
EL 3	0.6
EL 4	2.0
EL 5	9.0
EL 6	9.0
EL 7	9.0

Table 12.4.16 Large Gas-Fired Hot Water Industry Manufacturer Cumulative Capital Conversion Costs by Efficiency Level

Efficiency Level	Cumulative Capital Conversion Cost (2014$ M)
EL 1	1.3
EL 2	1.3
EL 3	4.0
EL 4	17.8
EL 5	17.8

Table 12.4.17 Small Oil-Fired Hot Water Industry Manufacturer Cumulative Capital Conversion Costs by Efficiency Level

Efficiency Level	Cumulative Capital Conversion Cost (2014$ M)
EL 1	-
EL 2	0.5
EL 3	0.5
EL 4	0.6
EL 5	0.6
EL 6	2.5

Table 12.4.18 Large Oil-Fired Hot Water Industry Manufacturer Cumulative Capital Conversion Costs by Efficiency Level

Efficiency Level	Cumulative Capital Conversion Cost (2014$ M)
EL 1	0.9
EL 2	1.3
EL 3	1.3
EL 4	5.1

Table 12.4.19 Small Gas-Fired Steam Industry Manufacturer Cumulative Capital Conversion Costs by Efficiency Level

Efficiency Level	Cumulative Capital Conversion Cost (2014$ M)
EL 1	0.5
EL 2	0.5
EL 3	0.5
EL 4	0.5
EL 5	0.5

Table 12.4.20 Large Gas-Fired Steam Industry Manufacturer Cumulative Capital Conversion Costs by Efficiency Level

Efficiency Level	Cumulative Capital Conversion Cost (2014$ M)
EL 1	0.4
EL 2	0.4
EL 3	0.4
EL 4	0.4
EL 5	0.4
EL 6	0.4

Table 12.4.21 Small Oil-Fired Steam Industry Manufacturer Cumulative Capital Conversion Costs by Efficiency Level

Efficiency Level	Cumulative Capital Conversion Cost (2014$ M)
EL 1	0.3
EL 2	0.3
EL 3	0.3

Table 12.4.22 Large Oil-Fired Steam Industry Manufacturer Cumulative Capital Conversion Costs by Efficiency Level

Efficiency Level	Cumulative Capital Conversion Cost (2014$ M)
EL 1	0.4
EL 2	0.4
EL 3	0.4

Table 12.4.23 Industry Cumulative Capital Conversion Costs by TSL

TSL	Cumulative Capital Conversion Cost (2014$ M)
No-New-Standards Case	0.0
TSL 1	4.8
TSL 2	9.3
TSL 3	20.8
TSL 4	33.9
TSL 5	35.2

12.4.8.2 Production Conversion Costs

Cumulative product conversion cost estimates were derived using the same top-down methodology as was used to derive capital conversion costs. DOE used manufacturer estimates of product conversion cost to meet each efficiency level as a starting point for the derived product conversion costs. DOE used a similar approach to estimate product conversion costs as it did to estimate capital conversion cost. DOE took manufacturer estimates for R&D, engineering, and testing; and then scaled these estimates based off product listings count to arrive at industry product conversion costs. Again, for steam products, DOE did not have sufficient product conversion cost data to scale up by product listings; therefore, manufacturer feedback was scaled up by the number of manufacturers producing steam products found in the equipment listing database.

In general, as the standard increases, more products require redesign. Furthermore, as the standard increases, the complexity of redesign increases. Table 12.4.24 through Table 12.4.31 represent industry cumulative product conversion costs associated with each efficiency level analyzed. Table 12.4.32 shows the industry cumulative product conversion costs for each TSL analyzed.

Table 12.4.24 Small Gas-Fired Hot Water Industry Manufacturer Cumulative Product Conversion Costs by Efficiency Level

Efficiency Level	Cumulative Product Conversion Costs (2014$ M)
EL 1	-
EL 2	0.8
EL 3	0.8
EL 4	4.4
EL 5	5.4
EL 6	5.4
EL 7	5.4

Table 12.4.25 Large Gas-Fired Hot Water Industry Manufacturer Cumulative Product Conversion Costs by Efficiency Level

Efficiency Level	Cumulative Product Conversion Costs (2014$ M)
EL 1	1.6
EL 2	1.6
EL 3	5.2
EL 4	6.7
EL 5	6.7

Table 12.4.26 Small Oil-Fired Hot Water Industry Manufacturer Cumulative Product Conversion Costs by Efficiency Level

Efficiency Level	Cumulative Product Conversion Costs (2014$ M)
EL 1	-
EL 2	0.4
EL 3	2.9
EL 4	3.1
EL 5	3.1
EL 6	3.3

Table 12.4.27 Large Oil-Fired Hot Water Industry Manufacturer Cumulative Product Conversion Costs by Efficiency Level

Efficiency Level	Cumulative Product Conversion Costs (2014$ M)
EL 1	4.2
EL 2	4.6
EL 3	4.6
EL 4	4.9

Table 12.4.28 Small Gas-Fired Steam Industry Manufacturer Cumulative Product Conversion Costs by Efficiency Level

Efficiency Level	Cumulative Product Conversion Costs (2014$ M)
EL 1	0.3
EL 2	0.3
EL 3	0.3
EL 4	0.3
EL 5	0.3

Table 12.4.29 Large Gas-Fired Steam Industry Manufacturer Cumulative Product Conversion Costs by Efficiency Level

Efficiency Level	Cumulative Product Conversion Costs (2014$ M)
EL 1	0.3
EL 2	0.3
EL 3	0.3
EL 4	0.3
EL 5	0.3
EL 6	0.3

Table 12.4.30 Small Oil-Fired Steam Industry Manufacturer Cumulative Product Conversion Costs by Efficiency Level

Efficiency Level	Cumulative Product Conversion Costs (2014$ M)
EL 1	0.2
EL 2	0.2
EL 3	0.2

Table 12.4.31 Large Oil-Fired Steam Industry Manufacturer Cumulative Product Conversion Costs by Efficiency Level

Efficiency Level	Cumulative Product Conversion Costs (2014$ M)
EL 1	0.3
EL 2	0.3
EL 3	0.3

Table 12.4.32 Industry Cumulative Product Conversion Costs by TSL

TSL	Cumulative Product Conversion Costs (2014$ M)
No-New-Standards Case	0
TSL 1	10.7
TSL 2	18.2
TSL 3	19.3
TSL 4	20.8
TSL 5	21.4

12.4.9 Markup Scenarios

DOE used multiple standards case markup scenarios to represent the uncertainty of the impacts of energy conservation standards on prices and profitability. In the no-new-standards case, DOE used the same markups applied in the engineering analysis. In the standards case, DOE modeled two markup scenarios to represent the uncertainty of the potential impacts on prices and profitability following the implementation of amended energy conservation standards; (1) a preservation of gross margin percentage scenario; and (2) a preservation of operating profit scenario. These scenarios lead to different markups values that, when applied to the inputted 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 scenario, DOE applied a single uniform "gross margin percentage" markup across all efficiency levels. As production costs increase with efficiency, this scenario implies that the absolute dollar markup will increase as well. As shown in Table 12.4.33, DOE assumed the non-production cost markup, which includes SG&A expenses, R&D expenses, interest, and profit to be 1.41 for small gas-fired hot water, small gas-fired steam boilers, large gas-fired hot water boilers, and large oil-fired hot water boilers; 1.40 for small oil-fired hot water boilers; 1.38 for small oil-fired steam boilers; and 1.37 for large gas-fired and oil-fired steam boilers in the no-new-standards case TSL. This markup is consistent with the one DOE assumed in the engineering analysis. Manufacturers indicated that it is optimistic to assume that, as their MPCs increase in response to an energy conservation standard, they would be able to maintain the same gross margin percentage markup. Therefore, DOE assumes that this scenario represents an upper bound for industry profitability under an energy conservation standard.

Table 12.4.33 Preservation of Gross Margin Markup in the No-New-Standards Case

Equipment	Markup
Small Gas-Fired Hot Water (300k–2,500k Btu/h)	1.41
Large Gas-Fired Hot Water (>2,500k Btu/h)	1.41
Small Oil-Fired Hot Water (300k–2,500k Btu/h)	1.40
Large Oil-Fired Hot Water (>2,500k Btu/h)	1.41
Small Gas-Fired Steam (300k–2,500k Btu/h)	1.41
Large Gas-Fired Steam (>2,500k Btu/h)	1.37
Small Oil-Fired Steam (300k–2,500k Btu/h)	1.38
Large Oil-Fired Steam (>2,500k Btu/h)	1.37

12.4.9.2 Preservation of Per-Unit Operating Profit Scenario

During interviews, multiple manufacturers expressed concern that the higher production costs could harm profitability. Because of market characteristics, several manufacturers suggested that the additional costs of higher minimum efficiency products could not be fully passed through to customers. Incorporating this feedback, DOE modeled the preservation of operating profit scenario.

In the preservation of operating profit scenario, manufacturer markups are set so that operating profit 1 year after the compliance date of the new energy conservation standards is the same as in the no-new-standards case (Table 12.4.34). Under this scenario, as the cost of production and the cost of sales go up, manufacturers are generally required to reduce their markups to a level that maintains no-new-standards case operating profit. The implicit assumption behind this markup scenario is that the industry can only maintain its operating profit in absolute dollars after the standard. Operating margin in percentage terms is reduced between the no-new-standards case and standards case.

Table 12.4.34 Preservation of Operating Profit Markup at the Proposed Standards Levels

Equipment	Markup
Small Gas-Fired Hot Water (300k–2,500k Btu/h)	1.39
Large Gas-Fired Hot Water (>2,500k Btu/h)	1.39
Small Oil-Fired Hot Water (300k–2,500k Btu/h)	1.38
Large Oil-Fired Hot Water (>2,500k Btu/h)	1.38
Small Gas-Fired Steam (300k–2,500k Btu/h)	1.39
Large Gas-Fired Steam (>2,500k Btu/h)	1.36
Small Oil-Fired Steam (300k–2,500k Btu/h)	1.37
Large Oil-Fired Steam (>2,500k Btu/h)	1.36

12.5 INDUSTRY FINANCIAL IMPACTS

Using the inputs and scenarios described in the previous sections, the GRIM estimated indicators of financial impacts on the CPB industry. The following sections detail additional inputs and assumptions for commercial packaged boilers. The main results of the MIA are also reported in this section. The MIA consists of two key financial metrics: INPV and annual cash flows.

The INPV measures the industry value and is used in the MIA to compare the economic impacts of different TSLs in the standards case. The INPV is different from DOE's 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, the same analysis period used in the NIA (chapter 10 of this TSD). This timeframe models both the short-term impacts on the industry from the base year of the analysis until the compliance date (2015–2018) and a long-term assessment over the analysis period used in the NIA (2019–2048).

In the MIA, DOE compares the INPV of the no-new-standards case (no amended energy conservation standards) to that of each TSL in the standards case. The difference between the no-new-standards case and a standards-case INPV is an estimate of the economic impacts that implementing that particular TSL would have on the industry. The markup scenarios are described in greater detail in section.

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 1 or 2 years could strain the industry's access to capital. Consequently, the 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.

Annual cash flows are discounted to the base year, 2015. After the standards announcement date (*i.e.*, the publication date of the final rule), industry cash flows begin to decline as companies use their financial resources to prepare for the amended 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 every year. The more stringent the amended energy conservation standard, the greater the impact on industry cash flows in the years leading up to the compliance date, as product conversion costs lower cash inflows from operations and capital conversion costs increase cash outflows for capital expenditures.

Free cash flow in the year the amended energy conservation standards take effect is driven by two competing factors. In addition to capital and product conversion costs, amended energy conservation standards could create stranded assets, *i.e.*, tooling and products that could have been used longer if the energy conservation standard had not made them obsolete. In this year, manufacturers write down the remaining book value of existing tooling and products whose value is affected by the amended energy conservation standard. This one-time write-down acts as a tax shield that alleviates decreases in cash flow from operations in the year of the write-down.

In this year, there is also an increase in working capital that reduces cash flow from operations. A large increase in working capital is needed due to more costly production components and materials, higher inventory carrying to sell more expensive products, and higher accounts receivable for more expensive products. Depending on these two competing factors, cash flow can be either positively or negatively affected in the year the standard takes effect.

12.5.1 Impacts on Commercial Packaged Boiler Industry Net Present Value

The markup scenarios modeled yield two sets of results; (1) preservation of gross Margin; and (2) per unit preservation of operating profit. DOE presents the highest and lowest INPV results from the combined scenarios to portray the range of potential impacts on the industry.

The most severe lower bound of impacts is the preservation of operation profit markup scenario shown in Table 12.5.1. The upper bound of the range of impacts is the preservation of gross margin scenario shown in Table 12.5.2.

Table 12.5.1 Preservation of Operating Profit Scenario: Impacts on INPV

	Units	No-New-Standards Case	Trial Standard Level				
			1	2	3	4	5
INPV	2014$ M	180.1	166.8	156.3	116.2	56.1	51.2
Change in INPV	2014$ M	-	(13.4)	(23.8)	(64.0)	(124.1)	(128.9)
	%		(7.4)	(13.2)	(35.5)	(68.9)	(71.6)

Table 12.5.2 Preservation of Gross Margin Percentage Scenario: Impacts on INPV

	Units	No-New-Standards Case	Trial Standard Level				
			1	2	3	4	5
INPV	2014$ M	180.1	173.7	167.0	157.7	145.9	146.7
Change in INPV	2014$ M	-	(6.4)	(13.1)	(22.4)	(34.3)	(33.4)
	%		(3.6)	(7.3)	(12.4)	(19.0)	(18.6)

12.5.2 Impacts on Commercial Packaged Boiler Industry 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 1 or 2 years could strain the industry's access to capital. Consequently, the 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 get an idea of the behavior of annual free cash flows, Figure 12.5.1 through Figure 12.5.2 present the annual free cash flows from 2015 through 2048 for the no-new-standards case and different TSLs in the standards case.

Annual cash flows are discounted to the base year, 2015. Between 2015 and the 2019 compliance date of the amended energy conservation standards, cash flows are driven by the level of conversion costs and the proportion of these investments spent every year. After the standard announcement date (*i.e.*, the publication date of the final rule), industry cash flows begin to decline as companies use their financial resources to prepare for the amended energy conservation standards. The more stringent the amended energy conservation standards, the greater the impact on industry cash flows in the years leading up to the compliance date, as product conversion costs lower cash inflows from operations and capital conversion costs increase cash outflows for capital expenditures.

Free cash flow in the year the amended energy conservation standards take effect is driven by two competing factors. In addition to capital and product conversion costs, amended energy conservation standards could create stranded assets (*i.e.,* tooling and equipment that would have enjoyed longer use if the energy conservation 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 energy conservation 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, higher inventories of more expensive products, and higher accounts receivable for more expensive products. Depending on these two competing factors, cash flow can either be positively or negatively affected in the year the standards takes effect.

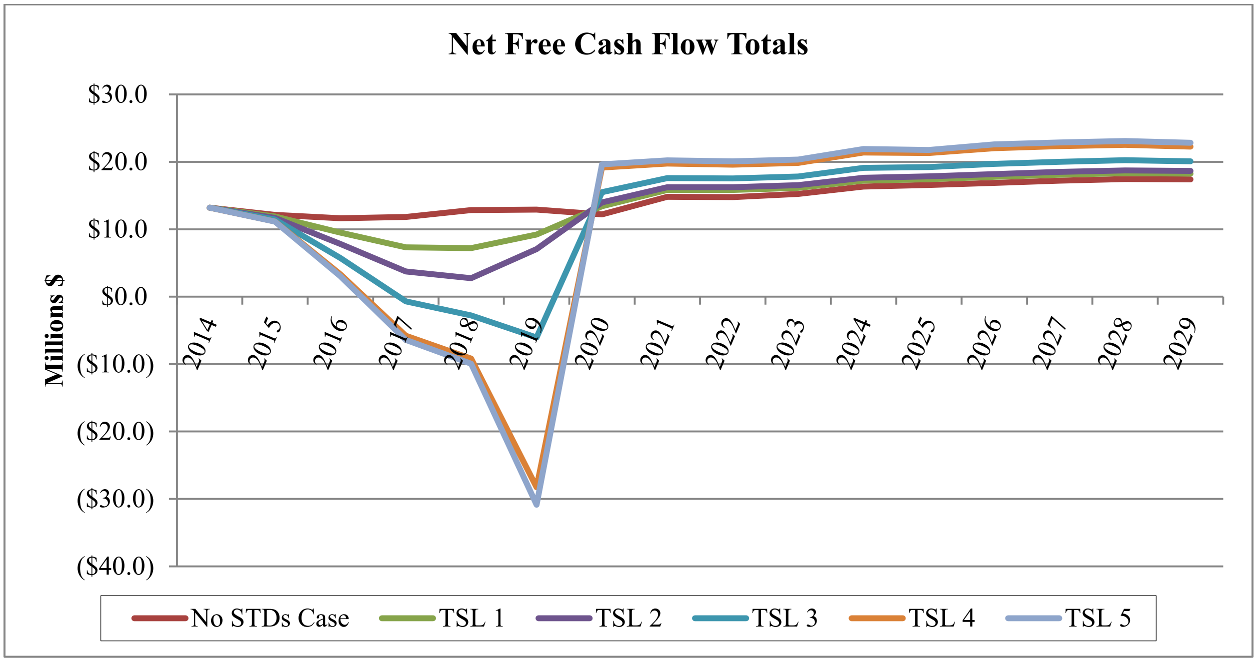

Figure 12.5.1 Annual Industry Free Cash Flows for Commercial Packaged Boilers – Preservation of Gross Margin Markup Scenario

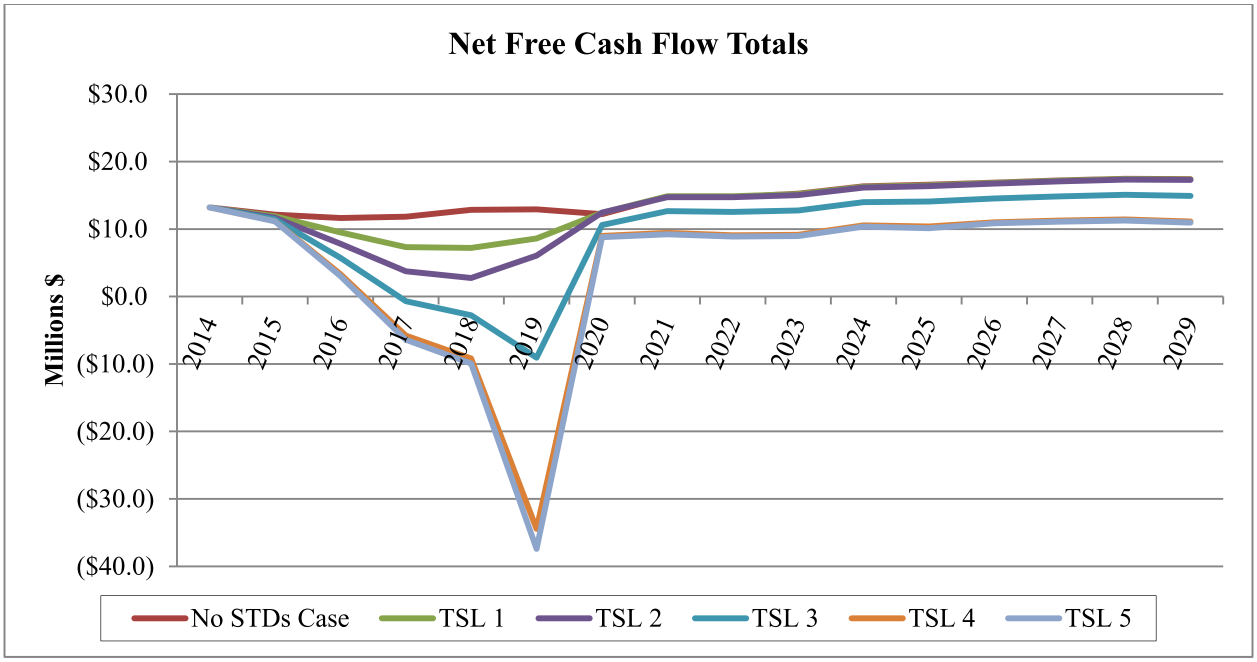

Figure 12.5.2 Annual Industry Free Cash Flows for Commercial Packaged Boilers – Per Unit Preservation of Operating Profit Markup Scenario

12.6 IMPACTS ON SMALL BUSINESS MANUFACTURERS

To better assess the potential impacts of this rulemaking on small entities, DOE conducted a more focused inquiry of the companies that could be small business manufacturers of products covered by this rulemaking. DOE conducted a market survey using available public information to identify potential small manufacturers. DOE's research involved DOE's Compliance Certification Management System (CCMS), industry trade association membership directories (including AHRI), individual company websites, and market research tools (*e.g.*, Hoovers reports) to create a list of companies that manufacture or sell the CPB products covered by this rulemaking. DOE also asked industry representatives if they were aware of any other small manufacturers during manufacturer interviews. DOE reviewed publicly available data and contacted companies on its list, as necessary, to determine whether they met the SBA's definition of a small business manufacturer of covered CPB products. DOE screened out companies that do not offer products covered by this rulemaking, do not meet the definition of a "small business," or are foreign-owned and operated.

DOE initially identified 45 potential manufacturers of commercial packaged boilers sold in the United States. DOE then determined that 15 are large manufacturers that are owned and operated. DOE was able to determine that 30 manufacturers meet the SBA's definition of a "small business." Of these 30 small businesses, DOE estimates that 23 domestically manufacturer commercial packaged boilers that are covered by this rulemaking. Additionally, based on literature reviews and the equipment database, DOE determined that approximately 80 percent of industry commercial packaged boilers are manufactured domestically, while 20 percent are manufactured overseas or outsourced by foreign companies.

DOE attempted to contact all the small domestic business manufacturers of commercial packaged boilers it had identified. Six small businesses consented to formal MIA interviews. DOE also attempted to obtain information about small business impacts while interviewing large manufacturers.

In the engineering analysis, DOE compiled an equipment database based on equipment listing information provided by the AHRI and ABMA trade associations. Though the database covers 41 companies, some of which are subsidiaries, DOE notes that it does not have product listings data for 11 of the identified 30 small manufacturers since they are not AHRI or ABMA trade association members. The following discussion reflects the available data provided by AHRI and ABMA and assumes the distribution of equipment efficiencies data to be representative of the industry.

DOE identified 18 small manufacturers and 13 large manufactures that produce gas-fired equipment covered by this rulemaking based on companies included in the equipment database. Roughly 54 percent of gas-fired equipment listings in DOE's equipment database already meet the proposed standard at TSL 2. This would suggest that TSL 2 already has a strong market presence. DOE's engineering analysis concludes that no proprietary technology is required to meet today's proposed standard level. Manufacturers would likely need to adopt one or a combination of different technology options: (1) switch from natural or atmospheric draft systems to mechanical draft boilers; (2) improve heat exchanger design using tabulators, fins and multi-pass designs; (3) use high efficiency burner technology such as pulse combustion; or (4) increase jacket insulation (*e.g.*, 3–4 inches of fiberglass wool).

Assuming the equipment database used in the engineering analysis is representative of the industry as a whole, small manufacturers have similar portions of product listings at TSL 2 as their larger competitors in the gas-fired sector. Industry conversion costs for gas-fired products at TSL 2 total $18.3 million. This results in an average conversion cost of approximately $0.42 million per manufacturer.

Table 12.6.1 estimates the percent of small manufacturers and their listings that currently comply with TSL 2. Table 12.6.2 estimates the percent of all manufacturers, both large and small, and their listings that currently comply with TSL 2.

Table 12.6.1 Small Gas-Fired Manufacturers Compliant at the Trial Standard Level

Product Class	Small Manufacturers: Manufacturers with Products Compliant at TSL 2	Small Manufacturers: Total Listings	Small Manufacturers: Listings Compliant at TSL 2	Small Manufacturers: Listings Compliant at TSL 2
Small Gas Hot Water	100%	433	348	80%
Large Gas Hot Water	67%	220	120	55%
Small Gas Steam	50%	106	26	25%
Large Gas Steam	71%	127	46	36%

Table 12.6.2 Industry Gas-Fired Manufacturers Compliant at the Trial Standard Level

Product Class	All Manufacturers: Manufacturers with Products Compliant at TSL 2	All Manufacturers: Total Listings	All Manufacturers: Listings Compliant at TSL 2	All Manufacturers: Listings Compliant at TSL 2
Small Gas Hot Water	97%	1,149	712	62%
Large Gas Hot Water	78%	373	188	50%
Small Gas Steam	67%	252	72	29%
Large Gas Steam	82%	186	80	43%

Using product listings as representative market data, DOE estimates average conversion costs of $0.63 million for large manufacturers and $0.31 million for small manufacturers of gas-fired equipment. Since this is a relatively low volume market where most products are built-to-order, DOE assumes that capital conversion costs do not vary significantly between large and small manufacturers.

In the market for oil-fired equipment, DOE identified seven small manufacturers and six large manufacturers producing equipment covered by this rulemaking based on the equipment database. Combined, they sell roughly 1,000 units per year, or 5 percent of the total annual market for CPB equipment. Due to the small size of the oil-fired market, DOE expects that the manufacturing processes and production costs to be similar for both small and large manufacturers. DOE notes that the market for oil-fired commercial packaged boilers is shrinking. Some manufacturers, both small and large, may choose not to invest in product redesign given the small market size and projected decline in shipments. For manufacturers that do stay in the oil-fired market, DOE's analysis indicates that there are no proprietary technologies required to meet TSL 2. Manufacturers would likely need to adopt one or a combination of different technology options: (1) integrate oxygen trimmers; (2) improve heat exchanger design; (3) use high efficiency burner technology, such as pulse combustion; or (4) increase jacket insulation.

Thus, DOE would expect similar conversion costs for small and large manufacturers on a per product basis.

Table 12.6.3 estimates the percent of small manufacturers and their listings that currently comply with TSL 2.

Table 12.6.4 estimates the percent of all manufacturers, both large and small, and their listings that currently comply with TSL 2.

Table 12.6.3 Small Oil-Fired Manufacturers Compliant at the Proposed Standard Level

Product Class	Small Manufacturers: Manufacturers with Products Compliant at TSL 2	Small Manufacturers: Total Listings	Small Manufacturers: Listings Compliant at TSL 2	Small Manufacturers: Listings Compliant at TSL 2
Small Oil Hot Water	33%	31	1	3%
Large Oil Hot Water	25%	24	3	13%
Small Oil Steam	25%	49	5	10%
Large Oil Steam	17%	45	6	13%

Table 12.6.4 Industry Oil-Fired Manufacturers Compliant at the Proposed Standard Level

Product Class	All Manufacturers: Manufacturers with Products Compliant at TSL 2	All Manufacturers: Total Listings	All Manufacturers: Listings Compliant at TSL 2	All Manufacturers: Listings Compliant at TSL 2
Small Oil Hot Water	36%	124	17	14%
Large Oil Hot Water	20%	83	5	6%
Small Oil Steam	44%	127	32	25%
Large Oil Steam	40%	109	36	33%

Using product listings as representative market data, DOE estimates average conversion costs of $0.90 million for large manufacturers and $0.28 million for small manufacturers of oil-fired equipment. Since this is a relatively low volume market where most products are built-to-order, DOE assumes that capital conversion costs do not vary significantly between large and small manufacturers.

DOE assumed the data for small manufacturer's products in the AHRI and ABMA databases are representative of all small manufacturers.

12.7 OTHER IMPACTS

12.7.1 Direct Impacts on Employment

To quantitatively assess the potential impacts of amended energy conservation standards on direct employment in the CPB industry, DOE used the GRIM to estimate the domestic labor expenditures and number of direct employees in the no-new-standards case and at each standards case (TSL) from 2015 through 2048. DOE used statistical data from the U.S. Census Bureau's 2013 Annual Survey of Manufacturers,[d] the results of the engineering analysis, and interviews with manufacturers to determine the inputs necessary to calculate industry-wide labor expenditures and domestic direct employment levels. Labor expenditures related to manufacturing of the product are a function of the labor intensity of the product, 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 U.S. Census Bureau's 2013 Annual Survey of Manufacturers). The production worker estimates in this section only cover workers up to the line-supervisor level who are directly involved in fabricating and assembling a product within an original equipment manufacturer (OEM) facility. Workers performing services that are closely associated with production operations, such as 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. The total direct employment impacts calculated in the GRIM are the sum of the changes in the number of production workers resulting from the amended energy conservation standards for commercial packaged boilers, as compared to the no-new-standards case.

DOE estimates that 80 percent of commercial packaged boilers sold in the United States are manufactured domestically. Table 12.7.1 shows the range of impacts of a potential amended energy conservation standard on U.S. production workers of CPB equipment. In the absence of amended energy conservation standards, DOE estimates that the industry would employ 464 domestic production workers in 2019, based on the following calculation:

$$Domestic\ Production\ Equipment = \frac{PLE \times 1{,}000{,}000}{PWAT} \div PWHW$$

Eq. 12.4

Where:

PLE = Production Labor Expenditures at Baseline in 2019 × 100% US Labor percentage ($17.5 M),
$PWAT$ = Production Worker Annual Time (1,977 hours/year), and

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[d] U.S. Census Bureau. *Annual Survey of Manufacturers: General Statistics: Statistics for Industry Groups and Industries*. 2011. www.census.gov/manufacturing/asm/index.html.

PWHW = Production Worker Hourly Wage ($19.07/hour)

Table 12.7.1. Potential Changes in the Total Number of Production Workers in the RCPB Industry in 2019

		Trial Standard Level				
	No-New-Standards Case	1	2	3	4	5
Total Number of Domestic Production Workers in 2019 (without changes in production locations)	464	371 to 495	292 to 516	232 to 522	130 to 608	32 to 629
Potential Changes in Domestic Production Workers in 2019*	-	(93) to 31	(172) to 52	(232) to 58	(334) to 144	(431) to 165

*DOE presents a range of potential employment impacts. Numbers in parentheses indicate negative values.

At the upper end of the range, all examined TSLs show positive impacts on domestic employment levels. Producing more-efficient commercial packaged boilers tends to require more labor, and DOE estimates that if CPB manufacturers chose to keep their current production in the United States, domestic employment could increase at each TSL. In interviews, some manufacturers who produce high-efficiency boiler products stated that a standard that went to condensing levels could cause them to hire more employees to increase their production capacity.

To establish a lower bound end of production worker employment, DOE assumes no manufacturer chooses to invest in redesign of products that do not meet the proposed standard. Production worker employment drops in proportion with the percentage of products that are retired. Since this is a lower bound, DOE does not account for additional production labor needed for higher efficiency products. Several manufacturers expressed that they could lose a significant number of employees at TSL 3, TSL 4 and TSL 5, due to the fact that these TSLs contain condensing efficiency levels for the gas-fired hot water boiler product classes and oil-fired hot water boiler product classes. These manufacturers have employees who work on production lines that produce cast iron sections and carbon steel or copper heat exchangers for lower to mid-efficiency products. If amended energy conservation standards were to require condensing efficiency levels, these employees would no longer be needed for that function, and manufacturers would have to decide whether to develop their own condensing heat exchanger production, source heat exchangers from Asia or Europe and assemble higher-efficiency products, or leave the market entirely.

Table 12.7.2 represents the percentage of products requiring redesign for each TSL to meet the proposed standard levels.

Table 12.7.2. Percentage of Products Requiring Redesign to Meet Proposed Standard Level

TSL	Products Requiring Redesign (%)
1	42.6
2	52.5
3	73.8
4	98.4

5	98.7

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 16 of the TSD.

12.7.2 Impacts on Manufacturing Capacity

Most CPB manufacturers stated that their current production is only running at 50-percent to 75-percent capacity and that any standard that does not propose efficiency levels where manufacturers would use condensing technology for hot water boilers would not have a large effect on capacity. The impacts of a potential condensing standard on manufacturer capacity are difficult to quantify. Some manufacturers who are already making condensing products with a sourced heat exchanger said they would likely be able to increase production using the equipment they already have by utilizing a second shift. Others said a condensing standard would idle a large portion of their business, causing stranded assets and decreased capacity. These manufacturers would have to determine how to best increase their condensing boiler production capacity. DOE believes that some larger domestic manufacturers may choose to add production capacity for a condensing heat exchanger production line.

Manufacturers stated that in a scenario where a potential standard would require efficiency levels at which manufacturers would use condensing technology, there is concern about the level of technical resources required to redesign and test all products. The engineering analysis shows that increasingly complex components and control strategies are required as standard levels increase. Manufacturers commented in interviews that the industry would need to add electrical engineering and control systems engineering talent beyond current staffing to meet the redesign requirements of higher TSLs. Additional training might be needed for manufacturing engineers, laboratory technicians, and service personnel if condensing products were broadly adopted. However, because TSL 2 (the proposed level) would not require condensing standards, DOE does not expect manufacturers to face long-term capacity constraints due to the standard levels proposed in this notice.

12.7.3 Cumulative Regulatory Burden

While any one regulation may not impose a significant burden on manufacturers, the combined effects of several recent or impending regulations may have serious consequences for some manufacturers, groups of manufacturers, or an entire industry. Assessing the impact of a single regulation may overlook this cumulative regulatory burden. Multiple regulations affecting the same manufacturer can strain profits and can 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.

For the cumulative regulatory burden analysis, DOE looks at other regulations that could affect CPB manufacturers that will take effect approximately 3 years before or after the 2019 compliance date of amended energy conservation standards for commercial packaged boilers. In interviews, manufacturers cited Federal regulations on equipment other than commercial packaged boilers that contribute to their cumulative regulatory burden. The compliance years and expected industry conversion costs of relevant amended energy conservation standards are indicated in Table 12.7.3.

Table 12.7.3 Compliance Dates and Expected Conversion Expenses of Federal Energy Conservation Standards Affecting Commercial Packaged Boiler Manufacturers

Regulation	Comm. Air Conditioners/ Heat Pumps (Air-Cooled)	Comm. Warm Air Furnaces	Res. Furnace Fans	Comm. Water Heaters	Res. Boilers	Res. Furnaces	Res. Central Air Conditioners/ Heat Pumps	Res. Water Heaters	Res. Pool Heaters
Approximate Compliance Date	2018	2018	2019	2019	2020	2021	2021	2021	2021
Industry Conversion Costs (*$M*)	226.4*	19.9*	40.6	TBD	4.3	TBD	TBD	TBD	TBD
Ace Heating Solutions LLC				x					
ACV International NV (Triangle Tube/Phase III Co.)				x	x			x	
AESYS Technologies, LLC									
AO Smith (Lochinvar)				x	x			x	x
Axeman-Anderson					x			x	
Bradford White (Laars Heating Systems)				x	x			x	
Burnham Holdings		x	x	x	x	x	x	x	
Camus Hydronics				x	x			x	
Dennison Holdings Ltd (NY Thermal)					x				
ECR International			x	x	x	x	x	x	
E-Z Rect Manufacturing (Allied Engineering Company)					x				
Fulton Heating Solutions									
Gasmaster Industries				x					
Hamilton Engineering				x	x				
Harbour Group Industries (Cleaver-Brooks)									
Harsco Industrial, Patterson-Kelley									
HTP, Inc				x	x				
Hurst Boiler & Welding Company									
IBC Technologies, Inc					x				
Lanair Holdings, LLC (Clean Burn, LLC)					x			x	
Mestek					x		x	x	
National Combustion Co, Inc				x					
Paloma Co, Ltd (Raypak, Inc)	x	x	x	x		x	x	x	x
Parker Boiler Company				x					

Regulation	Comm. Air Conditioners/ Heat Pumps (Air-Cooled)	Comm. Warm Air Furnaces	Res. Furnace Fans	Comm. Water Heaters	Res. Boilers	Res. Furnaces	Res. Central Air Conditioners/ Heat Pumps	Res. Water Heaters	Res. Pool Heaters
Peerless Boilers (PB Heat LLC)					x			x	
Rite Engineering & Manufacturing Corp (Rite Boiler)									
Robert Bosch (Bosch Thermotechnology Corp)				x	x				
SIME (SIME North America)					x			x	
Slant/Fin Corporation					x			x	
SPX					x			x	
Stichting Aandelen Remeha (Baxi S.P.A.)					x				
Superior Holdings, Inc									
Tennessee Valley Ventures LP (Precision Boiler)									
Unilux Advanced Manufacturing									
Vari Corp					x			x	
Watts Water Technologies, Inc (AERCO International, Inc)				x					
Williams & Davis Boilers									

*The final rule for this energy conversation standard has not been published. The compliance date and analysis of conversion costs have not been finalized at this time. (If a value is provided for total industry conversion expense, this value represents an estimate from the NOPR.)

12.8 CONCLUSION

The following section summarizes the impacts for the scenarios DOE determined are most likely to capture the range of impacts on manufacturers of commercial packaged boilers as a result of potential 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 the upper and lower bound INPV impacts and conversion costs projected to result from each of the trial standard levels analyzed.

Table 12.8.1 Results for Commercial Packaged Boilers

	Units	No-New-Standards	Trial Standard Level*				
		Case	1	2	3	4	5
INPV	2014$ M	180.1	166.8 to 173.7	156.3 to 167.0	116.2 to 157.7	56.1 to 145.9	51.2 to 146.7
Change in INPV	2014$ M	-	(13.4) to (6.4)	(23.8) to (13.1)	(64.0) to (22.4)	(124.1) to (34.3)	(128.9) to (33.4)
	%	-	(7.4) to (3.6)	(13.2) to (7.3)	(35.5) to (12.4)	(68.9) to (19.0)	(71.6) to (18.6)
Free Cash Flow (2018)	2014$ M	12.8	7.2	2.7	(2.8)	(9.2)	(9.9)
Change in Free Cash Flow (2018)	2014$ M	-	(5.6)	(10.1)	(15.6)	(22.0)	(22.8)
	%	-	(43.9)	(78.7)	(121.7)	(171.5)	(177.4)
Product Conversion Costs	2014$ M	-	10.7	18.2	19.3	20.8	21.4
Capital Conversion Costs	2014$ M	-	4.8	9.3	20.8	33.9	35.2

TSL 1 represents EL 3 (84 percent) for small gas-fired hot water boilers, EL 2 (84 percent) for large gas-fired hot water boilers, EL 4 (87 percent) for small oil-fired hot water boilers, EL 1 (86 percent) for large oil-fired hot water boilers, EL 3 (80 percent) for small gas-fired steam boilers, EL 4 (81 percent) for large gas-fired steam boilers, EL 1 (83 percent) for small oil-fired steam boilers, and EL 1 (83 percent) for large oil-fired steam boilers. At TSL 1, DOE estimates impacts on INPV for CPB manufacturers to range from -7.4 percent to -3.6 percent, or a change in INPV of -$13.4 million to -$6.4 million. At this potential standard level, industry free cash flow would be estimated to decrease by approximately 43.9 percent to $7.2 million, compared to the no-new-standards case value of $12.8 million in 2018, the year before the compliance date. Overall, DOE expects industry to incur product conversion costs of $10.7 million and capital conversion costs of $4.8 million to reach this standard level.

At TSL 1, DOE anticipates manufacturers to incur conversion costs totaling $15.5 million as roughly 42.6 percent of AHRI and ABMA equipment listings would require product redesigns and new tooling associated with their equipment offerings.

TSL 2 sets the efficiency level at EL 4 (85 percent) for small gas-fired hot water boilers, EL 3 (85 percent) for large gas-fired hot water boilers, EL 4 (87 percent) for small oil-fired hot water boilers, EL 2 (88 percent) for large oil-fired hot water, EL 4 (81 percent) for small gas-fired steam boilers, EL 5 (82 percent) for large gas-fired steam boilers, EL 2 (84 percent) for small oil-fired steam boilers, and EL 2 (85 percent) for large oil-fired steam boilers. At TSL 2, DOE estimates impacts on INPV for CPB manufacturers to range from -13.2 percent to -7.3 percent, or a change in INPV of -$23.8 million to -$13.1 million. At this potential standard level, industry free cash flow would be estimated to decrease by approximately 78.7 percent to $2.7 million, compared to the no-new-standards case value of $12.8 million in 2018, the year before the compliance date.

Overall, DOE estimates manufactures would incur product conversion costs of $18.2 million and capital conversion costs of $9.3 million at TSL 2. DOE anticipates high product conversion costs, as 52.5 percent of AHRI and ABMA equipment listings necessitate additional investments in tooling and heat exchangers to meet this potential standard level. Given the expectation for a shrinking market and high conversion costs, some manufacturers indicated during interviews that they would source condensing heat exchangers from lower-cost foreign manufacturers at this level.

TSL 3 represents EL 6 (95 percent) for small gas-fired hot water boilers, EL 5 (85 percent) for large gas-fired hot water boilers, EL 4 (87 percent) for small oil-fired hot water boilers, EL 2 (88 percent) for large oil-fired hot water boilers, EL 4 (81 percent) for small gas-fired steam boilers, EL 5 (82 percent) for large gas-fired steam boilers, EL 2 (84 percent) for small oil-fired steam boilers, and EL 2 (85 percent) for large oil-fired steam boilers. At TSL 3, DOE estimates impacts on INPV for CPB manufacturers to range from -35.5 percent to -12.4 percent, or a change in INPV of -$64.0 million to -$22.4 million. At this potential standard level, industry free cash flow would be estimated to decrease by approximately 121.7 percent in 2018, the year before compliance to -$2.8 million compared to the no-new-standards case value of $12.8 million. DOE estimates manufactures would incur product conversion costs of $19.3 million and capital conversion costs of 20.8 million to reach this standard level.

At TSL 3, industry wide shipments drop by less than 1 percent in 2019. However, much of the drop in free cash flow at TSL 3 is due to conversion cost expenses manufacturers must make before the compliance year to reach condensing levels for small gas-fired hot water boilers. Additionally, approximately 73.8 percent of equipment listings in the AHRI and ABMA equipment database require redesign and new tooling to meet this TSL. A key indicator of impact on the industry is industry free cash flow. The negative free cash flow indicates that players in the industry would need to access cash reserves or borrow money from capital markets to cover conversion costs.

TSL 4 represents EL 7 (99 percent) for small gas-fired hot water boilers, EL 5 (97 percent) for large gas-fired hot water boilers, EL 5 (88 percent) for small oil-fired hot water boilers, EL 3 (89 percent) for large oil-fired hot water boilers, EL 5 (83 percent) for small gas-fired steam boilers, EL 6 (84 percent) for large gas-fired steam boilers, EL 3 (86 percent) for small oil-fired steam boilers, and EL 3 (87 percent) for large oil-fired steam boilers. At TSL 4, DOE estimates impacts on INPV for CPB manufacturers to range from -68.9 percent to -19.0 percent, or a change in INPV of -$124.1 million to -$34.3 million. At this potential standard level, industry free cash flow would be estimated to decrease by approximately 171.5 percent in the year before compliance (2018) to -$9.2 million relative to the no-new-standards case value of $12.8 million. DOE estimates that manufacturers would incur product conversion costs of $20.8 million and capital conversion costs of $33.9 million to reach this standard level.

At TSL 4, the industry is likely to face a small contraction as a result of adopting condensing levels. DOE anticipates conversion costs totaling $54.7 million to reach this standard level for the industry as roughly 98.4 percent of equipment listings in the AHRI and ABMA database would need to be redesigned in order to meet the higher proposed efficiency levels. A key indicator of impact on the industry is industry free cash flow. The negative free cash flow indicates that players in the industry would need to access cash reserves or borrow money from capital markets to cover conversion costs. Given the large upfront conversion costs, strain on short-term industry cash flow, and large increases in manufacturer production costs, TSL 4 could have significant impacts on the CPB industry.

TSL 5 represents EL 7 (99 percent) for small gas-fired hot water boilers, EL 5 (97 percent) for large gas-fired hot water boilers, EL 6 (97 percent) for small oil-fired hot water boilers, EL 4 (97 percent) for large oil-fired hot water boilers, EL 5 (83 percent) for small gas-fired steam boilers, EL 6 (84 percent) for large gas-fired steam boilers, EL 3 (86 percent) for small oil-fired steam boilers, and EL 3 (87 percent) for large oil-fired steam boilers. TSL 5 represents max-tech for all product classes. At TSL 5, DOE estimates impacts on INPV for CPB manufacturers to range from -71.6 percent to -18.6 percent, or a change in INPV of -$128.9 million to -$33.4 million. At this potential standard level, industry free cash flow would be estimated to decrease by approximately 177.4 percent in the year before compliance (2018) to -$9.9 million relative to the no-new-standards case value of $12.8 million. DOE estimates manufacturers would incur product conversion costs of $21.4 million and capital conversion costs of $35.2 million to reach this standard level.

At max-tech, the industry is likely to face a small contraction as a result of adopting condensing levels. DOE anticipates conversion costs totaling $56.6 million to reach this standard level for the industry as roughly 98.7 percent of equipment listing in the AHRI and ABMA database would need to be redesigned in order to meet the higher proposed efficiency levels. Given the large upfront conversion costs, strain on short-term industry cash flow, and the large increases in manufacturer production costs, TSL 5 could have significant impacts on the industry. It is possible that some manufacturers could choose to not make the necessary conversion investments and seek to divest their CPB business or withdraw from the industry. For manufacturers that do remain, they may have fewer opportunities to create differentiation between their products and competitors' products.

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APPENDIX 12A. MANUFACTURER IMPACT ANALYSIS INTERVIEW GUIDE

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CHAPTER 12. MANUFACTURER IMPACT ANALYSIS INTERVIEW GUIDE

12A.1 MANUFACTURER IMPACT ANALYSIS INTERVIEW GUIDE FOR COMMERCIAL PACKAGED BOILERS

Introduction

As part of the rulemaking process for amended energy conservation standards for Commercial Packaged Boilers, the Department of Energy (DOE) conducts a manufacturer impact analysis (MIA). In this analysis, DOE uses publicly available information and information provided by manufacturers during interviews to assess possible impacts on manufacturers due to amended energy conservation standards.

This questionnaire is a part of the MIA process and is intended to inform the Department's understanding of how changes in the energy conservation standard will affect commercial packaged boiler manufacturers. All information provided in response to this questionnaire will be treated as confidential. The questions below range from requests about specific financial figures for use in industry modeling to questions intended to solicit more qualitative comments. Topics covered will include:

1) Key Issues
2) Models Offered
3) Shipments Data
4) Pricing Data
5) Commercial Packaged Boiler Components
6) Company Overview and Organizational Characteristics
7) Markups and Profitability
8) Financial Parameters
9) Product Mix
10) Distribution Channels
11) Conversion Costs
12) Cumulative Regulatory Burden
13) Direct Employment
14) Capacity / Outsourcing / Foreign Competition
15) Consolidation
16) Impacts on Small Businesses
17) Test Procedure Issues
18) Other Issues

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 packaged boiler rulemaking?

1.2 For the issues identified, how significant are they for different equipment classes and/or efficiency levels?

1.3 How would amended energy conservation standards affect your ability to compete in the marketplace?

2 MODELS OFFERED

In the preliminary analysis, DOE analyzed 16 commercial packaged boiler equipment classes that were divided based on draft type (mechanical or natural), fuel type (gas or oil), input rating (300,000 Btu/h to less than or equal to 2,500,000 (“small”), or greater than 2,500,000 Btu/h (“large”)), and heating medium (hot water or steam).

DOE is interested in understanding the number of models that are offered at different input capacities under each equipment class. Please provide the number of models by equipment class and capacity range in Table 2.1 below:

Table 2.1 Equipment offered under each equipment class for different input capacity bins.

Heating Medium	Draft Type	Fuel	≤2,500 kBtu/h	>2,500 and ≤6,000kBtu/h	>6,000 and ≤10,000kBtu/h	>10,000 kBtu/h
Hot Water	Mechanical Draft	Gas				
		Oil				
	Natural Draft	Gas				
		Oil				
Steam	Mechanical Draft	Gas				
		Oil				
	Natural Draft	Gas				
		Oil				

2.1 Does your firm offer products that are custom-built or built to order? What are the input capacities and thermal or combustion efficiencies of such equipment? Do these characteristics differ significantly from models that are not custom-built or built to order?

3 SHIPMENTS DATA

DOE is interested in receiving unit shipments data on commercial packaged boilers for different input capacity ranges and each equipment class. Please provide the shipments by equipment class and capacity range in Table 3.1 below:

Table 3.1 Annual shipment data of commercial packaged boilers under each equipment class for different input capacity bins.

Heating Medium	Draft Type	Fuel	≤2,500 kBtu/h	>2,500 and ≤6,000kBtu/h	>6,000 and ≤10,000kBtu/h	>10,000 kBtu/h
Hot Water	Mechanical Draft	Gas				
		Oil				
	Natural Draft	Gas				
		Oil				
Steam	Mechanical Draft	Gas				
		Oil				
	Natural Draft	Gas				
		Oil				

3.1 How is the overall demand for boilers changing? Is it increasing, decreasing or more or less constant?

3.2 Are there any identifiable trends in the demand for specific types of boilers (e.g., natural draft boilers, very large boilers with input capacities >10,000 kBtu/h, etc.)? For those types of boilers where trends have been observed, what are the shipments trends?

3.3 Do you see a shift to having multiple smaller input capacity boilers instead of a single large input capacity boiler?

3.4 For each size range identified in Table 3.1 (i.e., ≤2,500 kBtu, >2,500 and ≤6,000kBtu/h, >6,000 and ≤10,000kBtu/h, and >10,000 kBtu/h), what is the input capacity that corresponds to the maximum number of annual shipments?

3.5 What percentage of the models offered, consists of condensing commercial boilers? What percentage of your total sales is condensing commercial boilers?

3.6 What percentage of the models offered, is natural draft commercial boilers? What percentage of your total sales are natural draft commercial boilers?

3.7 What percentage of your total sales are commercial boilers that utilize pre-mix combustion?

3.8 Can you estimate the fraction of commercial packaged boilers that are installed in the single family residential sector? What is the typical input capacity of commercial boilers that are shipped to single family residential sector?

3.9 Can you estimate the fraction of commercial packaged boilers that are installed in the multi-family residential sector? What is the typical input capacity of commercial boilers that are shipped to multi-family residential sector?

3.10 What is the percentage of large boilers in your product line that are composed of multiple smaller boilers and are pre-assembled at the factory prior to shipping?

4 PRICING DATA

DOE is interested in obtaining price information for commercial packaged boilers that would help DOE in developing its price-efficiency relationship for this rulemaking. DOE is particularly interesting in the price at which the manufacturer sells the boiler to first customer in the distribution chain.

4.1 Does your company publish price lists or price books for distributors? If so, are you willing to provide price lists or price books for the commercial boiler products?

If you do not have a price book or standard list pricing, or are unable to provide that information, please fill in approximate minimum and maximum boiler prices by model series in the Table 4.1 below.

Commercial packaged boilers typically include several options for features available to the customer when purchasing a commercial boiler, which often do not impact thermal/combustion efficiency. For the purpose of filling the prices in the table below, please choose the feature that is the least expensive among the possible options. For example, if there are several types of control options that the customer can choose from, please include the price of the least expensive option.

Further Table 4.1 has columns for minimum price (Min Price [$x1000]) and the maximum price (Max Price [$x1000]). These prices refer to the minimum and maximum price of the boiler within the entire series and not for one particular boiler. The minimum price of the boiler generally corresponds to the boiler that has the least input capacity; while the maximum price of the boiler corresponds to the boiler that has the maximum input capacity within a boiler model series. Please note that both the boilers that correspond to minimum and maximum price must have the same feature set, or if that is not possible, the feature set should be maintained as similar as possible.

Table 4.1 Estimate of commercial boiler prices for each series of boilers that the manufacturer produces

Series Name	Gas or Oil?	Hot Water, Steam or Both?	Draft Type	Input Capacity Range [kBtu/h]	Efficiency Range [%]	TE or CE	Min Price [$x1000]	Max Price [$x1000]

4.2 What is the typical discount from the list price (if applicable) that you provide to your first customer (whether distributers, contractors or wholesalers)? Is there any other discount that is applied while selling the boiler to the first customer in the distribution chain?

4.3 DOE is interested in understanding how the boiler price changes with input capacity. Does the price generally vary linearly or exponentially with input? Or is there another trend (e.g., a step-change at certain inputs)?

4.4 In the preliminary analysis comments, commenters noted that there exists a different price structure for large commercial packaged boilers. Is this difference in price true for all large sized boilers (>2,500kBtu/h)? If not, at what input capacity does the price structure change and why?

4.5 Table 4.2 seeks to gather information regarding how the price of commercial boiler changes with input rating. Using a commercial boiler with an input rating of 800kBtu/h as a reference point, please provide the percentage change in price for larger sized boilers. Please consider the feature set, and to the extent possible, keep the features and characteristics constant across boiler input ratings when conducting this exercise. If you do not have a specific boiler model within each size category or equipment class, please feel free to estimate the percentage change for a typical boiler within a size category.

Table 4.2 Variation in price expressed in % as compared to small sized boiler at 800kBtu/h for different equipment classes

Equipment Class	**Small Sized Boiler** [800kBtu/h]	**Large Sized Boiler** [3000kBtu/h]	**Very Large Boiler -1** [10,000kBtu/h]	**Very Large Boiler -2** [25,000kBtu/h]
Gas Mechanical Draft Hot Water	Reference Point			
Oil Mechanical Draft Hot Water	Reference Point			
Gas Mechanical Draft Steam	Reference Point			
Oil Mechanical Draft Steam	Reference Point			
Gas Natural Draft Hot Water	Reference Point			
Oil Natural Draft Hot Water	Reference Point			

Gas Natural Draft Steam	Reference Point			
Oil Natural Draft Steam	Reference Point			

4.6 For custom-engineered boilers, what percentage of your sale price is typically attributed to one-time engineering cost? Would the cost of custom engineering scale with efficiency or capacity?

4.7 For very large boilers, are non-recurring (i.e., custom) engineering costs subject to mark-up in the downstream distribution chain?

5 COMMERCIAL PACKAGED BOILER COMPONENTS

5.1 Below is the list of components that were identified in the preliminary analysis as being unique to natural draft systems. Are there any other components that are should be included in this list?

Unique components of a Natural Draft CPB
Draft hood
Vent dampers
Flue collectors & Sensors

5.2 Below is a list of components that were identified in the preliminary analysis as being unique to mechanical draft systems. Are there any other components that should be included in this list?

Unique components of a Mechanical Draft CPB
Inducer fan/ Blower/ Forced draft fan
Vent connector kit

5.3 How does the burner of a natural draft system compare to that of a mechanical draft system?

5.4 Are there any other differences between natural draft and mechanical draft systems that should be accounted for?

5.5 If you have condensing boiler products in your catalog, what percentage of those condensing products (product lines) are designed to allow field-replaceable heat exchangers? How often is polypropylene-venting installed on condensing commercial boilers?

5.6 What is the relative difference between service call rates, and or warranty return rates between condensing products versus a similar non-condensing model? What would an average service call cost for condensing products compared to similar non-condensing models? Note: we are asking for the differences between the two product types, not the actual values for either type.

5.7 How would the expected maintenance activities differ between a 3,000kBtu/h boiler with that of a 6,000kBtu/h boiler and a 12,000kBtu/h boiler? What would be the approximate percentage increase in maintenance cost with reference to a 3,000kBtu/h boiler?

6 COMPANY OVERVIEW AND ORGANIZATIONAL CHARACTERISTICS

6.1 Do you have a parent company and/or subsidiary? If so, please provide their names.

6.2 What is your company's approximate market share in the commercial packaged boiler market in the U.S.? Does this vary significantly for any particular equipment class that you manufacture?

6.3 What are your product niche lines and relative strengths in the commercial packaged boiler market?

6.4 What percentage of your overall revenue is from commercial packaged boiler sales?

6.5 Who are your competitors in the commercial packaged boiler market and what are their approximate market shares?

6.6 What other products do you manufacture in addition to commercial packaged boilers? Do you produce them in the same facilities?

6.7 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 6.1 below.

Table 6.1 Manufacturing Locations

Location	Equipment Class	Production Employees	Non-Production Employees	Units/Yr. Produced

6.8 Are higher efficiency products built at different plants than lower efficiency products of the same equipment class?

7 MARKUPS AND PROFITABILITY

One of the primary objectives of the Manufacturer Impact Analysis (MIA) is to assess the impact of energy conservation standards on industry profitability. In this section, DOE would like to understand the markup structure of the industry and how setting an energy conservation standard would impact your company's markup structure and profitability.

The manufacturer markup is a multiplier applied to manufacturer production cost to cover per unit research and development, selling, general, and administrative expenses, and profit. It is NOT a profit margin. The manufacturer production cost multiplied by the manufacturer markup plus the shipping costs covers all costs involved in manufacturing and profit for the product.

7.1 Based on publicly-available data for commercial packaged boiler manufacturers, DOE estimated an average markup of 1.41 for all equipment classes. DOE modified its estimates subsequent to preliminary interviews with manufacturers. Please comment on the accuracy of DOE's modified estimates in the Table 7.1 below.

Table 7.1 Commercial Packaged Boiler Manufacturer Markup

Equipment Class	DOE Estimate Markup	Manufacturer Markup
Small Gas-Fired Hot Water – Mechanical Draft	1.41	
Small Gas-Fired Hot Water – Natural Draft	1.41	
Small Gas-Fired Steam – Mechanical Draft	1.41	
Small Gas-Fired Steam – Natural Draft	1.41	
Small Oil-Fired Hot Water – Mechanical Draft	1.40	
Small Oil-Fired Hot Water – Natural Draft	1.40	
Small Oil-Fired Steam – Mechanical Draft	1.38	
Small Oil-Fired Steam – Natural Draft	1.38	
Large Gas-Fired Hot Water – Mechanical Draft	1.41	
Large Gas-Fired Hot Water – Natural Draft	1.41	
Large Gas-Fired Steam – Mechanical Draft	1.37	
Large Gas-Fired Steam – Natural Draft	1.37	
Large Oil-Fired Hot Water – Mechanical Draft	1.41	
Large Oil-Fired Hot Water – Natural Draft	1.41	
Large Oil-Fired Steam – Mechanical Draft	1.37	
Large Oil-Fired Steam – Natural Draft	1.37	

7.2 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?

7.3 What factors besides efficiency affect markups for products that are in the same equipment class?

7.4 Would you expect energy conservations standards to affect your profitability? If so, please explain why.

8 FINANCIAL PARAMETERS

Navigant Consulting, Inc. (NCI) 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. DOE has modified its estimates of these financial parameters, taking into account feedback from manufacturers during preliminary interviews.

Table 8.1 Financial Parameters for Commercial Packaged Boiler Manufacturers

GRIM Input	Definition	Industry Estimated Value	Your Actual
Income Tax Rate	Corporate effective income tax paid (percentage of earnings before taxes, EBT)	29.7%	
Discount Rate	Weighted average cost of capital (inflation-adjusted weighted average of corporate cost of debt and return on equity)	11.5%	
Working Capital	Current assets less current liabilities (percentage of revenues)	9.6%	
SG&A	Selling, general, and administrative expenses (percentage of revenues)	18.2%	
R&D	Research and development expenses (percentage of revenues)	3.1%	
Depreciation	Amortization of fixed assets (percentage of revenues)	2.3%	
Capital Expenditures	Outlay of cash to acquire or improve capital assets (percentage of revenues, not including acquisition or sale of business units)	2.0%	
Cost of Goods Sold	Includes material, labor, overhead, and depreciation (percentage of revenues)	74.2%	

8.1 Are the figures in Table 8.1 representative of the commercial packaged boilers industry as a whole?

8.2 Do any of the financial parameters in Table 8.1 change for a particular subgroup of manufacturers? Please describe any differences.

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 Could 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 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 efficiency level set by an amended energy conservation standard. DOE assumes the distribution of efficiencies above the efficiency level set by the energy conservation standards will not change. In other words, those customers already purchasing more-efficient products will continue to do so irrespective of amended energy conservation standards. How do you think amended energy conservation standards will affect the sale of more efficient products?

10 DISTRIBUTION CHANNELS

10.1 DOE has preliminarily identified the distribution channels below for both large and small commercial boilers. Are these channels representative of your equipment distribution? Are there market segments that are not being captured below?

Small Boilers

- Replacement Channel:
- Manufacturer → Manufacturer's Rep (optional) → Wholesaler → Mechanical Contractor → End User
- New Construction Channel:
- Manufacturer → Manufacturer's Rep (optional) → Wholesaler → Mechanical Contractor → General Contractor → End User

Large boilers

- Replacement Channel:
- Manufacturer → Manufacturer's Rep → Mechanical Contractor → End User
- New Construction Channel:
- Manufacturer → Manufacturer's Rep → Mechanical Contractor → General Contractor → End User

10.2 What is the share of equipment (by efficiency and/or equipment class) going through each distribution channel?

10.3 What percentage of large boiler (input capacity >2,500kBtu/h) sales are conducted through a manufacturer's sales representative? What percentage of overall sales volume does this correspond to?

11 CONVERSION COSTS

An increase in energy conservation standards may cause the industry to incur capital and product conversion costs to meet the energy conservation standard. The MIA considers three types of conversion expenditures:

- Capital conversion costs - One-time investments in plant, property, and equipment (PPE) necessitated by an energy conservation standard. These may be incremental changes to existing PPE or the replacement of existing PPE. Included are expenditures on buildings, equipment, and tooling.
- Product conversion costs – One-time investments in research, product development, testing, marketing, and other costs for redesigning products necessitated by an energy conservation standard.
- Stranded assets – Assets replaced before the end of their useful lives as a direct result of the change in energy conservation standard.

With a detailed understanding of the conversion costs necessitated by different standard levels, DOE can better model the impact of amended standards on the commercial packaged boiler 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 In the tables below please describe the capital and product conversion costs you expect to incur as a result of amended standards, as well any stranded assets that may result from amended standards. Please provide dollar amounts as well as descriptions of the kind of changes that would need to be implemented in production lines and production facilities. Because of the large number of equipment classes, DOE has provided some general tables for feedback on conversion costs below that cover more than one equipment class. For a full list of equipment classes and efficiency levels that DOE considered in the preliminary analysis, please see Chapter 5 of the preliminary TSD.[1]

Table 11.1 Conversion Costs for Small Hot Water Commercial Packaged Boilers

Draft Type Covered	Efficiency Level Approximation (Thermal Efficiency)	Capital Conversion Costs	Product Conversion Costs	Stranded Assets	Overview of Changes
Mechanical and Natural draft	82% for Gas Fired 84% for Oil Fired				
Mechanical and Natural draft	85% for Gas Fired 87% for Oil Fired				
Mechanical	90% for Oil and Gas Fired				

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[1] The preliminary TSD is available at http://www.regulations.gov/#!documentDetail;D=EERE-2013-BT-STD-0030-0027.

draft					
Mechanical draft	95% for Oil and Gas Fired				
Mechanical draft	98% for Oil and Gas fired (max tech)				

Table 11.2 Conversion Costs for Large Hot Water Commercial Packaged Boilers

Draft Type Covered	**Efficiency Level Approximation (Combustion Efficiency)**	**Capital Conversion Costs**	**Product Conversion Costs**	**Stranded Assets**	**Overview of Changes**
Mechanical and Natural draft	84% for Gas Fired 86% for Oil Fired				
Mechanical and Natural draft	86% for Gas Fired 88% for Oil Fired				
Mechanical draft	90% for Oil and Gas Fired				
Mechanical draft	95% for Oil and Gas Fired				
Mechanical draft	97% for Oil and Gas Fired (max-tech)				

Table 11.3 Conversion Costs for Small Steam Commercial Packaged Boilers

Draft Type Covered	**Efficiency Level Approximation (Thermal Efficiency)**	**Capital Conversion Costs**	**Product Conversion Costs**	**Stranded Assets**	**Overview of Changes**
Natural Draft	79% for Gas Fired 83% for Oil Fired (max-tech)				
Mechanical Draft	81% for Gas Fired 83% for Oil Fired				
Natural Draft	80% for Gas Fired (max-tech)				
Mechanical Draft	83% for Gas Fired (max-tech) 86% for Oil Fired (max-tech)				

Table 11.4 Conversion Costs for Large Steam Commercial Packaged Boilers

Draft Type Covered	**Efficiency Level Approximation (Thermal Efficiency)**	**Capital Conversion Costs**	**Product Conversion Costs**	**Stranded Assets**	**Overview of Changes**
Natural Draft	79% for Gas Fired 83% for Oil Fired				
Mechanical Draft	81% for Gas Fired 83% for Oil Fired				
Natural Draft	81% for Gas Fired (max-tech)				

	85% for Oil Fired (max-tech)				
Mechanical Draft	83% for Gas Fired (max-tech) 86% for Oil Fired (max-tech)				

11.3 Do you produce equipment from different equipment classes on the same production lines? For example, do you produce hot water and steam boilers on the same production lines? Natural draft and mechanical draft boilers? Oil and gas-fired boilers?

11.4 Are there any circumstances under which you would consider developing your own condensing heat exchanger production capacity?

11.5 For efficiency levels that would require new production equipment, please describe how much downtime would be required. What impact would downtime have on your business?

11.6 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 recent or impending standards that commercial packaged boiler manufacturers face from other US federal agencies, State regulators, foreign government agencies, or other standard setting bodies? If so, please identify the regulation and the corresponding possible effective dates for those regulations.

12.2 Are there any additional regulatory burdens that DOE should take into consideration? If so, please identify the regulation, the corresponding effective dates, and your expected compliance date.

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 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 packaged boiler 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.

13.2 Would the workforce skills necessary under amended energy conservation standards require extensive retraining or replacement of employees at your manufacturing facilities?

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 packaged boiler 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 packaged boiler equipment is imported?

14.7 What are alternatives to commercial boiler 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 and related trends over the last 10 years.

15.2 In the absence of amended energy conservation standards, do you expect any industry consolidation? Please describe your explanations.

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

16.1 The Small Business Association (SBA) denotes a small business in the commercial boiler industry as having less than 500 employees. By this definition, is your company considered a small business?

16.2 Below is an initial list of small manufacturers of commercial boilers. Please provide feedback on the accuracy of this list. Information on additional small manufacturers would be appreciated. Are there specific manufacturers on this list that may be more severely impacted by an energy conservation standard than others?

- Ace Heating Solutions LLC
- AESYS Technologies, LLC
- Axeman-Anderson
- Boyertown Furnace Company
- Clean Burn, LLC
- Columbia Boiler Company of Pottstown
- ECR International
- EFM Heating
- Energy Kinetics
- Fulton Heating Solutions
- Hamilton Engineering
- HTP, Inc.
- Hurst Boiler & Welding Company
- Parker Boiler Company
- PB Heat LLC
- Pensotti, LLC
- Precision Boiler
- Rite Boiler
- Slant/Fin Corporation
- Superior Boiler Works
- Thermo-Dynamics Boiler Company
- Triangle Tube/Phase III Co.
- Unilux Advanced Manufacturing
- Williams & Davis Boilers

16.3 Are there any reasons a small business might be at a disadvantage relative to a larger business under amended energy conservation standards? Please consider such factors as technical expertise, access to capital, bulk purchasing power for materials/components, engineering resources, and any other relevant issues.

16.4 Would small business manufacturers have different incremental impacts from energy conservation standards than the rest of the industry?

17 TEST PROCEDURE

17.1 What is the typical or anticipated cost of testing to demonstrate DOE compliance with the current test procedure? What testing, in addition to testing to show DOE compliance for regulated equipment, do all or most equipment typically undergo? How much do these additional tests cost? What is the primary cost associated with testing, i.e., labor, equipment, time? Are the tests conducted in-house or at a third-party lab?

17.2 Based on your experience with efficiency testing/rating, what have you found to be the margin for error with the current DOE test procedure for commercial packaged boilers?

17.3 Besides the DOE test procedure, are you currently using any other standards or test procedures (e.g. ASME PTC 4 or 4.1) to evaluate the thermal and/or combustion efficiency of your boilers? If so, which standard or standards are you using and why?

17.4 If you currently offer large steam boilers that are capable of operating at steam pressures both below and above 15 psi, are there any design characteristics that preclude these boilers from being tested below 15 psi? What are they? Are these concerns for the long-term life of the boiler, or do these characteristics prevent even one-time testing below 15 psi? Do you have concerns about the effect of testing below 15 psi on the thermal and/or combustion efficiency rating?

17.5 If you currently offer hot water boilers, what is the maximum temperature rise at which these boilers are designed operate? What are typical temperature rises for your water boilers when installed in the field? If the temperature rise requirement of the DOE test procedure (BTS-2000) were lowered from its current value of 100 degrees Fahrenheit, how do you anticipate this would affect the thermal efficiency ratings of your currently rated equipment?

17.6 Do you use a recirculating loop when performing BTS-2000 tests? If so, what is the actual temperature rise across the boiler alone during testing?

17.7 What is the largest boiler input capacity (Btu/h) that your facility is capable of testing for thermal efficiency? Is this maximum rating different between testing hot water and steam units? What are the constraints in your laboratory facilities that prevent testing boilers larger than this input capacity? If you were to upgrade your facility to accommodate larger boilers, what would the upgrades entail and what is your estimate for the cost of this upgrade? Which independent test labs do you currently use for evaluating thermal efficiency? What is the largest input capacity (Btu/h) the independent lab is capable of testing for thermal efficiency? Is this maximum rating different between testing hot water and steam units?

17.8 Are tests of your boilers conducted in a psychrometric chamber or a tightly controlled ambient environment (whether at your facility or in a third-party laboratory facility)? How do you anticipate your testing costs (one-time and/or recurring) would change should this be necessary?

17.9 Do you currently use ubiquitous digital data acquisition during testing? If no, how do you anticipate your testing costs (one-time and/or recurring) would change should this be necessary?

18 OTHER ISSUES

18.1 Do you have an estimate of the commercial packaged boiler lifetime? Typically how long do your customers use your boilers before replacing them? Is lifetime related to efficiency of the boiler? Please provide details by equipment class and efficiency range. Are there differences in the lifetimes between boilers with different HX materials (cast-iron, steel and copper/aluminum) and different designs (high- and low-mass)?

18.2 How long are the warranties offered for your commercial packaged boilers and what do these warranties cover?

18.3 In the absence of stricter DOE energy conservation standards, what are the factors that drive you to improve the energy efficiency of your equipment?

18.4 Are shipping costs relatively similar across all efficiency levels or do higher efficiency units cost more to ship? Please comment on this as it relates to your equipment lines.

18.5 Generally, how much does it cost to ship a small packaged boiler to a wholesaler or a large boiler to a job site? How are trailers generally loaded? That is, are they always sent out full, or sometimes partially empty?

18.6 Generally, who pays for the cost of shipping your equipment to the next member of the distribution chain? Is it included in the purchase price, does your company provide shipping, does the purchaser arrange shipping, or is another arrangement used?

APPENDIX 12B. GOVERNMENT REGULATORY IMPACT MODEL OVERVIEW

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APPENDIX 12B. GOVERNMENT REGULATORY IMPACT MODEL OVERVIEW

12B.1 INTRODUCTION AND PURPOSE

The purpose of the Government Regulatory Impact Model (GRIM) is to help quantify the impacts of energy conservation standards and other regulations on manufacturers. The basic mode of analysis is to estimate the change in the value of the industry or manufacturers(s) following a regulation or a series of regulations. The model structure also allows an analysis of multiple equipment types with regulations taking effect over a period of time, and of multiple regulations on the same equipment.

Industry net present value is defined, for the purpose of this analysis, as the discounted sum of industry free cash flows plus a discounted terminal value. The model calculates the actual cash flows by year and then determines the present value of those cash flows both without an energy conservation standard (*i.e.*, the 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) ***Total Shipments:*** Total annual shipments for the industry were obtained from the National Impact Analysis Spreadsheet.

3) ***Material:*** The portion of cost of goods sold (COGS) that includes materials.

4) ***Labor:*** The portion of COGS that includes direct labor, commissions, dismissal pay, bonuses, vacation, sick leave, social security contributions, fringe, and assembly labor up-time.

5) ***Depreciation:*** The portion of overhead that includes an allowance for the total amount of fixed assets used to produce that one unit. Annual depreciation is computed as a percentage of ***COGS.*** Depreciation is broken out from overhead as a separate line item.

6) ***Overhead:*** The portion of COGS that includes indirect labor, indirect material, energy use, maintenance, depreciation, property taxes, and insurance related to assets. Depreciation is broken out from overhead as a separate line item.

7) ***Standard SG&A:*** Selling, general, and administrative costs are computed as a percentage of ***Revenues (1)***.

8) ***R&D:*** GRIM separately accounts for ordinary research and development (R&D) as a percentage of ***Revenues (1)***.

9) ***Product Conversion Costs:*** Product conversion costs are one-time investments in research, development, testing, marketing, and other costs focused on making equipment designs comply with the new energy conservation standard. The GRIM allocates these costs over the period between the standard's announcement and compliance dates.

10) ***Stranded Assets:*** In the year the standard becomes effective, a one-time write-off of stranded assets is accounted for.

11) ***Earnings Before Interest and Taxes (EBIT):*** Includes profits before deductions for interest paid and taxes.

12) ***Per Unit EBIT ($/unit):*** GRIM calculates Per Unit EBIT as ***EBIT (11)*** divided by ***Shipments (2).***

13) ***EBIT as a Percentage of Sales (EBIT/Revenues):*** GRIM calculates EBIT as a percentage of sales to compare with the industry's average reported in financial statements.

14) ***Taxes:*** Taxes on ***EBIT (11)*** are calculated by multiplying the tax rate contained in Major Assumptions by ***EBIT (11)***.

15) ***Net Operating Profits After Taxes (NOPAT):*** Computed by subtracting ***Cost of Goods Sold ((3) to (6))***, ***SG&A (7)***, ***R&D (8)***, ***Product Conversion Costs (9)***, and ***Taxes (14)*** from ***Revenues (1)***.

16) ***NOPAT repeated***: NOPAT is repeated in the Statement of Cash Flows.

17) ***Depreciation repeated***: Depreciation is added back in the Statement of Cash Flows because it is a non-cash expense.

18) ***Loss on Disposal of Stranded Assets repeated***: Stranded Assets are added back in the Statement of Cash Flows because they are non-cash expenses.

19) ***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.

20) ***Cash Flow from Operations***: Calculated by taking ***NOPAT (15)***, adding back non-cash items such as a ***Depreciation (17) and Stranded Assets (18)***, and subtracting the ***Change in Working Capital (19)***.

21) ***Ordinary Capital Expenditures:*** Ordinary investments in property, plant, and equipment to maintain and replace existing production assets, computed as a percentage of ***Revenues (1)***.

22) ***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.

23) ***Capital Investment:*** Total investments in property, plant, and equipment are computed by adding ***Ordinary Capital Expenditures (21)*** and ***Capital Conversion Costs (22)***.

24) ***Free Cash Flow:*** Annual cash flow from operations and investments; computed by subtracting ***Capital Investment (23)*** from ***Cash Flow from Operations (20)***.

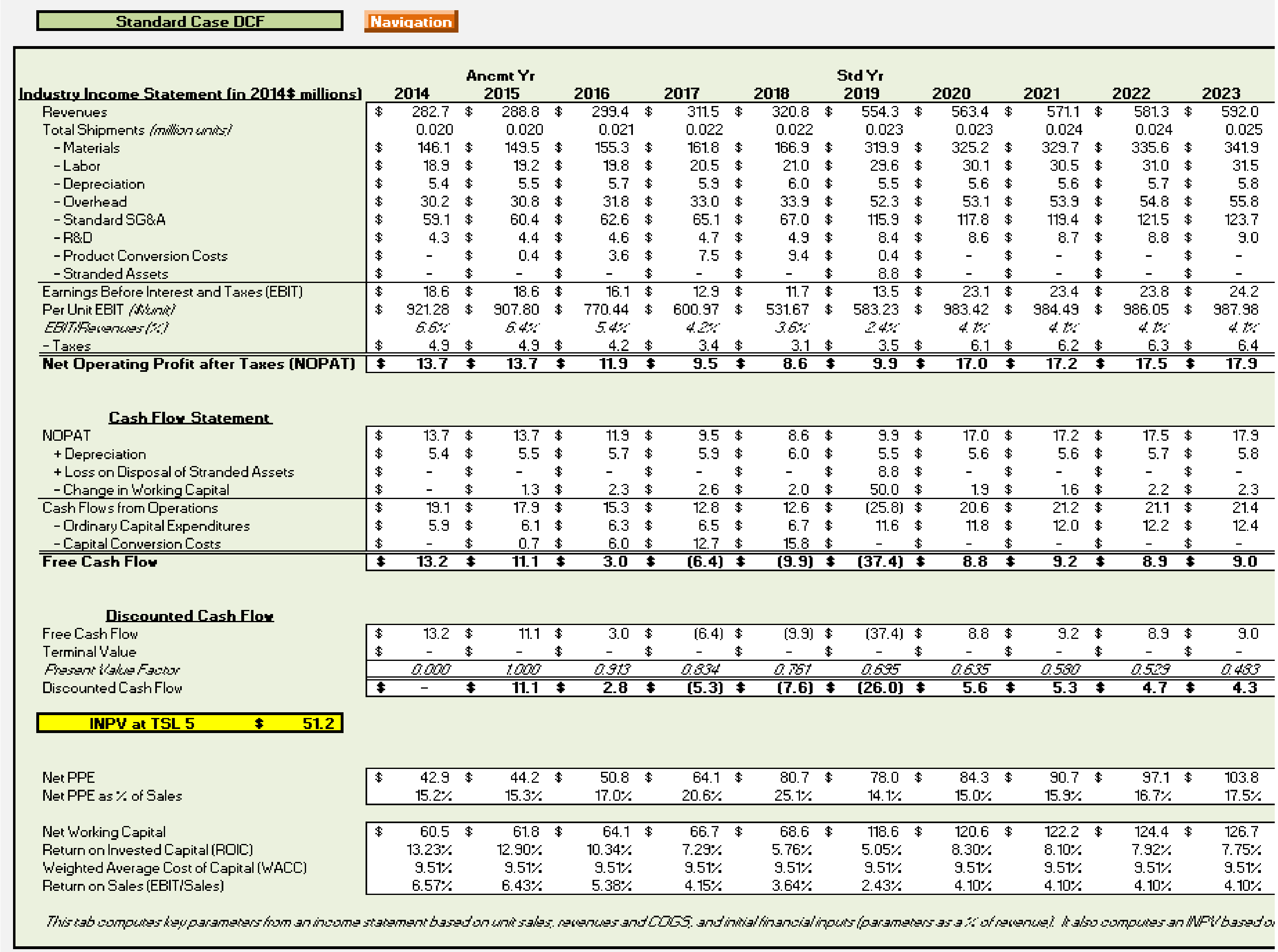
25) ***Terminal Value:*** Estimate of the continuing value of the industry after the analysis period. Computed by growing the Free Cash Flow at a constant rate in perpetuity.

26) ***Present Value Factor:*** Factor used to calculate an estimate of the present value of an amount to be received in the future.

27) ***Discounted Cash Flow: Free Cash Flows (24)*** multiplied by the ***Present Value Factor (26)***. For the end of 2048, the discounted cash flow includes the discounted ***Terminal Value (25)***.

28) ***Industry Value thru the end of 2048:*** The sum of ***Discounted Cash Flows (27)***.

Table 12B.1 Detailed Cash Flow Example



Industry Income Statement (in 2014$ millions)	2014	Ancmt Yr 2015	2016	2017	2018	Std Yr 2019	2020	2021	2022	2023
Revenues	$ 282.7	$ 288.8	$ 299.4	$ 311.5	$ 320.8	$ 554.3	$ 563.4	$ 571.1	$ 581.3	$ 592.0
Total Shipments *(million units)*	0.020	0.020	0.021	0.022	0.022	0.023	0.023	0.024	0.024	0.025
- Materials	$ 146.1	$ 149.5	$ 155.3	$ 161.8	$ 166.9	$ 319.9	$ 325.2	$ 329.7	$ 335.6	$ 341.9
- Labor	$ 18.9	$ 19.2	$ 19.8	$ 20.5	$ 21.0	$ 29.6	$ 30.1	$ 30.5	$ 31.0	$ 31.5
- Depreciation	$ 5.4	$ 5.5	$ 5.7	$ 5.9	$ 6.0	$ 5.5	$ 5.6	$ 5.6	$ 5.7	$ 5.8
- Overhead	$ 30.2	$ 30.8	$ 31.8	$ 33.0	$ 33.9	$ 52.3	$ 53.1	$ 53.9	$ 54.8	$ 55.8
- Standard SG&A	$ 59.1	$ 60.4	$ 62.6	$ 65.1	$ 67.0	$ 115.9	$ 117.8	$ 119.4	$ 121.5	$ 123.7
- R&D	$ 4.3	$ 4.4	$ 4.6	$ 4.7	$ 4.9	$ 8.4	$ 8.6	$ 8.7	$ 8.8	$ 9.0
- Product Conversion Costs	$ -	$ 0.4	$ 3.6	$ 7.5	$ 9.4	$ 0.4	$ -	$ -	$ -	$ -
- Stranded Assets	$ -	$ -	$ -	$ -	$ -	$ 8.8	$ -	$ -	$ -	$ -
Earnings Before Interest and Taxes (EBIT)	$ 18.6	$ 18.6	$ 16.1	$ 12.9	$ 11.7	$ 13.5	$ 23.1	$ 23.4	$ 23.8	$ 24.2
Per Unit EBIT *($/unit)*	$ 921.28	$ 907.80	$ 770.44	$ 600.97	$ 531.67	$ 583.23	$ 983.42	$ 984.49	$ 986.05	$ 987.98
EBIT/Revenues (%)	*6.6%*	*6.4%*	*5.4%*	*4.2%*	*3.6%*	*2.4%*	*4.1%*	*4.1%*	*4.1%*	*4.1%*
- Taxes	$ 4.9	$ 4.9	$ 4.2	$ 3.4	$ 3.1	$ 3.5	$ 6.1	$ 6.2	$ 6.3	$ 6.4
Net Operating Profit after Taxes (NOPAT)	**$ 13.7**	**$ 13.7**	**$ 11.9**	**$ 9.5**	**$ 8.6**	**$ 9.9**	**$ 17.0**	**$ 17.2**	**$ 17.5**	**$ 17.9**

Cash Flow Statement	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
NOPAT	$ 13.7	$ 13.7	$ 11.9	$ 9.5	$ 8.6	$ 9.9	$ 17.0	$ 17.2	$ 17.5	$ 17.9
+ Depreciation	$ 5.4	$ 5.5	$ 5.7	$ 5.9	$ 6.0	$ 5.5	$ 5.6	$ 5.6	$ 5.7	$ 5.8
+ Loss on Disposal of Stranded Assets	$ -	$ -	$ -	$ -	$ -	$ 8.8	$ -	$ -	$ -	$ -
- Change in Working Capital	$ -	$ 1.3	$ 2.3	$ 2.6	$ 2.0	$ 50.0	$ 1.9	$ 1.6	$ 2.2	$ 2.3
Cash Flows from Operations	$ 19.1	$ 17.9	$ 15.3	$ 12.8	$ 12.6	$ (25.8)	$ 20.6	$ 21.2	$ 21.1	$ 21.4
- Ordinary Capital Expenditures	$ 5.9	$ 6.1	$ 6.3	$ 6.5	$ 6.7	$ 11.6	$ 11.8	$ 12.0	$ 12.2	$ 12.4
- Capital Conversion Costs	$ -	$ 0.7	$ 6.0	$ 12.7	$ 15.8	$ -	$ -	$ -	$ -	$ -
Free Cash Flow	**$ 13.2**	**$ 11.1**	**$ 3.0**	**$ (6.4)**	**$ (9.9)**	**$ (37.4)**	**$ 8.8**	**$ 9.2**	**$ 8.9**	**$ 9.0**

Discounted Cash Flow	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Free Cash Flow	$ 13.2	$ 11.1	$ 3.0	$ (6.4)	$ (9.9)	$ (37.4)	$ 8.8	$ 9.2	$ 8.9	$ 9.0
Terminal Value	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	-
Present Value Factor	*0.000*	*1.000*	*0.913*	*0.834*	*0.761*	*0.695*	*0.635*	*0.580*	*0.529*	*0.483*
Discounted Cash Flow	**$ -**	**$ 11.1**	**$ 2.8**	**$ (5.3)**	**$ (7.6)**	**$ (26.0)**	**$ 5.6**	**$ 5.3**	**$ 4.7**	**$ 4.3**

INPV at TSL 5 $ 51.2

	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Net PPE	$ 42.9	$ 44.2	$ 50.8	$ 64.1	$ 80.7	$ 78.0	$ 84.3	$ 90.7	$ 97.1	$ 103.8
Net PPE as % of Sales	15.2%	15.3%	17.0%	20.6%	25.1%	14.1%	15.0%	15.9%	16.7%	17.5%
Net Working Capital	$ 60.5	$ 61.8	$ 64.1	$ 66.7	$ 68.6	$ 118.6	$ 120.6	$ 122.2	$ 124.4	$ 126.7
Return on Invested Capital (ROIC)	13.23%	12.90%	10.34%	7.29%	5.76%	5.05%	8.30%	8.10%	7.92%	7.75%
Weighted Average Cost of Capital (WACC)	9.51%	9.51%	9.51%	9.51%	9.51%	9.51%	9.51%	9.51%	9.51%	9.51%
Return on Sales (EBIT/Sales)	6.57%	6.43%	5.38%	4.15%	3.64%	2.43%	4.10%	4.10%	4.10%	4.10%

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 o

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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 hours (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 space 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).

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[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 CPB Equipment

Emissions	**TSL**				
	1	**2**	**3**	**4**	**5**
Power Sector and Site Emissions					
CO_2 (*million metric tons*)	12.66	19.61	46.61	111.89	114.33
NO_X (*thousand tons*)	74.66	118.07	156.81	294.40	366.68
Hg (*tons*)	0.0002	0.0002	(0.002)	(0.002)	(0.002)
N_2O (*thousand tons*)	0.07	0.11	0.15	0.32	0.37
CH_4 (*thousand tons*)	0.29	0.45	0.95	2.34	2.41
SO_2 (*thousand tons*)	1.24	1.96	1.49	2.87	4.18
Upstream Emissions					
CO_2 (*million metric tons*)	1.84	2.85	6.84	16.28	16.66
NO_X (*thousand tons*)	28.43	43.99	108.03	258.23	263.07
Hg (*tons*)	0.00003	0.0001	0.00003	0.0001	0.0001
N_2O (*thousand tons*)	0.01	0.01	0.02	0.03	0.04
CH_4 (*thousand tons*)	150.66	232.21	616.94	1,502.56	1,507.48
SO_2 (*thousand tons*)	0.08	0.13	0.14	0.25	0.34
Total Emissions					
CO_2 (*million metric tons*)	14.50	22.46	53.45	128.17	130.99
NO_X (*thousand tons*)	103.09	162.06	264.84	552.63	629.75
Hg (*tons*)	0.0002	0.0003	(0.002)	(0.002)	(0.002)
N_2O (*thousand tons*)	0.07	0.12	0.17	0.36	0.41
CH_4 (*thousand tons*)	150.95	232.66	617.89	1,504.90	1,509.89
SO_2 (*thousand tons*)	1.32	2.10	1.63	3.12	4.53

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.

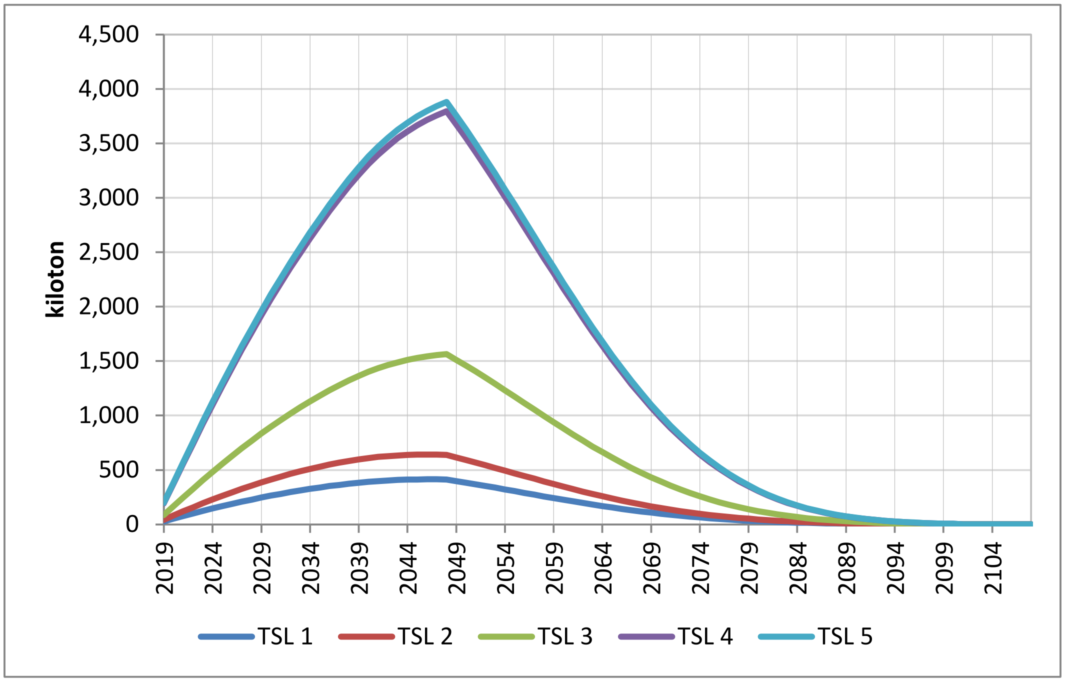

Figure 13.3.1 CPB Equipment: CO_2 Total Emissions Reduction

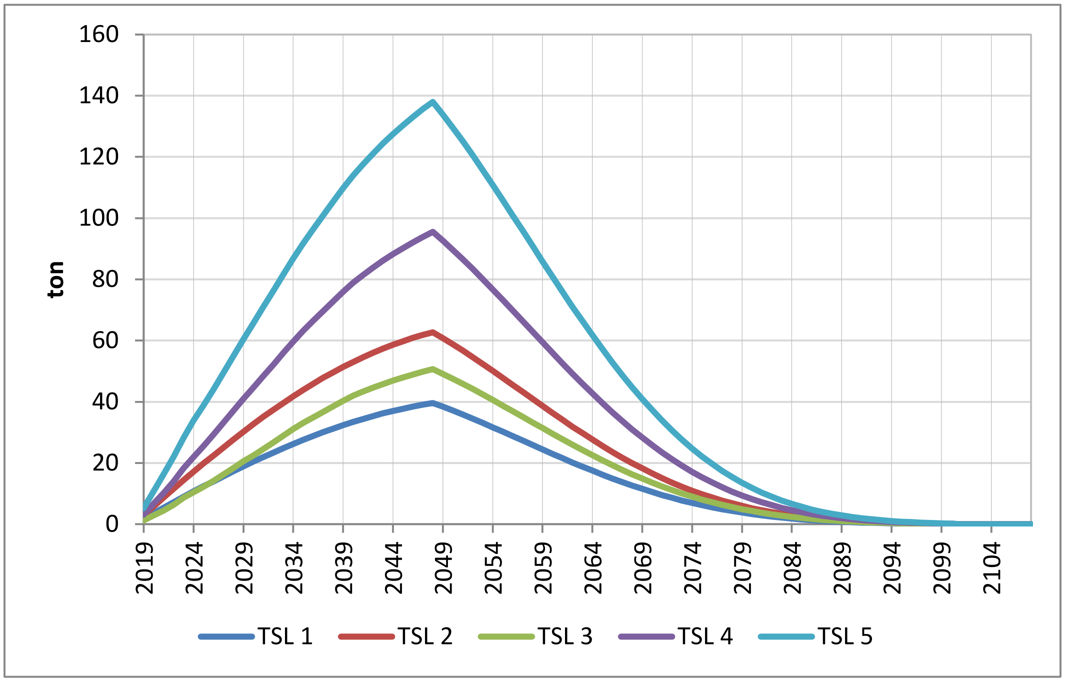

Figure 13.3.2 CPB Equipment: SO_2 Total Emissions Reduction

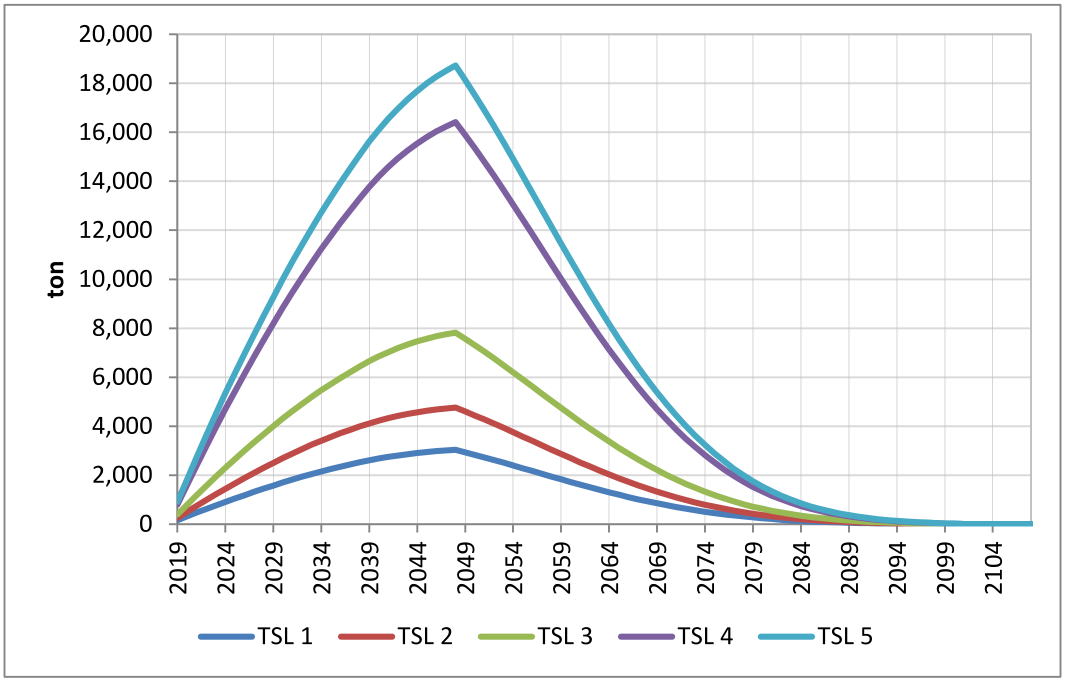

Figure 13.3.3 CPB Equipment: NO_X Total Emissions Reduction

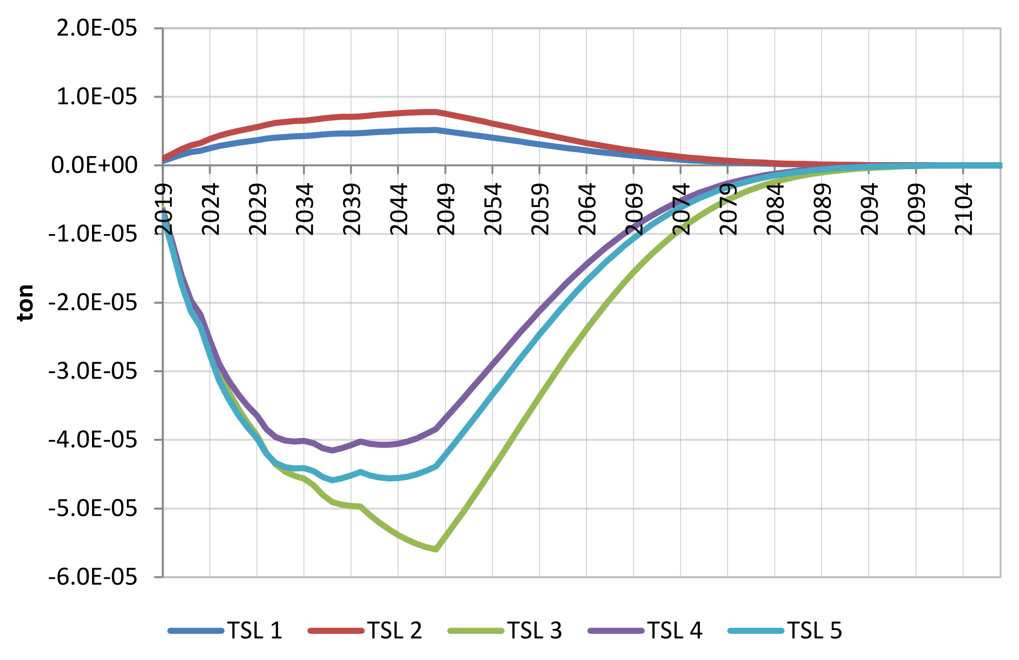

Figure 13.3.4 CPB Equipment: Hg Total Emissions Reduction

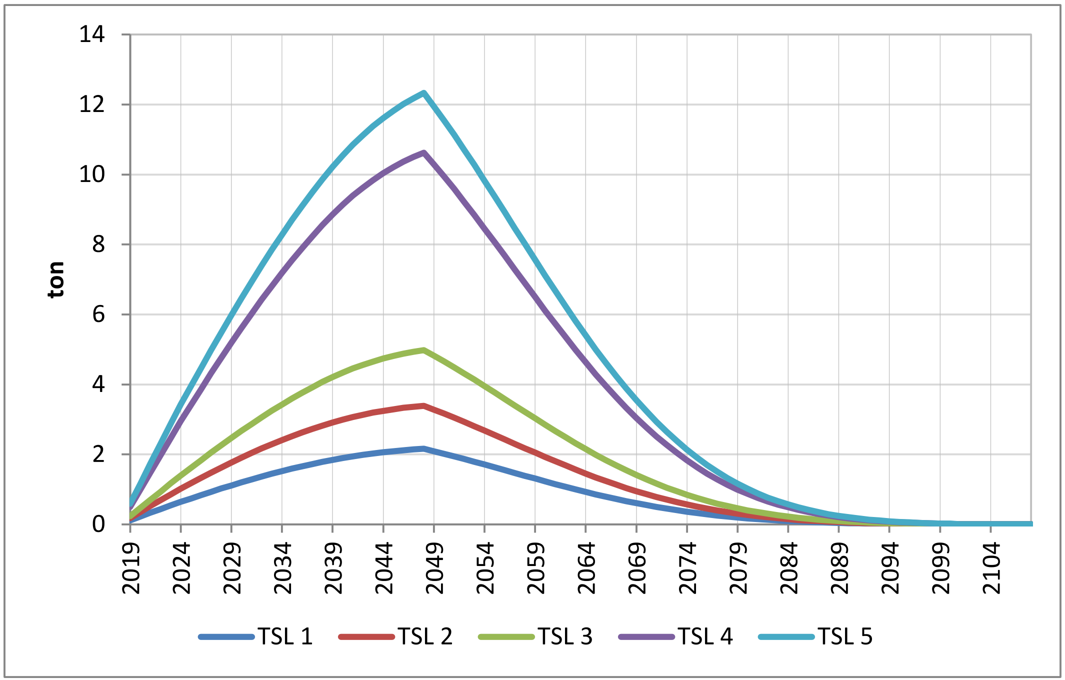

Figure 13.3.5 CPB Equipment: N_2O Total Emissions Reduction

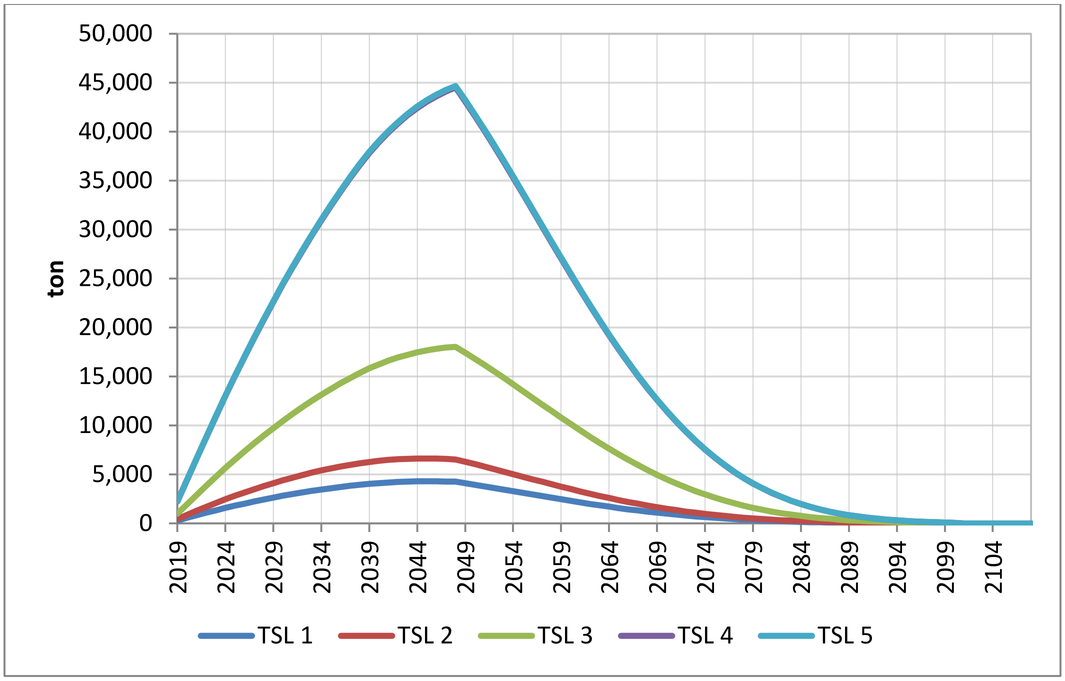

Figure 13.3.6 CPB Equipment: CH_4 Total Emissions Reduction

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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 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 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 of 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 NEMS as listed in the tables below. Total emissions reductions are estimated by multiplying the intensity factors times the energy savings calculated in the national impact analysis (chapter 10). Power sector emissions factors are presented in Table 13A.4.2 through Table 13A.4.7.

Site combustion of fossil fuels in buildings (for example in water-heating, space-heating or cooking applications) also produces emissions of CO_2 and other pollutants. To quantify the reduction in these emissions from a considered standard level, DOE used emissions factors published by the U.S. Environmental Protection Agency (EPA),[3,4] 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).[5] The upstream emissions include both emissions from fuel combustion during extraction, processing and transportation of fuel, and "fugitive" emissions (direct leakage to the atmosphere) of CH_4 and CO_2.

The FFC accounting approach is described briefly in appendix 10B and in Coughlin (2013).[5] When demand for a particular fuel is reduced, there is a corresponding reduction in the upstream activities associated with production of that fuel (mining, refining etc.) These upstream activities also consume energy and therefore produce combustion emissions. The FFC accounting estimates the total consumption of electricity, natural gas, and petroleum-based fuels in these upstream activities. The relevant combustion emissions factors are then applied to this fuel use to determine the total upstream emissions intensities from combustion, per unit of fuel delivered to the consumer.

In addition to combustion emissions, extraction and processing of fossil fuels also produces fugitive emissions of CO_2 and CH_4. Fugitive emissions of CO_2 are small relative to combustion emissions, comprising about 2–3 percent of total CO_2 emissions for natural gas and 1–2 percent for petroleum fuels. In contrast, the fugitive emissions of methane from fossil fuel production are relatively large compared to combustion emissions of CH_4. Hence, fugitive emissions make up over 99 percent of total methane emissions for natural gas, about 95 percent for coal, and 93 percent for petroleum fuels.

Fugitive emissions factors for CO_2 and methane from coal mining and natural gas production were estimated based on a review of recent studies compiled by Burnham (2011).[6] 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.[7,8] 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 below. 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, 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

* (S) is a value corresponding to the weight percent of sulfur in the fuel. For example, if the fuel is 1% sulfur, then (S) = 1.

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

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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 packaged boiler (CPB) 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

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[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 technical support document (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

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[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.

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[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 CPB 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	76	369	594	1,125
2	118	572	920	1,744
3	275	1,343	2,165	4,096
4	655	3,208	5,175	9,784
5	670	3,278	5,287	9,996
Upstream Emissions				
1	11	54	86	163
2	17	83	134	254
3	40	197	318	602
4	95	467	753	1,424
5	98	478	770	1,457
Total Emissions				
1	87	423	680	1,288
2	136	655	1,054	1,998
3	316	1,540	2,483	4,697
4	751	3,675	5,928	11,208
5	767	3,755	6,057	11,452

* 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 CO2 Emissions Reduction for Potential Standards for CPB 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	5.3 to 17.5	25.8 to 84.9	41.6 to 136.5	78.7 to 258.7
2	8.3 to 27.2	40.1 to 131.6	64.4 to 211.7	122.1 to 401.2
3	19.3 to 63.3	94.0 to 308.9	151.5 to 497.9	286.7 to 942.0
4	45.9 to 150.7	224.6 to 737.9	362.2 to 1190.2	684.9 to 2250.3
5	46.9 to 154.0	229.4 to 753.8	370.1 to 1216.0	699.7 to 2299.0
Upstream Emissions				
1	0.8 to 2.5	3.8 to 12.3	6.0 to 19.8	11.4 to 37.6
2	1.2 to 4.0	5.8 to 19.1	9.4 to 30.8	17.7 to 58.3
3	2.8 to 9.3	13.8 to 45.4	22.3 to 73.1	42.1 to 138.4
4	6.7 to 21.9	32.7 to 107.4	52.7 to 173.2	99.7 to 327.5
5	6.8 to 22.5	33.4 to 109.9	53.9 to 177.2	102.0 to 335.1
Total Emissions				
1	6.1 to 20.1	29.6 to 97.2	47.6 to 156.4	90.2 to 296.3
2	9.5 to 31.2	45.9 to 150.7	73.8 to 242.4	139.9 to 459.5
3	22.1 to 72.7	107.8 to 354.3	173.8 to 571.0	328.8 to 1080.4
4	52.6 to 172.7	257.3 to 845.3	414.9 to 1363.4	784.5 to 2577.8
5	53.7 to 176.4	262.9 to 863.7	424.0 to 1393.2	801.7 to 2634.1

* 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 CPB Equipment

TSL	3% Discount Rate	7% Discount Rate
	million 2014$	
Power Sector Emissions		
1	203	71
2	322	112
3	428	149
4	802	279
5	997	346
Upstream Emissions		
1	80	29
2	125	46
3	299	106
4	708	248
5	721	253
Total Emissions		
1	284	100
2	447	158
3	727	255
4	1,510	527
5	1,718	599

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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,

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[a] In this document, we present all values of the SCC as the cost per metric ton of CO_2 emissions. Alternatively, one could report the SCC as the cost per metric ton of carbon emissions. The multiplier for translating between mass of CO_2 and the mass of carbon is 3.67 (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 95th percentile at a 3-percent discount rate. The central value is the average SCC across models at the 3-percent discount rate. For purposes of capturing the uncertainties involved in regulatory impact analysis, we emphasize the importance and value of considering the full range. These SCC estimates also grow over time. For instance, the central value increases to \$24 per ton of CO_2 in 2015 and \$26 per ton of CO_2 in 2020. See 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

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[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

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[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).

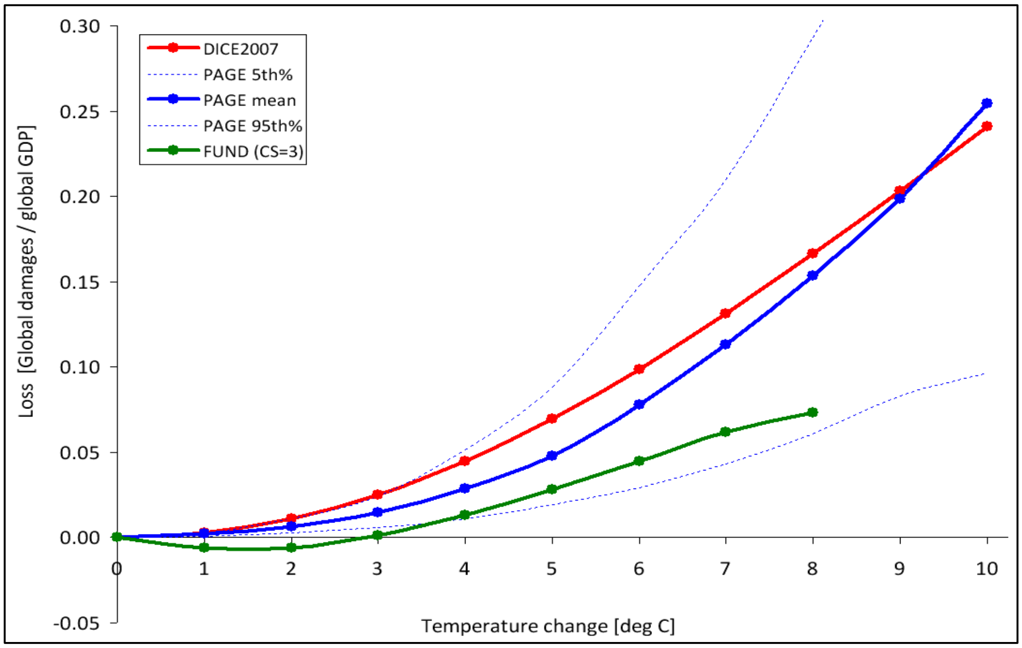
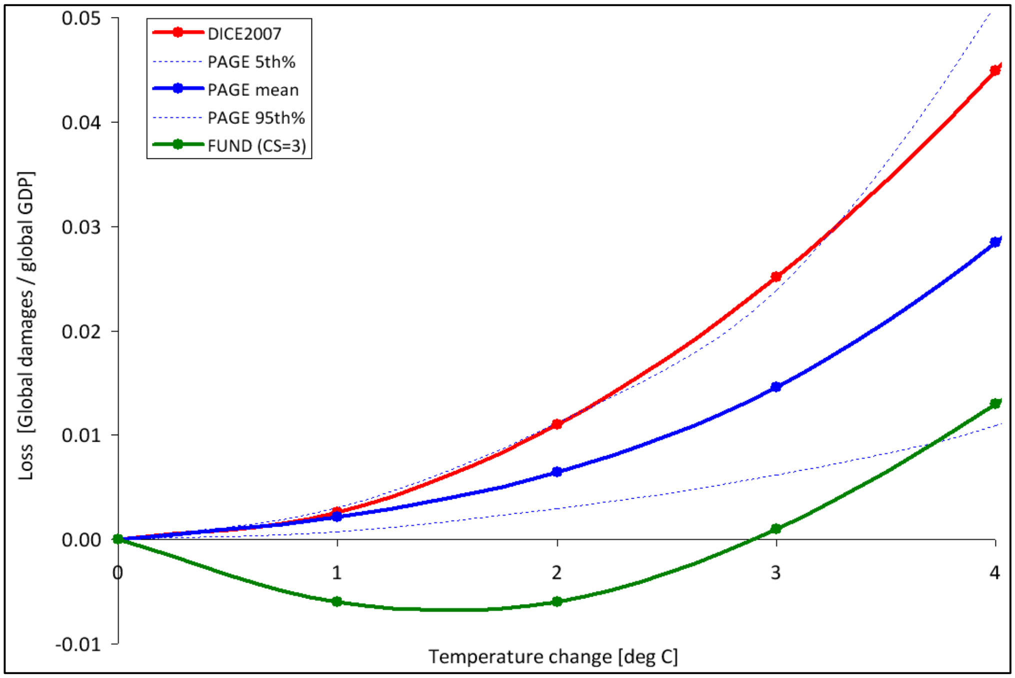


Figure 14A.4.1 Annual Consumption Loss as a Fraction of Global GDP in 2100 Due to an Increase in Annual Global Temperature in the DICE, FUND, and PAGE Models[e]



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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.

Figure 14A.4.2 Annual Consumption Loss for Lower Temperature Changes in DICE, FUND, and PAGE

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

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[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.

solution to a global problem, the United States has been actively involved in seeking international agreements to reduce emissions and in encouraging other nations, including emerging major economies, to take significant steps to reduce emissions. When these considerations are taken as a whole, the interagency group concluded that a global measure of the benefits from reducing U.S. emissions is preferable.

When quantifying the damages associated with a change in emissions, a number of analysts (*e.g.*, Anthoff *et al*. 2009a) employ "equity weighting" to aggregate changes in consumption across regions. This weighting takes into account the relative reductions in wealth in different regions of the world. A per-capita loss of $500 in GDP, for instance, is weighted more heavily in a country with a per-capita GDP of $2,000 than in one with a per-capita GDP of $40,000. The main argument for this approach is that a loss of $500 in a poor country causes a greater reduction in utility or welfare than does the same loss in a wealthy nation. Notwithstanding the theoretical claims on behalf of equity weighting, the interagency group concluded that this approach would not be appropriate for estimating a SCC value used in domestic regulatory analysis.[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.

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[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

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[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

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[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]

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[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.

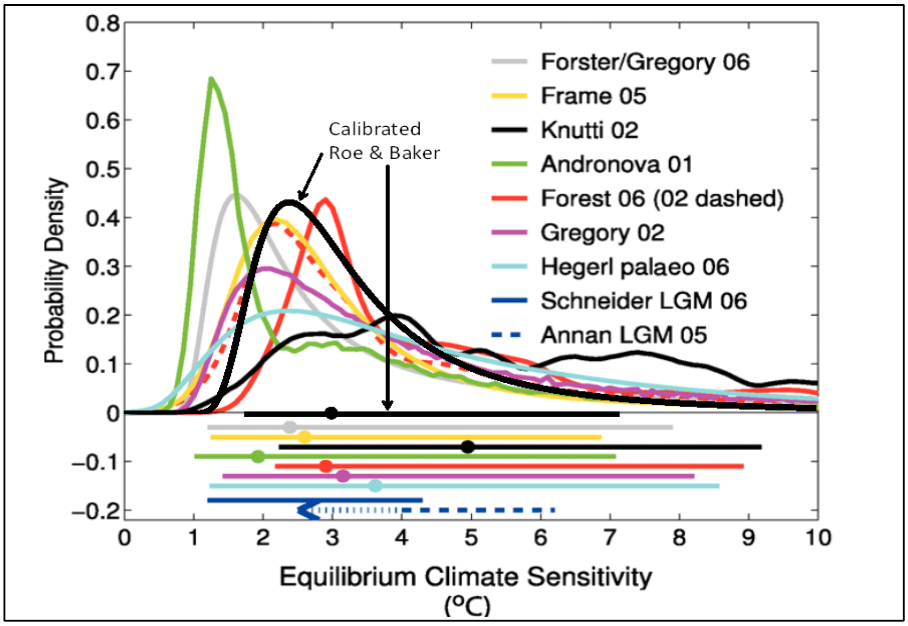

Figure 14A.4.3 Estimates of the Probability Density Function for Equilibrium Climate Sensitivity

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.

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[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.

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
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

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[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.

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.

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.

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[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.

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 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

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[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.

[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).

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 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 inter-generational setting, it may make sense to use a small positive pure rate of time preference because of the small probability of unforeseen cataclysmic events (Stern 2006).

- g. A commonly accepted approximation is around 2 percent per year. For the socio-economic scenarios used for this exercise, the EMF models assume that g is about 1.5–2 percent to 2100.

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[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.

[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 $\rho = 1.07$.

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.

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.

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[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.)

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]

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

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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.

[z] Calculations done by Pizer *et al.* using the original simulation program from Newell and Pizer (2003).

or normative approach and to ethical objections that have been raised about rates of 3 percent or higher.

14A.5 REVISED SCC ESTIMATES

Our general approach to estimating SCC values is to run the three integrated assessment models (FUND, DICE, and PAGE) using the following inputs agreed upon by the interagency group:

- A Roe and Baker distribution for the climate sensitivity parameter bounded between 0 and 10 with a median of 3 °C and a cumulative probability between 2 and 4.5 °C of two-thirds.
- Five sets of GDP, population and carbon emissions trajectories based on EMF-22.
- Constant annual discount rates of 2.5, 3, and 5 percent.

Because the climate sensitivity parameter is modeled probabilistically, and because PAGE and FUND incorporate uncertainty in other model parameters, the final output from each model run is a distribution over the SCC in year *t*.

For each of the IAMS, the basic computational steps for calculating the SCC in a particular year *t* are:

1. Input the path of emissions, GDP, and population from the selected EMF-22 scenarios, and the extrapolations based on these scenarios for post-2100 years.

2. Calculate the temperature effects and (consumption-equivalent) damages in each year resulting from the baseline path of emissions.

    a. In PAGE, the consumption-equivalent damages in each period are calculated as a fraction of the EMF GDP forecast, depending on the temperature in that period relative to the pre-industrial average temperature in each region.

    b. In FUND, damages in each period depend on both the level and the rate of temperature change in that period.

    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]

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.

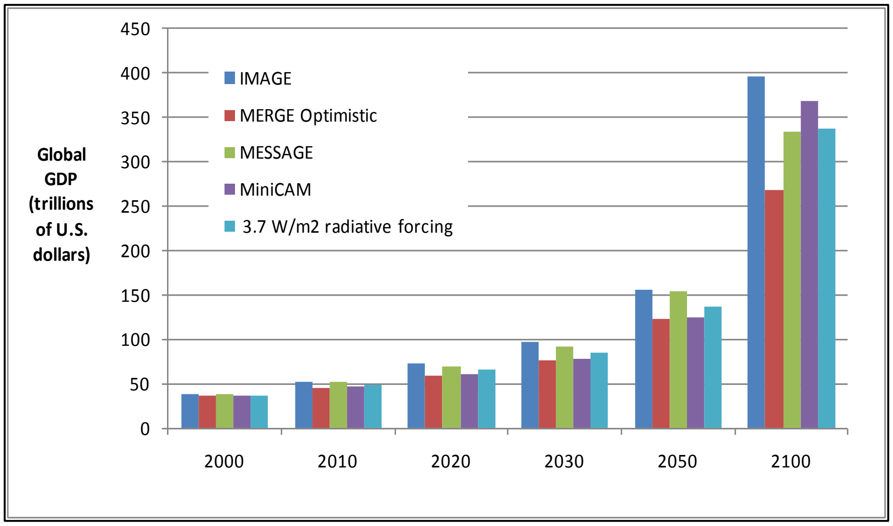

Figure 14A.5.1 Level of Global GDP Across EMF Scenarios

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.

[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.

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,

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[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.

and ethical understandings. During the course of our modeling, it became apparent that there are several areas in particular need of additional exploration and research. These caveats and additional observations in the following section are necessary to consider when interpreting and applying the SCC estimates.

Incomplete treatment of non-catastrophic damages. The impacts of climate change are expected to be widespread, diverse, and heterogeneous. In addition, the exact magnitude of these impacts is uncertain because of the inherent complexity of climate processes, the economic behavior of current and future populations, and our inability to accurately forecast technological change and adaptation. Current IAMs do not assign value to all of the important physical, ecological, and economic impacts of climate change recognized in the climate change literature (some of which are discussed above) because of lack of precise information on the nature of damages and because the science incorporated into these models understandably lags behind the most recent research. Our ability to quantify and monetize impacts will undoubtedly improve with time. 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

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[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).

preference in determining the social cost of carbon." Since Circular A-4 allows for a different assumption on risk preference in regulatory analysis if it is adequately justified, we plan to continue investigating this issue.

14A.7 A FURTHER DISCUSSION OF CATASTROPIC 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.10.1 Other (Non-CO_2) Gases

In addition to fossil and industrial CO_2 emissions, each EMF scenario provides projections of methane (CH_4), nitrous oxide (N_2O), fluorinated gases, and net land use CO_2 emissions to 2100. These assumptions are used in all three IAMs while retaining each model's default radiative forcings (RF) due to other factors (*e.g.*, aerosols and other gases). Specifically, to obtain the RF associated with the non-CO_2 EMF emissions only, we calculated the RF associated with the EMF atmospheric CO_2 concentrations and subtracted them from the EMF total RF.[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.

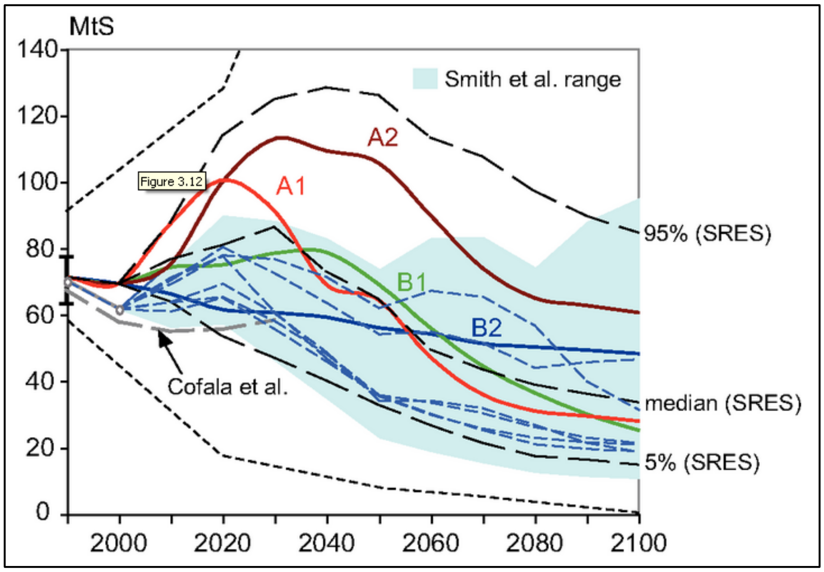

Figure 14A.10.1 Sulphur Dioxide Emission Scenarios

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.10.2 Extrapolating Emissions Projections to 2300

To run each model through 2300 requires assumptions about GDP, population, greenhouse gas emissions, and radiative forcing trajectories after 2100, the last year for which these projections are available from the EMF-22 models. These inputs were extrapolated from 2100 to 2300 as follows:

1. Population growth rate declines linearly, reaching zero in 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*. www.un.org/esa/population/publications/longrange2/WorldPop2300final.pdf.

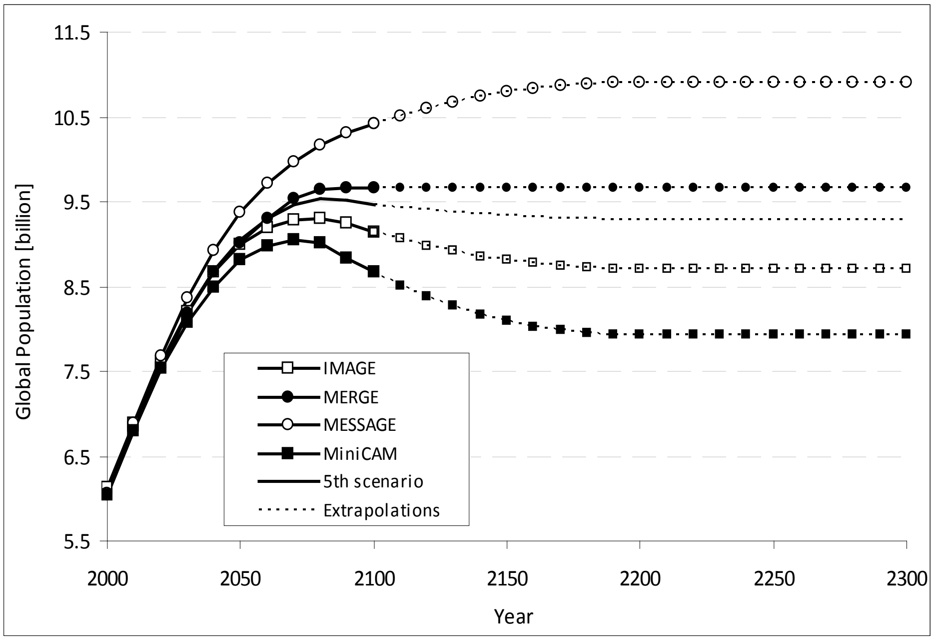

Figure 14A.10.2 Global Population, 2000–2300 (post-2100 extrapolations assume the population growth rate changes linearly to reach a zero growth rate by 2200)

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.

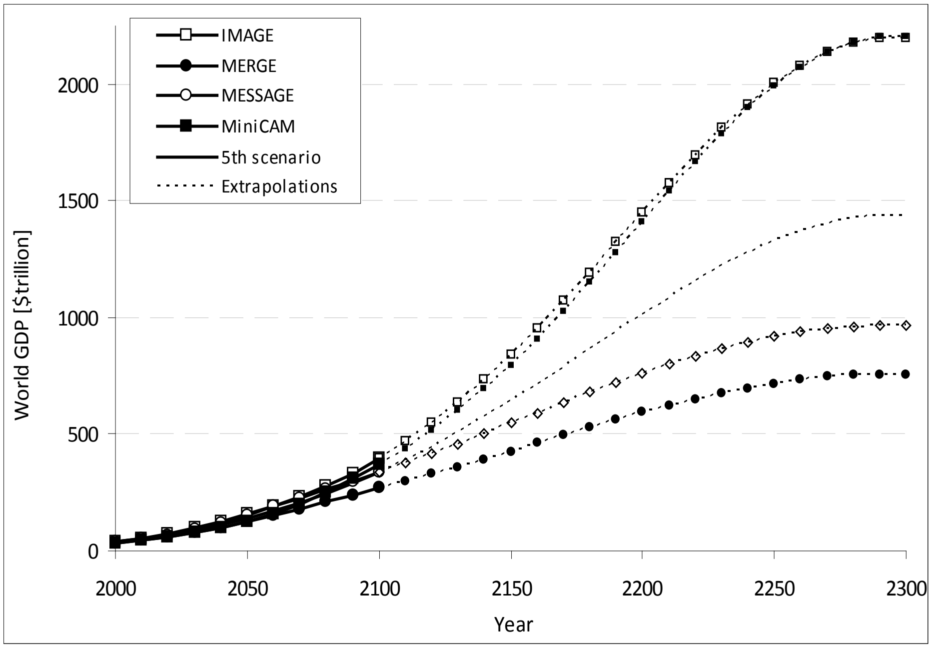

Figure 14A.10.3 World GDP, 2000-2300 (post-2100 extrapolations assume GDP per capita growth declines linearly, reaching zero in 2300)

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.

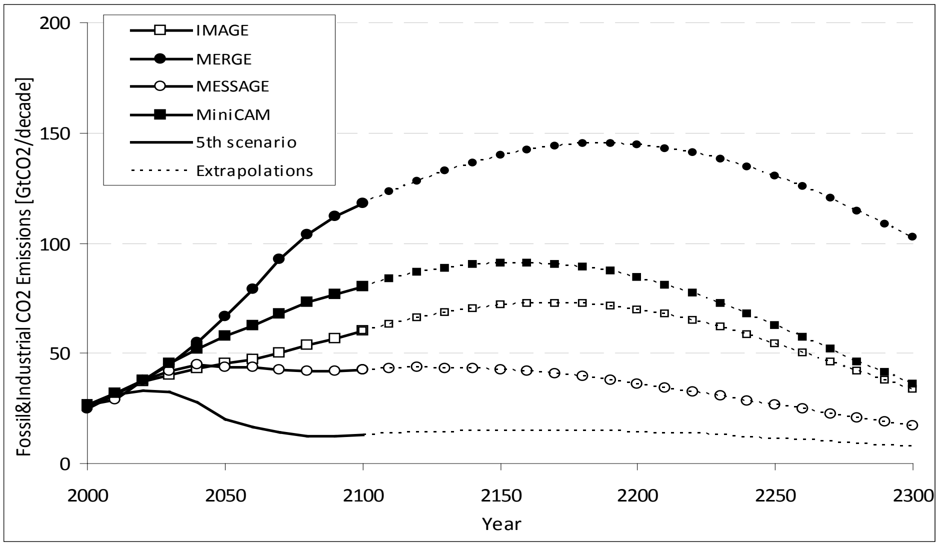

Figure 14A.10.4 Global Fossil and Industrial CO_2 Emissions, 2000-2300 (post-2100 extrapolations assume growth rate of CO_2 intensity (CO_2/GDP) over 2090–2100 is maintained through 2300)

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.

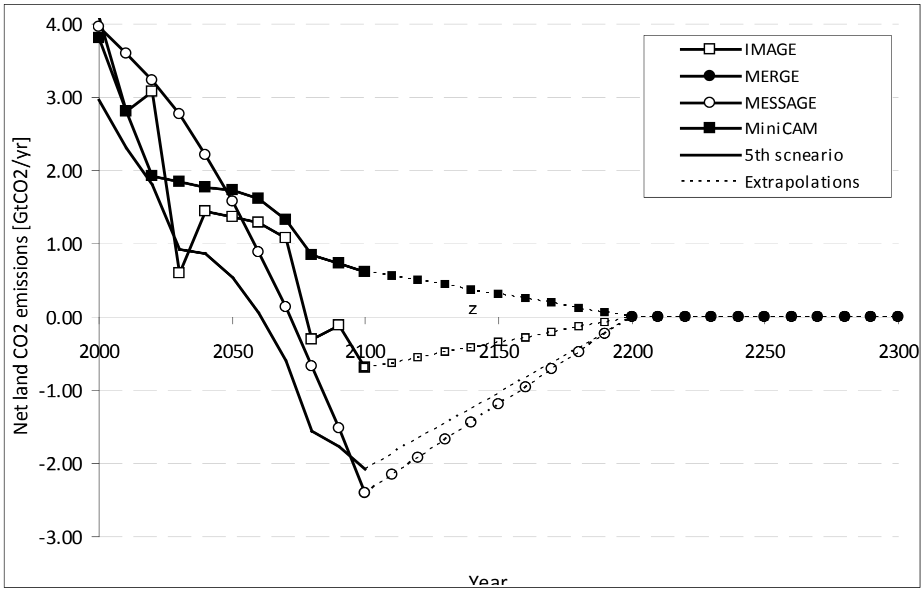

Figure 14A.10.5 Global Net Land Use CO_2 Emissions, 2000–2300 (post-2100 extrapolations assume emissions decline linearly, reaching zero in 2200)[jj]

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).

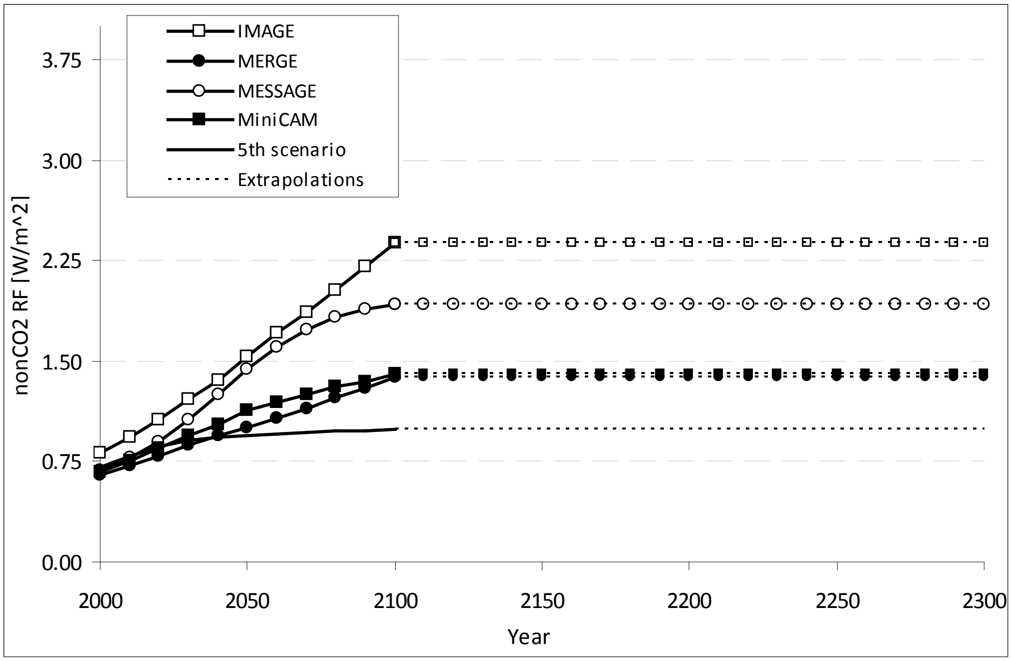

Figure 14A.10.6 Global Non-CO₂ Radiative Forcing, 2000–2300 (post-2100 extrapolations assume constant non-CO₂ radiative forcing after 2100)

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.

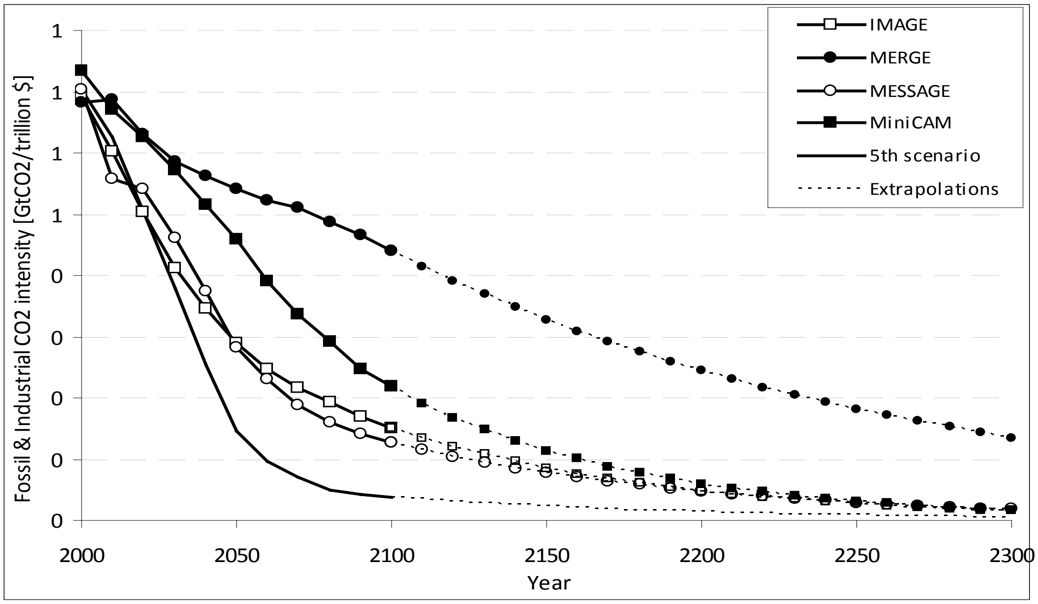

Figure 14A.10.7 Global CO₂ Intensity (fossil & industrial CO₂ emissions/GDP), 2000–2300 (post-2100 extrapolations assume decline in CO₂/GDP growth rate over 2090–2100 is maintained through 2300)

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

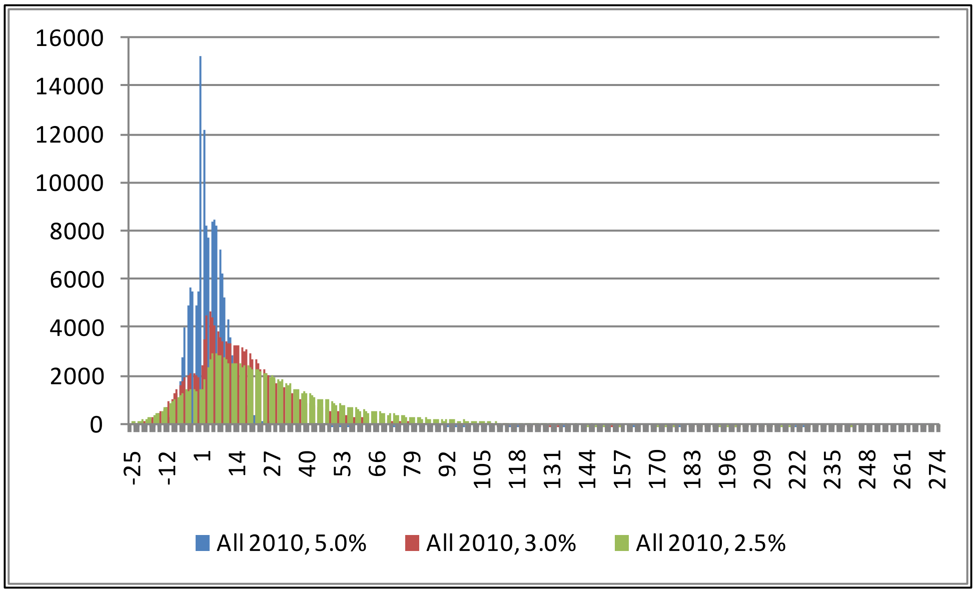

Figure 14A.10.8 Histogram of Global SCC Estimates in 2010 (2007$/ton CO_2), by Discount Rate*

* 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 Table 14B.2.1 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	5.0%	3.0%	2.5%	3.0%
Year	Avg	Avg	Avg	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).[11] E.O. 13563 commits the Administration to regulatory decision making "based on the best available science."[b] Additionally, the interagency group recommended in 2010 that the SCC estimates be revisited on a regular basis or as model updates that reflect the growing body of scientific and economic knowledge become available.[c] New versions of the three integrated assessment models used by the U.S. government to estimate the SCC (DICE, FUND, and PAGE), are now available and have been published in the peer reviewed literature. While acknowledging the continued limitations of the approach taken by the interagency group in 2010 (documented in the original 2010 TSD), this document provides an update of the SCC estimates based solely on the latest peer-reviewed version of the models, replacing model versions that were developed up to ten years ago in a rapidly evolving field. It does not revisit other assumptions with regard to the discount rate, reference case socioeconomic and emission scenarios, or equilibrium climate sensitivity. Improvements in the way damages are modeled are confined to those that have been incorporated into the latest versions of the models by the developers themselves in the peer-reviewed literature. The Environmental Protection

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[a] In this document, we present all values of the SCC as the cost per metric ton of CO_2 emissions. Alternatively, one could report the SCC as the cost per metric ton of carbon emissions. The multiplier for translating between mass of CO_2 and the mass of carbon is 3.67.

[b] http://www.whitehouse.gov/sites/default/files/omb/inforeg/eo12866/eo13563_01182011.pdf

[c] See p. 1, 3, 4, 29, and 33 (Interagency Working Group on Social Cost of Carbon 2010).[1]

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).[2,d] Carbon cycle transfer coefficient values in DICE2010 are based on re-calibration of the model to match the newer version of MAGICC (Nordhaus 2010 p 2).[3] For example, in DICE2010 in each decade, 12 percent of the carbon in the atmosphere is transferred to the shallow ocean, 4.7 percent of the carbon in the shallow ocean is transferred to the atmosphere, 94.8 percent remains in the shallow ocean, and 0.5 percent is transferred to the deep ocean. For comparison, in DICE 2007, 18.9 percent of the carbon in the atmosphere is transferred to the shallow ocean each 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.[4,5,6,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 ^{o}C and increases linearly from 0 meters to a maximum of 7.3 meters. The contribution to SLR in each period is proportional to the difference between the previous period's sea level anomaly and the equilibrium sea level anomaly, where the constant of proportionality increases with the temperature anomaly in the current period.

The contribution to SLR from the melting of the Antarctic ice sheet is -0.001 meters per decade when the temperature anomaly is below 3 °C and increases linearly to a maximum rate of 0.025 meters per decade at a temperature anomaly of 6 °C.

14B.4.1.3 Re-calibrated Damage Function

Economic damages from climate change in the DICE model are represented by a fractional loss of gross economic output in each period. A portion of the remaining economic output in each period (net of climate change damages) is consumed and the remainder is invested in the physical capital stock to support future production, so each period's climate damages will reduce consumption in that period and in all future periods due to the lost investment. The fraction of output in each period that is lost due to climate change impacts is represented as one minus a fraction, which is one divided by a quadratic function of the temperature anomaly, producing a sigmoid ("S"-shaped) function. The loss function in DICE2010 has been expanded by adding a quadratic function of SLR to the quadratic function of temperature. In DICE2010 the temperature anomaly coefficients have been recalibrated to avoid double-counting damages from sea level rise that were implicitly included in these parameters in DICE2007.

The aggregate damages in DICE2010 are illustrated by Nordhaus (2010 p 3),[3] who notes that "…damages in the uncontrolled (baseline) (*i.e.*, reference) case … in 2095 are $12 trillion, or 2.8 percent of global output, for a global temperature increase of 3.4 ^{o}C above 1900 levels." This compares to a loss of 3.2 percent of global output at 3.4 ^{o}C in DICE2007. However, in DICE2010 (as downloaded from the homepage of William Nordhaus), annual damages are lower in most of the early periods but higher in later periods of the time horizon than would be calculated using the DICE2007 damage function. Specifically, the percent difference between damages in the base run of DICE2010 and those that would be calculated using the DICE2007 damage function starts at +7 percent in 2005, decreases to a low of -14 percent in 2065, then continuously increases to +20 percent by 2300 (the end of the interagency analysis time horizon), and to +160 percent by the end of the model time horizon in 2595. The large increases in the far future years of the time horizon are due to the permanence associated with damages from sea

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[f] For a review of post-IPCC AR4 research on sea level rise, see Nicholls et al. (2011)[5] and NAS (2011).[6]

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.[7,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.

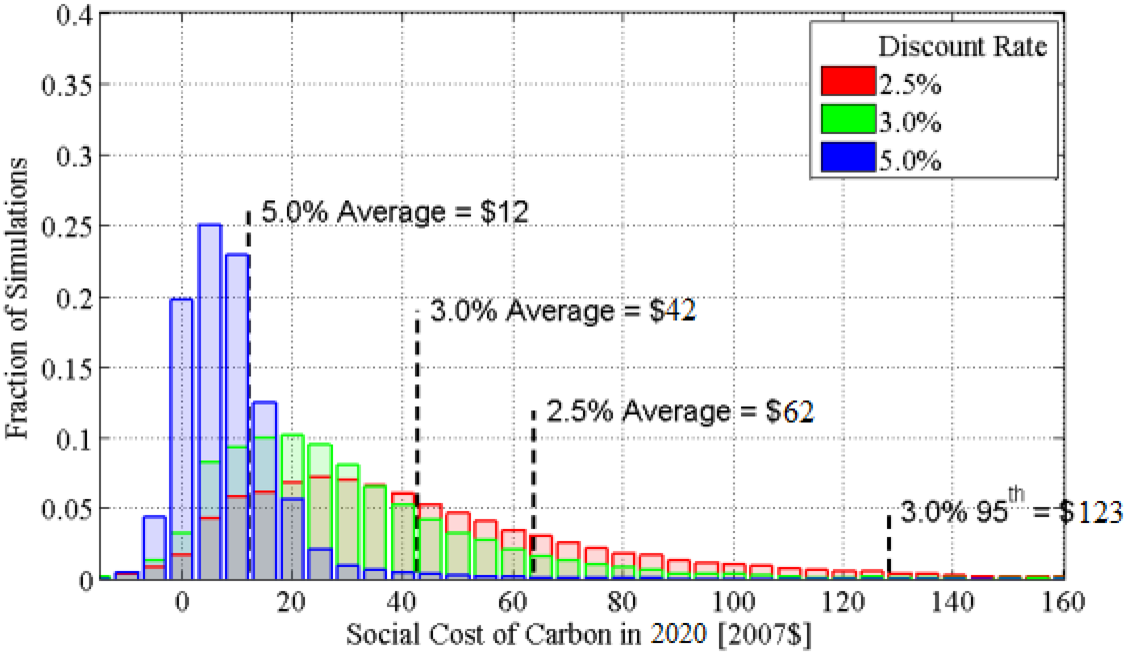

Figure 14B.5.1 Distribution of SCC Estimates for 2010 (in 2007$ per ton CO_2)

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.

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 CO2)

Percentile	1st	5th	10th	25th	50th	Avg	75th	90th	95th	99th
Scenario	**PAGE**									
IMAGE	6	10	15	26	55	123	133	313	493	949
MERGE	4	6	8	15	32	75	79	188	304	621
MESSAGE	4	7	10	19	41	104	103	266	463	879
MiniCAM Base	5	8	12	21	45	102	108	255	412	835
5th Scenario	2	4	6	11	24	81	66	192	371	915

Scenario	DICE									
IMAGE	25	31	37	47	64	72	92	123	139	161
MERGE	14	18	20	26	36	40	50	65	74	85
MESSAGE	20	24	28	37	51	58	71	95	109	221
MiniCAM Base	20	25	29	38	53	61	76	102	117	135
5th Scenario	17	22	25	33	45	52	65	91	106	126

Scenario	FUND									
IMAGE	-14	-2	4	15	31	39	55	86	107	157
MERGE	-6	1	6	14	27	35	46	70	87	141
MESSAGE	-16	-5	1	11	24	31	43	67	83	126
MiniCAM Base	-7	2	7	16	32	39	55	83	103	158
5th Scenario	-29	-13	-6	4	16	21	32	53	69	103

Table 14B.7.3 SCC Estimates at 3 Percent Discount Rate (2007$/ton CO2)

Percentile	1st	5th	10th	25th	50th	Avg	75th	90th	95th	99th
Scenario	**PAGE**									
IMAGE	4	7	9	17	36	87	91	228	369	696
MERGE 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.

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CHAPTER 15. UTILITY IMPACT ANALYSIS

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CHAPTER 15. UTILITY IMPACT ANALYSIS

15.1 INTRODUCTION

In the utility impact analysis, the U.S. Department of Energy (DOE) analyzes the changes in electric installed capacity and 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, that 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 of this technical support document (TSD). The methodology is described in more detail in Coughlin, *Utility Sector Impacts of Reduced Electricity Demand.*[2]

This chapter presents the results for commercial packaged boiler (CPB) 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/forecasts/archive/0581(2009).pdf

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: (1) the annual generation (TWh) from the stock of electric generating capacity changes, (2) the total generation capacity itself (GW) may change, and (3) 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 of this TSD) to produce estimates of the utility impacts. The utility impact factors are presented in appendix 15A of this TSD. For CPB equipment, DOE used the impact factors for space 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 of this TSD. Units are megawatts of capacity per gigawatt-hour of site electricity use (MW/GWh).[b]

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[b] These units are identical to GW/TWh.

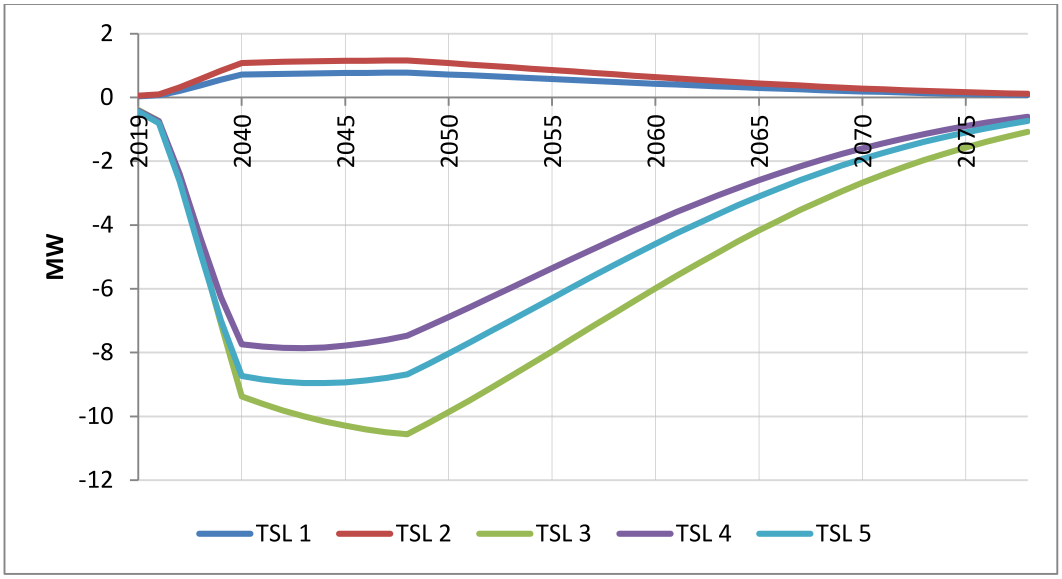

Figure 15.3.1 CPB Equipment: Total Capacity Reduction

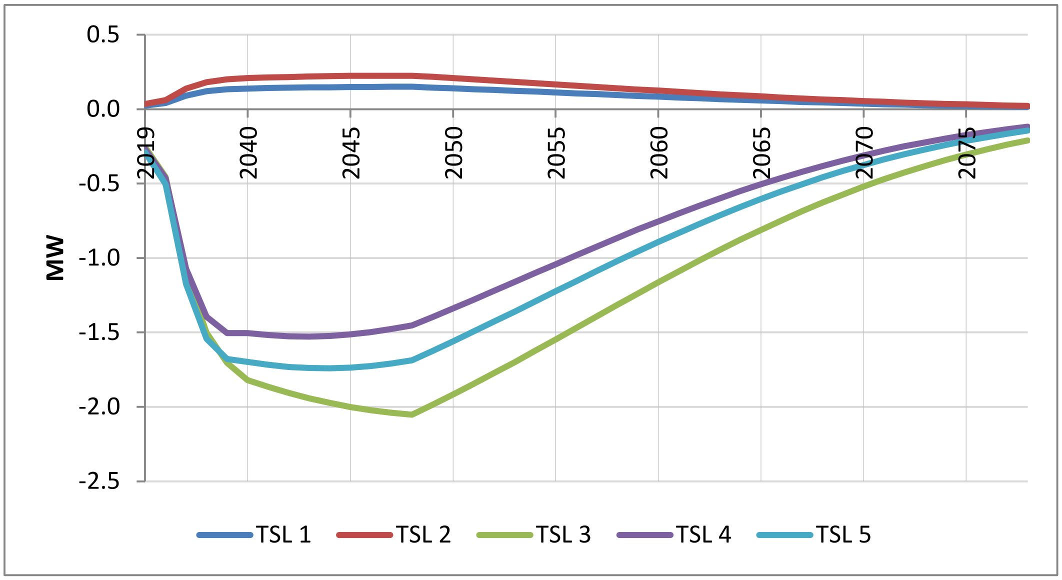

Figure 15.3.2 CPB Equipment: Coal Capacity Reduction

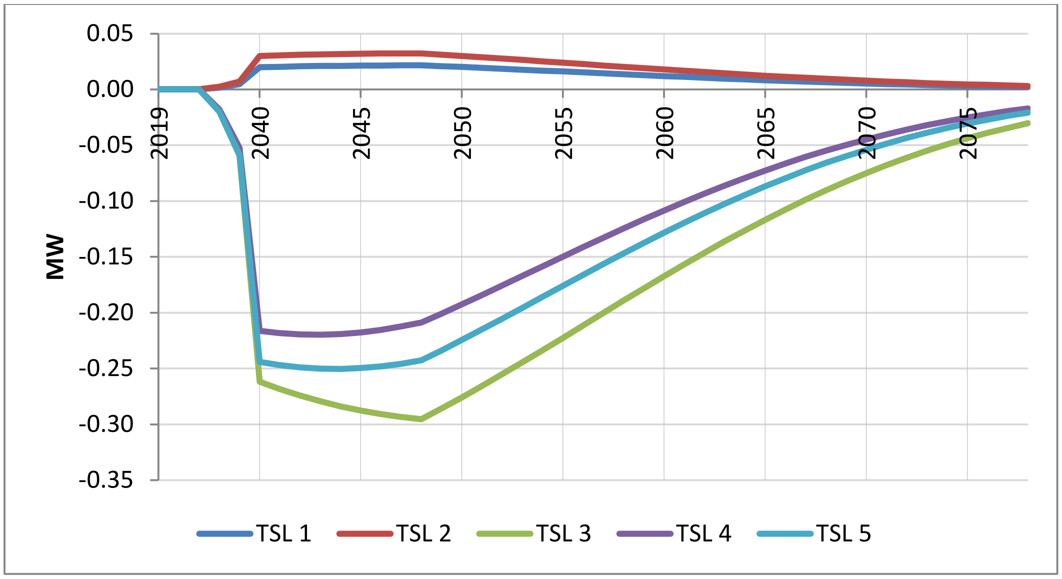

Figure 15.3.3 CPB Equipment: Nuclear Capacity Reduction

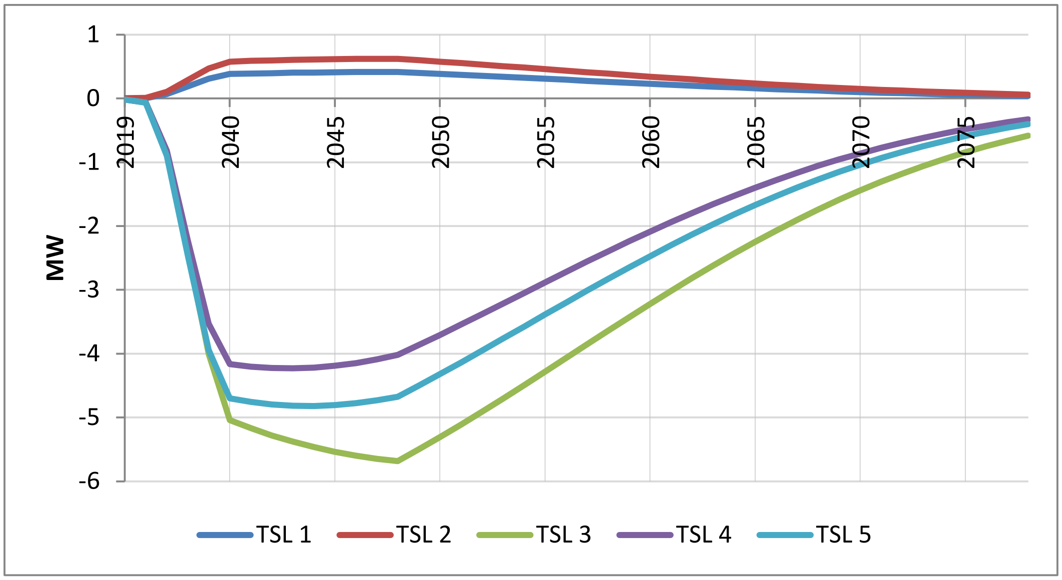

Figure 15.3.4 CPB Equipment: Gas Combined Cycle Capacity Reduction

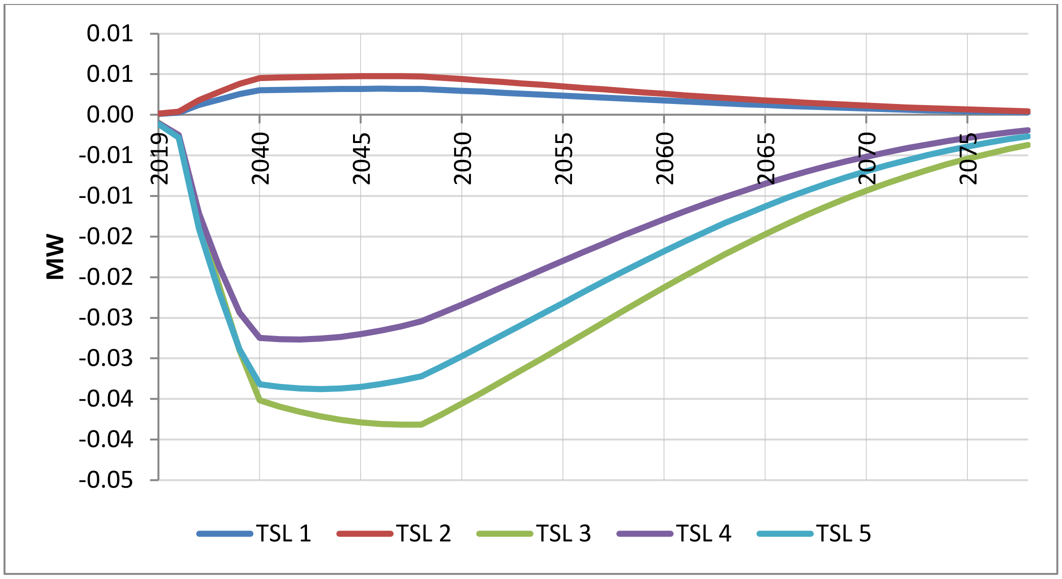

Figure 15.3.5 CPB Equipment: Peaking Capacity Reduction

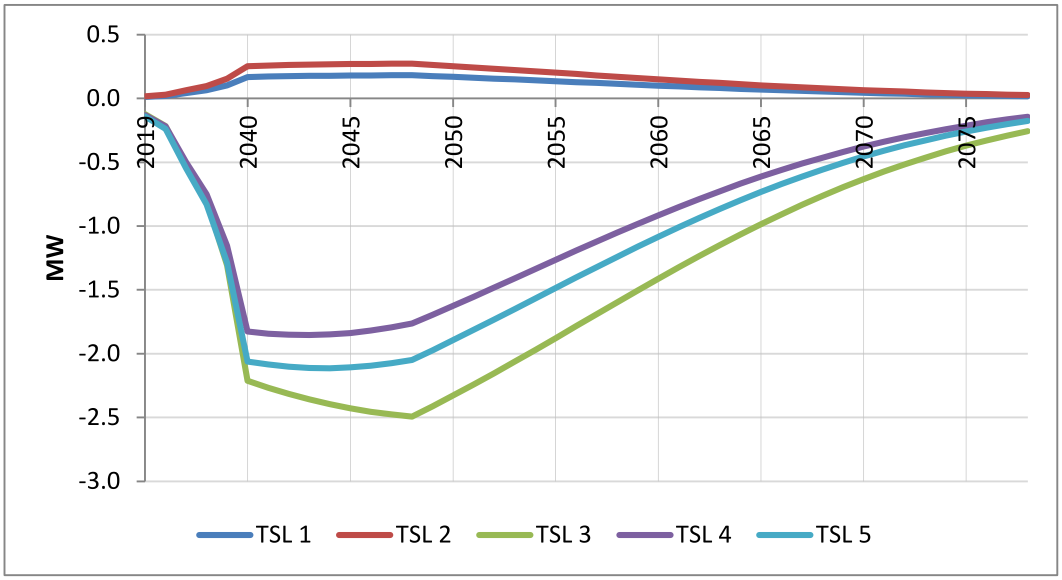

Figure 15.3.6 CPB Equipment: Renewables Capacity Reduction

15.3.2 Electricity Generation

Figure 15.3.7 through Figure 15.3.12 show the annual changes 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 of this TSD.

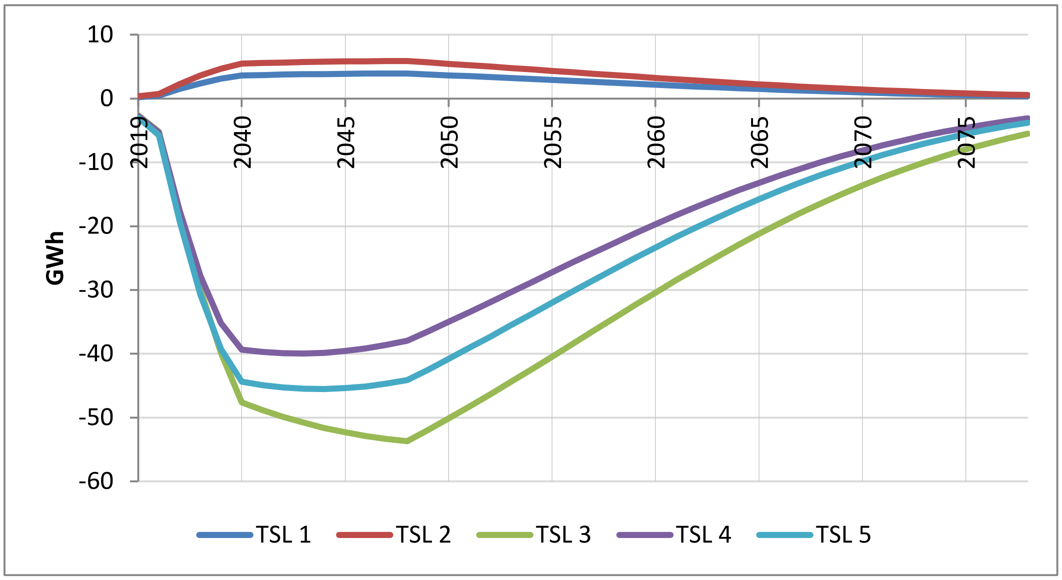

Figure 15.3.7 CPB Equipment: Total Generation Reduction

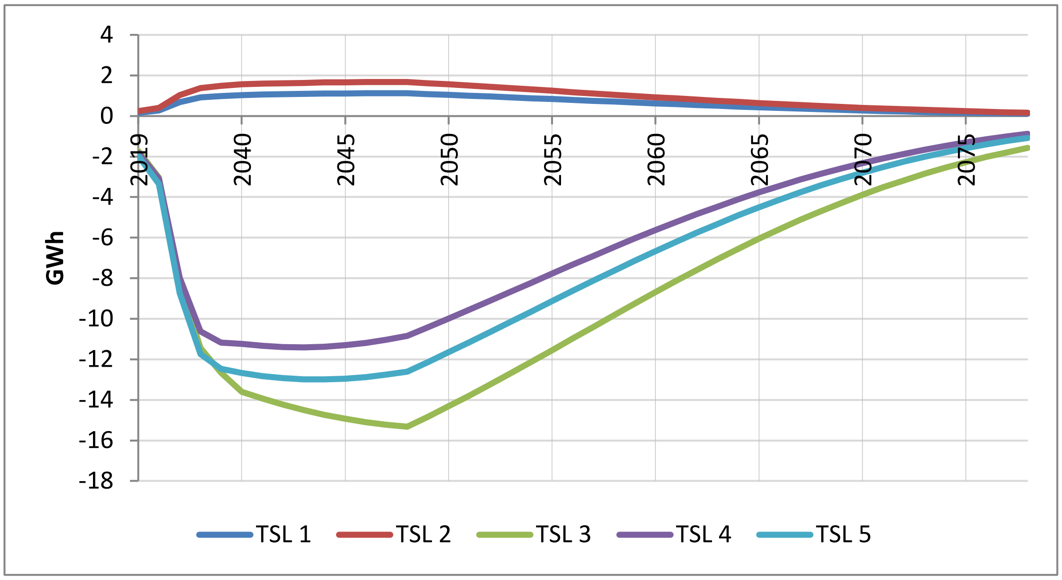

Figure 15.3.8 CPB Equipment: Coal Generation Reduction

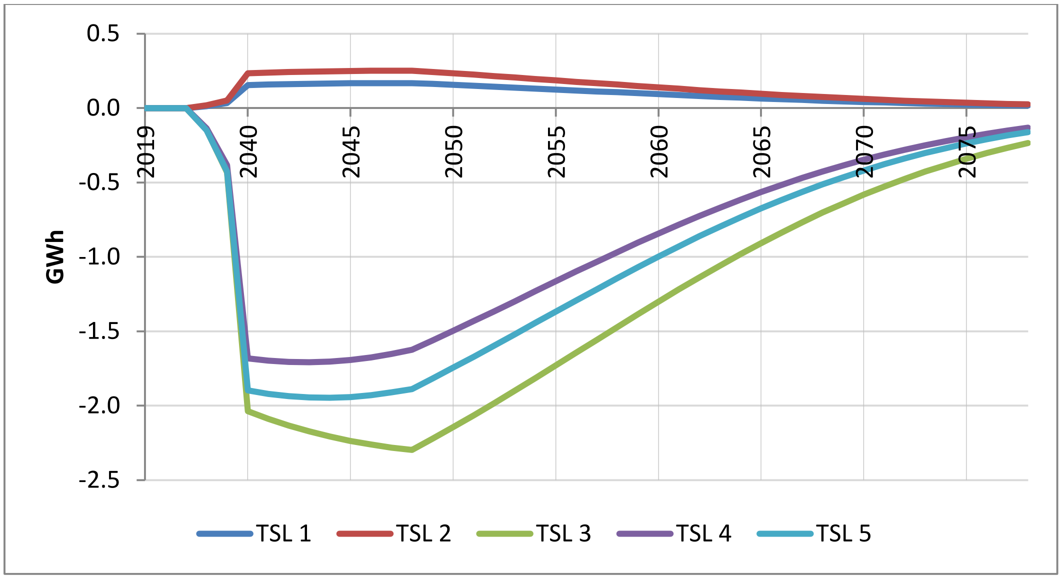

Figure 15.3.9 CPB Equipment: Nuclear Generation Reduction

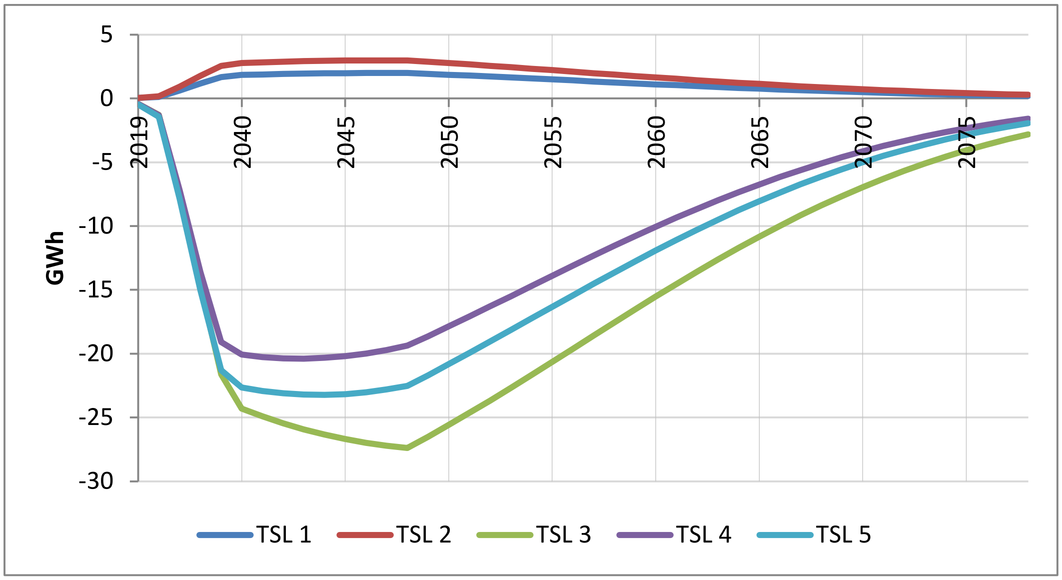

Figure 15.3.10 CPB Equipment: Gas Combined Cycle Generation Reduction

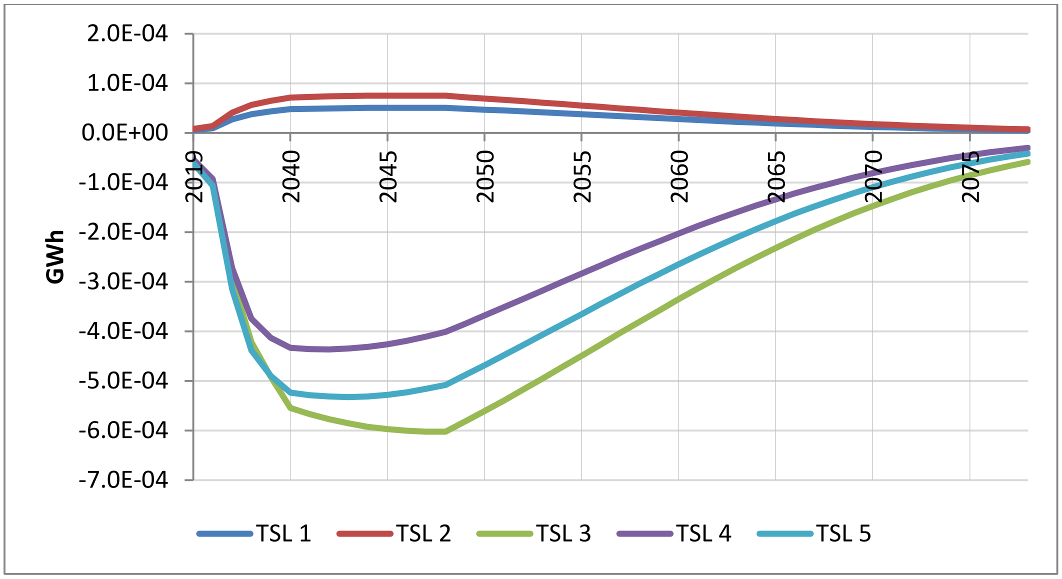

Figure 15.3.11 CPB Equipment: Oil Generation Reduction

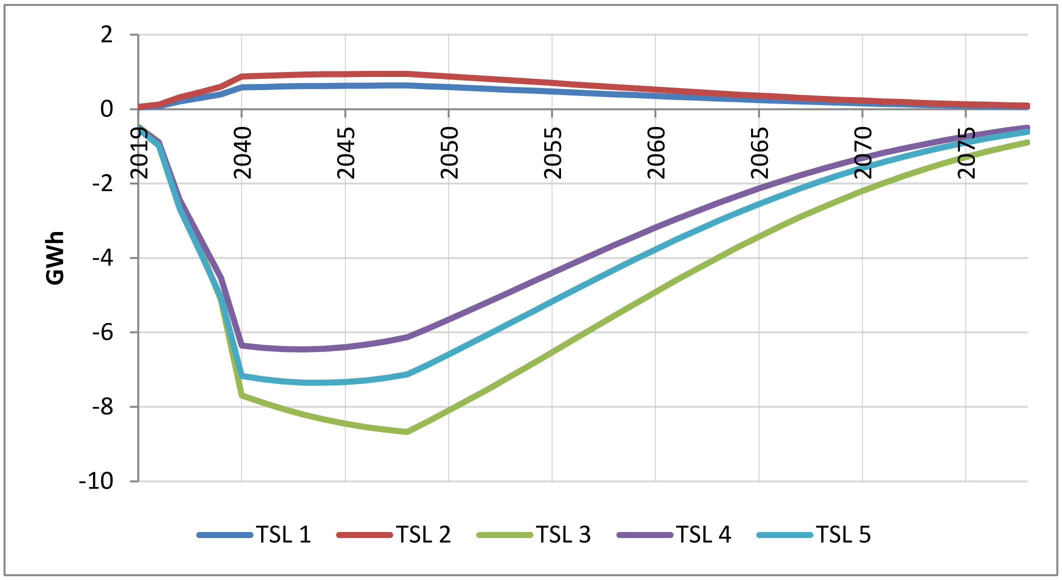

Figure 15.3.12 CPB Equipment: Renewables Generation Reduction

15.3.3 Results Summary

Table 15.3.1 presents a summary of the utility impact results for CPB equipment.

Table 15.3.1 CPB Equipment: Summary of Utility Impact Results

	TSL 1	**TSL 2**	**TSL 3**	**TSL 4**	**TSL 5**
Installed Capacity Reduction *MW*					
2020	0.07	0.10	(0.74)	(0.75)	(0.81)
2025	0.21	0.31	(2.49)	(2.40)	(2.63)
2030	0.38	0.57	(4.76)	(4.41)	(4.88)
2035	0.55	0.84	(7.10)	(6.27)	(7.00)
2040	0.71	1.07	(9.37)	(7.74)	(8.74)
Electricity Generation Reduction *GWh*					
2020	0.46	0.70	(5.22)	(5.30)	(5.76)
2025	1.50	2.27	(18.21)	(17.58)	(19.27)
2030	2.39	3.62	(29.98)	(27.83)	(30.77)
2035	3.10	4.69	(39.86)	(35.18)	(39.25)
2040	3.62	5.46	(47.63)	(39.34)	(44.39)

Note: Parenthesis indicates negative values.

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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), and
- 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 9:00 p.m. to 6:00 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 10B of this TSD). 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 10B of this TSD.

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%

End Use	Coal	Natural Gas	Nuclear	Oil	Renewables
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 commercial packaged boiler (CPB) equipment. Job increases or decreases reported in this chapter are separate from the direct CPB sector employment impacts reported in chapter 12 and reflect the employment impact of efficiency standards on all other sectors of the economy. DOE conducted this analysis as part of the notice of proposed rulemaking.

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 packaged boilers, 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 for 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 of this technical support document (TSD)).

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 rulemaking. Also, because 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 a more complete and automated analysis of the economic impacts of energy-efficiency investments in buildings.

In an input/output model, the level of employment in an economy is determined by the 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 products. The increased cost of products leads to higher employment in the product manufacturing sectors and lower employment in other economic sectors. Second, commercial firm and residential spending are redirected from utilities toward firms that supply production inputs. Third, utility sector investment funds are released for use in other sectors of the economy. When consumers use less energy, the electric, natural gas, and oil 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 CPB manufacturing sector estimated in chapter 12 of this TSD, which uses 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 CPB standards relative to a no-new-standards scenario. 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. Energy cost savings were further disaggregated into electricity, natural gas, and oil cost savings.

Conceptually, one can consider the impact of the rule in its first year on three aggregate sectors: the CPB 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 packaged boilers; 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, natural gas, and fuel oil. The reduction in electricity and fuel demand causes reductions in employment in the utilities sectors. Finally, based on the net impact of increased expenditures on commercial packaged boilers and reduced expenditures on energy, expenditures on other sectors of the economy are either positively or negatively affected, increasing or reducing jobs 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 amended standards for commercial packaged boilers in 2020 and 2025. As mentioned in chapter 12 of this TSD, 80 percent of commercial packaged boilers are produced domestically and 20 percent are imported.

Table 16.4.1 Net Short-Term Change in Employment (Number of Employees)

Trial Standard Level	2020	2025
1	22–49	45–70
2	34–76	71–111
3	78–194	142–256
4	183–454	336–605
5	193–480	351–638

16.5 LONG-TERM RESULTS

Over the long term, DOE expects the energy savings to consumers to increasingly dominate the increase in equipment costs, resulting in increased aggregate savings to consumers. As a result, DOE expects that the demand for energy by affected consumers of commercial packaged boilers to decline over time and consequently demand for other goods by those consumers 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

For “economically significant regulatory actions,” Executive Order 12866 requires Federal agencies to provide “an assessment, including the underlying analysis, of costs and benefits of potentially effective and reasonably feasible alternatives to the planned regulation, identified by the agencies or the public (including improving the current regulation and reasonably viable non-regulatory actions), and an explanation why the planned regulatory action is preferable to the identified potential alternatives.” 58 FR 51735, 51741 (October 4, 1993). Accordingly, in the notice of proposed rulemaking (NOPR) stage, the U.S. Department of Energy (DOE) analyzed feasible alternatives that could possibly provide incentives for the same energy efficiency levels as the proposed standards for the equipment that is the subject of the commercial packaged boilers (CPB) rulemaking. In addition, DOE analyzed five feasible policy alternatives to energy conservation standards for the equipment considered in this rulemaking. The policy alternatives are listed in Table 17.1.1. DOE evaluated each of the alternatives in terms of its ability to achieve significant energy savings at a reasonable cost, and compared the effectiveness of each alternative to the effectiveness of the proposed trial standard level (TSL).

The technical support document (TSD) is prepared in support of DOE’s NOPR and includes a complete quantitative analysis of each alternative, the methodology for which is briefly addressed below.

Table 17.1.1 Policy Alternatives to Standards

No New Regulatory Action
Consumer Rebates
Consumer Tax Credits
Voluntary Energy Efficiency Targets
Bulk Government Purchases

17.2 METHODOLOGY

DOE used the national impact analysis (NIA) spreadsheet model to calculate the national energy savings and the net present value (NPV) corresponding to each alternative to proposed energy conservation standards. The NIA model is discussed in chapter 10 of this TSD. To compare each alternative quantitatively to the proposed energy conservation standards, DOE quantified the effect of each alternative on the purchase and use of energy-efficient equipment, such as commercial packaged boilers. DOE then created an integrated model, built on the NIA model, in order to make the appropriate revisions to the inputs in the NIA models. Key inputs that DOE may revise are the market shares of equipment meeting the target efficiency levels, which correspond to the efficiency levels set for the mandatory standards at each TSL, and the cost of the equipment after the relevant rebate or credit is applied.

The following are the key measures of the impact of each alternative:

- *National Energy Savings (NES),* given in quadrillion (quads) British thermal units (Btu), describes the potential cumulative national primary energy to be saved over the lifetime of equipment purchased during the 30-year analysis period starting in the effective date of the policy.[a]

- *Net Present Value (NPV)* represents the value of net monetary savings from equipment purchased during the 30-year analysis period starting in the compliance date of the policy. DOE calculates NPV as the difference between the present values of installed equipment cost and operating expenditures in the no-new-standards case and the present values of those costs in each policy case. DOE then calculates operating expenses (including energy costs) for the life of equipment.

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 CPB 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 packaged boiler with an energy-efficient product. Although no national rebate program was identified for CPB equipment, DOE identified representative rebate amounts and the structure of available rebate programs across the country. This research identified four utility companies that operate in seven states: New Hampshire, Massachusetts, Missouri, Iowa, Washington, Oregon, and California. Review of these entities identified that they offer various rebates for commercial boiler products, typically based upon the efficiency level of the appliance.

During the research, different program structures were observed for various programs, with several of the commercial programs offering rebates for boilers with inputs less than 300,000 Btu/h. Such programs were not considered in this analysis as the current standard applies to boilers with inputs of 300,000 Btu/h and greater. Among these programs, Gas Networks[1] provides a structured rebate program that several of the member utilities base their

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[a] The British thermal unit (Btu) is the amount of energy needed to cool or heat 1 pound of liquid water by 1 degree Fahrenheit at a constant pressure of one atmosphere.

programs upon. Specifically, Columbia Gas of Massachusetts,[2] Berkshire Gas,[3] and Unitil Energy[4] offer a tiered rebate structure based upon the input of the boiler, as shown in Table 17.3.1.

Table 17.3.1 Gas Networks Rebate Structure of Gas-Fired Hot Water Commercial Packaged Boilers

Input Range *1,000 Btu/h*	**Efficiency (minimum)**	**Rebate** *$*
301 to 499	90%	$2,000
500 to 999	90%	$4,000
1,000 to 1,700	90%	$7,500
1,701 to 2,000	90%	$10,000

MidAmerican Energy[5] of Iowa considers commercial packaged boilers as a part of their "Non-Residential Equipment Custom Systems" program and hence does not publish specifics as to the program. However, Energy Trust[6,7] provides a simple rebate of $6/1,000 Btu/h for commercial packaged boilers in both Washington and Oregon. The Sempra Energy Companies (Southern California Gas Company[8] (SoCalGas) and San Diego Gas & Electric[9] (SDG&E)) offer a rebate structured around the input rating of the appliance, with rates ranging between $0.50/1,000 Btu/h and $4/1,000 Btu/h. It is worth noting that although these programs are related, SDG&E only offers a rebate for the large hot water boilers where SoCalGas provides rebates for several types of commercial packaged boilers. The SoCalGas CPB rebate program is outlined in Table 17.3.2.

Table 17.3.2 Southern California Gas CPB Rebate Program Structure

Type of Boiler	**Input Rating** *1,000 Btu/h*	**Required Efficiency***	**Rebate Amount** *$/1,000 Btu/h*
Medium/Large Steam	≥300	≥83% E_C (81% E_T)	$0.50
Medium/Large Hot Water (Tier I)	≥300	≥85% E_C (83% E_T)	$0.50
Medium/Large Hot Water (Tier II)	≥300	≥92% E_C (90% E_T)	$4.00

* E_C is combustion efficiency. E_T is thermal efficiency.

Laclede Gas[10] offers rebates for both hot water and steam commercial packaged boilers, as shown in Table 17.3.3. Additionally, several other types of rebate programs are offered by Laclede to improve efficiency. These alternative programs range from an annual tune-up of existing boilers to a complete retrofit of the combustion systems allowing the boiler to utilize modulating burners, vent dampers, outdoor temperature reset controls, and advanced load controls. Programs also exist for the replacement of steam traps.

Table 17.3.3 Laclede Gas CPB Rebate Program Structure

Type of Boiler	**Input Rating** *1,000 Btu/h*	**Required Efficiency***	**Rebate Amount** *$*
Gas-Fired Hot Water	≥300 to <1,000	83% E_T	Up to $1,500
Gas-Fired Hot Water	≥1,000	83% E_T	Up to $3,000
Gas-Fired Low Pressure Steam	≥300 to <1,000	83% E_T	Up to $1,500

Type of Boiler	Input Rating *1,000 Btu/h*	Required Efficiency*	Rebate Amount *$*
Gas-Fired Low Pressure Steam	≥1,000	83% E_T	Up to $3,000

* E_T is thermal efficiency.

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. DOE determined the rebate amounts used in the analysis based upon the representative units analyzed throughout the life-cycle cost (LCC); small boilers with an input of 800,000 Btu/h and large boilers with an input of 3,000,000 Btu/h. Based upon the data collected, DOE assumes that small equipment would have an average rebate of $4,000 and large equipment would have an average rebate of $10,000 as shown in Table 17.3.4.

Table 17.3.4 Flat Rebate Scenarios Modeled by DOE

Class of Boiler	Input Rate (1,000 Btu/h)	Rebate Efficiency	Rebate Amount ($)
Gas Small Hot Water	800	90%	$4,000
Gas Large Hot Water	3,000	90%	$10,000
Gas Small Steam	800	83%	$400
Gas Large Steam	3,000	83%	$1,500

To estimate the market shares of efficiency levels (see chapter 10 of this TSD) that would result from such a rebate, DOE assumed that if a national rebate program were available, it would induce a market shift similar to the affect the U.S. Environmental Protection Agency's (EPA) voluntary ENERGY STAR® program for Commercial Water Heaters[11] and other commercial equipment ENERGY STAR programs have achieved. DOE considers this a valid estimate as not all ENERGY STAR programs have associated Federal rebates or credits, but that many local and regional rebate programs reference the ENERGY STAR criteria. Furthermore, in this estimate, DOE assumes the resulting shift in market share would occur regardless of which TSL the standard references.

DOE examined available information on efficiency choices in equipment classes covered by ENERGY STAR. Available ENERGY STAR shipment information indicates that, on average, ENERGY STAR programs have a market penetration of 46.9 percent. [12] Examining these data identifies that currently, ENERGY STAR has 13 commercial equipment programs.[b] The commercial equipment programs reported in the most recent ENERGY STAR market penetration report have an average market penetration of 41.3 percent.[c] Therefore, DOE modeled the market penetration for rebates at 45 percent of total shipments in those equipment classes

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[b] Current ENERGY STAR programs for commercial equipment include commercial dishwashers, commercial fryers, commercial griddles, commercial hot food holding cabinets, commercial ice makers, commercial ovens, commercial refrigerators and freezers, commercial steam cookers, commercial clothes washers, vending machines, water coolers, light commercial HVAC, and commercial water heaters. However, as the commercial water heater program started in 2013, these data have not been reported by the EPA as of August 24, 2015.

[c] These data were obtained from the *ENERGY STAR Unit Shipment and Market Penetration Report Calendar Year 2013 Summary*.

meeting or exceeding the ENERGY STAR level. DOE considers this an acceptable estimate as the reported market penetration for residential boilers is 56 percent.

For determining the potential impact of rebate programs targeting TSL 2, 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 2 was 45 percent. To do this, DOE calculated the existing market shares of shipments above TSL 2, if any, and the remainder of 45 percent minus existing market shares was assigned to the TSL 2 efficiency level. Shipments below TSL 2 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 2 exceeded 45 percent, the distribution was left at the no-new-standards case distribution.

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 17.3.5 presents the NES and NPV values for the 45 percent rebate scenario and compares them against the NES and NPV values at TSL 2. NES and NPV are calculated for equipment purchased in the 2019–2048 analysis period and include energy savings, operation and maintenance costs, and savings extending for the life of equipment purchased in 2048.

Table 17.3.5 Customer Rebate NES and NPV Comparison to TSL 2

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 Rebate Credits	0.127	0.269	0.049
Proposed Standards at TSL 2	0.349	0.414	1.687

* 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 Customer Tax Credits

Consumer tax credits are considered a viable non-regulatory market transformation program, as shown by allowable deductions equal to an amount up to the cost of the energy-efficient commercial building property placed in service during the taxable year, as per 26 U.S. Code §179D, and 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.

As with consumer rebates, DOE assumed that consumer tax credits paid the same amount towards the purchase of equipment (small boilers would be eligible for a rebate of $4,000 and large boilers would have a rebate of $10,000), 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 (or 80 percent of 45 percent) and, therefore, a corresponding shift of 36 percent in market shares to or above TSL 2 with no change in total shipments. In cases (if any) where the existing cumulative no-new-standards case market share at or above TSL 2 exceeded 36 percent, the distribution was left at the no-new-standards case distribution. DOE estimated NPV and NES values under these assumptions; the results are presented in Table 17.3.6.

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 17.3.6 presents the NES and NPV values for the tax credit scenario and compares them against the NES and NPV values at TSL 2.

Table 17.3.6 Tax Credit NES and NPV Comparison to TSL 2

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 Tax Credits	0.037	0.104	0.205
Proposed Standards at TSL 2	0.349	0.414	1.687

* 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. DOE notes that several of the ENERGY STAR programs have been referenced in Federal tax credit programs. Similarly, local and regional utilities have adopted the ENERGY STAR criteria for independent rebate programs. While all of these are voluntary, there is a micro-economic benefit to the purchaser to participate. There is not a macro-economic benefit as the cost is only shifted to another payer. The voluntary program considered here has no financial incentive; hence, no quantitative comparison is available.

As there is no financial incentive to voluntary efficiency programs, broader economic and social considerations are in play 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 CPB 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 packaged boilers is relatively small, especially for Federally owned equipment; therefore, distributed across a broad set of customers, the savings most likely would not 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 that creates 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 2 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	0.127
Customer Tax Credits	0.037
Voluntary Energy Efficiency Targets	0
Early Replacement	0
Proposed Standards at TSL 2	0.349

* 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	0.049	0.269
Customer Tax Credits	0.104	0.205
Voluntary Energy Efficiency Targets	0	0
Early Replacement	0	0
Proposed Standards at TSL 2	0.414	1.687

* Net present value is the value in the present of a time series of costs and savings.

DOE is aware of the recently proposed ENERGY STAR program for commercial boilers and recognizes that the efficiency level proposed (94%) is higher than the current efficiency requirement for many rebate programs. As the ENERGY STAR program for commercial boilers has not been finalized as of the time of publication of this document, DOE considers the stated regulatory impact analysis (RIA) is appropriate for this analysis. However, DOE conducted a sensitivity analysis using data from the draft of the ENERGY STAR program in order to understand the magnitude of the impact this program change may have on the RIA.

In order to evaluate any effects the program may have on the RIA, DOE repeated the analysis with all necessary modifications to represent the ENERGY STAR program based upon the draft specification of the program.[13] In this model, DOE adopts the higher thermal efficiency of the ENERGY STAR program for hot water boilers, but maintains the existing proposed structure for policy alternatives for high-efficiency steam boilers. This model therefore overstates the energy savings benefit the draft ENERGY STAR program would provide. The results of the augmented analysis are presented in Table 17.4.3 and Table 17.4.4; these results do not achieve the same level of energy savings that could be realized with a change in the standard level.

Table 17.4.3 Cumulative NES of Non-Regulatory Alternatives Based on the Draft ENERGY STAR Program and Compared to the Proposed Standard

Policy Alternative	Cumulative Primary Energy Savings* *quads*
No New Regulatory Action	0
Customer Rebates	0.197
Customer Tax Credits	0.072
Voluntary Energy Efficiency Targets	0
Early Replacement	0
Proposed Standards at TSL 2	0.349

* Energy savings are in primary energy quads.

Table 17.4.4 Cumulative NPV of Non-Regulatory Alternatives Based on the Proposed ENERGY STAR Program and 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	0.172	0.625
Customer Tax Credits	0.162	0.378
Voluntary Energy Efficiency Targets	0	0
Early Replacement	0	0
Proposed Standards at TSL 2	0.414	1.687

* Net present value is the value in the present of a time series of costs and savings.

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