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

RESIDENTIAL FURNACES

February 10, 2015

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

The U.S. Department of Energy (DOE) is conducting a rulemaking to consider amending the energy conservation standards for for non-weatherized gas furnaces (NWGFs) and mobile home gas furnaces (MHGFs) under the Energy Policy and Conservation Act (EPCA).This technical support document (TSD) is a stand-alone report that provides the technical analyses and results supporting the information presented in the notice of proposed rulemaking (NOPR) for NWGFs and MHGFs. This NOPR TSD reports on the activities and analyses conducted in support of the NOPR.

1.2 SUMMARY OF NATIONAL BENEFITS[1]

DOE's analyses indicate that the proposed annual fuel utilization efficiency (AFUE) energy conservation standards for NWGFs and MHGFs would save a significant amount of energy. The lifetime energy savings for NWGFs and MHGFs purchased in the 30-year period that begins in the first full year of compliance with amended standards (2021–2050) amount to 2.78 quads[2] of full-fuel-cycle energy. This is a savings of 1.1 percent relative to the energy use of these products in the base case without amended standards.

The cumulative net present value (NPV) of total consumer costs and savings for the proposed NWGF and MHGF AFUE standards ranges from $3.1 billion to $16.1 billion at 7-percent and 3-percent discount rates, respectively. This NPV expresses the estimated total value of future operating-cost savings minus the estimated increased installed product costs for NWGFs and MHGFs purchased in 2021–2050.

In addition, the proposed NWGF and MHGF AFUE standards would have significant environmental benefits. The proposed standards would result in cumulative emission reductions of 137 million metric tons (Mt)[3] of carbon dioxide (CO_2), 3,424 thousand tons of methane (CH_4), and 816 thousand tons of nitrogen oxides (NO_X).[4] Projected emissions show an increase of 203 thousand tons of sulfur dioxide (SO_2), 2.61 thousand tons of nitrous oxide (N_2O), and 0.629 tons of mercury (Hg). The increase is due to projected switching from NWGFs to electric heat pumps and electric furnaces under the proposed standards. The cumulative reduction in CO_2 emissions through 2030 amounts to 4.2 Mt, which is a savings of 0.2 percent relative to the CO_2 emissions in the base case without amended standards.

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[1] Energy savings in this section refer to full-fuel-cycle savings (see chapter 10 for discussion).

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

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

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

The value of the CO_2 reductions is calculated using a range of values per metric ton of CO_2 (otherwise known as the Social Cost of Carbon, or SCC) developed by a recent Federal interagency process.[5] The derivation of the SCC values is discussed in chapter 14 of this TSD. Using discount rates appropriate for each set of SCC values, DOE estimates the present monetary value of the CO_2 emissions reduction is between \$0.7 billion and \$11.7 billion. Additionally, DOE estimates the present monetary value of the NO_X emissions reduction to be \$0.32 billion to \$0.88 billion at 7-percent and 3-percent discount rates, respectively.[6]

Table 1.2.1 summarizes the national economic benefits and costs expected to result from the proposed AFUE standards for NWGFs and MHGFs using trial standard level (TSL) 3.

Table 1.2.1 Summary of National Economic Benefits and Costs of Proposed AFUE Energy Conservation Standards for Non-Weatherized Gas Furnaces and Mobile Home Gas Furnaces (TSL 3)*

Category	Present Value Billion 2013$	Discount Rate %
Benefits		
Consumer Operating Cost Savings	8.9	7
	27.7	3
CO_2 Reduction Monetized Value (\$12.0/t case)**	0.7	5
CO_2 Reduction Monetized Value (\$40.5/t case)**	3.8	3
CO_2 Reduction Monetized Value (\$62.4/t case)**	6.1	2.5
CO_2 Reduction Monetized Value (\$119/t case)**	11.7	3
NO_X Reduction Monetized Value (at \$2,684/ton)**	0.3	7
	0.9	3
Total Benefits†	13.0	7
	32.4	3
Costs		
Consumer Incremental Installed Costs	5.8	7
	11.6	3
Total Net Benefits		
Including Emissions Reduction Monetized Value†	7.2	7
	20.8	3

* This table presents the costs and benefits associated with NWGFs and MHGFs shipped in 2021–2050. These results include benefits to consumers which accrue after 2050 from the products purchased in 2021–2050. The

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[5] *Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866,* Interagency Working Group on Social Cost of Carbon, United States Government (May 2013; revised November 2013) (Available at: www.whitehouse.gov/sites/default/files/omb/assets/inforeg/technical-update-social-cost-of-carbon-for-regulator-impact-analysis.pdf).

[6] DOE is investigating valuation of avoided Hg and SO_2 emissions.

results account for the incremental variable and fixed costs incurred by manufacturers due to the standard, some of which may be incurred in preparation for the rule.

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

† Total benefits for both the 3% and 7% cases are derived using the series corresponding to average SCC with a 3-percent discount rate ($40.5/t in 2015).

For the proposed standby mode and off mode standards, the lifetime energy savings for NWGFs and MHGFs purchased in the 30-year period that begins in the first full year of compliance with amended standards (2021–2050) amount to 0.28 quads of energy. This is a savings of 15.9 percent relative to the standby energy use of these products in the base case without amended standards.

The cumulative net present value (NPV) of total consumer costs and savings for the proposed NWGF and MHGF standby mode and off mode standards ranges from $1.0 billion to $3.3 billion at 7-percent and 3-percent discount rates, respectively. This NPV expresses the estimated total value of future operating-cost savings minus the estimated increased product costs for NWGFs and MHGFs purchased in 2021–2050.

In addition, the proposed standby mode and off mode standards would have significant environmental benefits. The energy savings would result in cumulative emission reductions of 15.6 Mt of CO_2, 75 thousand tons of CH_4, 0.22 thousand tons of N_2O, 13.0 thousand tons of SO_2, 24.3 thousand tons of NO_X, and 0.04 tons of Hg. The cumulative reduction in CO_2 emissions through 2030 amounts to 1.5 Mt.

As noted above, the value of the CO_2 reductions is calculated using a range of SCC values developed by a recent Federal interagency process. Using discount rates appropriate for each set of SCC values, DOE estimates the present monetary value of the CO_2 emissions reduction is between $0.09 billion and $1.37 billion. Additionally, DOE estimates the present monetary value of the NO_X emissions reduction to be $0.01 billion to $0.03 billion at 7-percent and 3-percent discount rates, respectively.

Table 1.2.2 summarizes the national economic benefits and costs expected to result from the proposed standby mode and off mode standards for NWGFs and MHGFs.

Table 1.2.2 Summary of National Economic Benefits and Costs of Proposed Standby Mode and Off Mode Energy Conservation Standards for Non-Weatherized Gas Furnaces and Mobile Home Gas Furnaces (TSL 3)*

Category	Present Value Billion 2013$	Discount Rate %
Benefits		
Consumer Operating Cost Savings	1.4	7
	3.9	3
CO_2 Reduction Monetized Value ($12.0/t case)**	0.1	5
CO_2 Reduction Monetized Value ($40.5/t case)**	0.4	3
CO_2 Reduction Monetized Value ($62.4/t case)**	0.7	2.5
CO_2 Reduction Monetized Value ($119/t case)**	1.4	3
NO_X Reduction Monetized Value (at $2,684/ton)**	0.01	7
	0.03	3
Total Benefits†	1.8	7
	4.4	3
Costs		
Consumer Incremental Installed Costs	0.33	7
	0.67	3
Total Net Benefits		
Including Emissions Reduction Monetized Value†	1.5	7
	3.7	3

* This table presents the costs and benefits associated with NWGFs and MHGFs shipped in 2021–2050. These results include benefits to consumers which accrue after 2050 from the products purchased in 2021-2050. The results account for the incremental variable and fixed costs incurred by manufacturers due to the standard, some of which may be incurred in preparation for the rule.

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

† Total benefits for both the 3% and 7% cases are derived using the series corresponding to average SCC with a 3-percent discount rate ($40.5/t in 2015).

The benefits and costs of the proposed energy conservation standards for NWGFs and MHGFs products sold in 2021–2050 can also be expressed in terms of annualized values. Benefits and costs for the AFUE standards are considered separately from benefits and costs for the standby mode and off mode electrical consumption standards because it was not feasible to develop a single, integrated standard. As discussed in the October 20, 2010 test procedure final rule, DOE concluded that, due to the magnitude of the active mode energy consumption as compared to the standby mode and off mode electrical consumption, an integrated metric would not be feasible because the standby and off mode electrical consumption would be a *de minimis* portion of the overall energy consumption. 75 FR 64621, 64627. Thus, an integrated metric could not be used to effectively regulate the standby mode and off mode energy consumption. The annualized monetary values are the sum of: (1) the annualized national economic value of the benefits from consumer operation of products that meet the proposed new or amended standards (consisting primarily of operating cost savings from using less energy, minus increases in product purchase and installation costs, which is another way of representing consumer NPV), and (2) the annualized monetary value of the benefits of emission reductions, including CO_2 emission reductions.[7]

Although combining the values of operating savings and CO_2 emission reductions provides a useful perspective, two issues should be considered. First, the national operating savings are domestic U.S. consumer monetary savings that occur as a result of market transactions, whereas the value of CO_2 reductions is based on a global value. Second, the assessments of operating cost savings and CO_2 savings are performed with different methods that use different time frames for analysis. The national operating cost savings is measured for the lifetime of NWGFs and MHGFs shipped in 2021–2050. The SCC values, on the other hand, reflect the present value of some future climate-related impacts resulting from the emission of one ton of carbon dioxide in each year. These impacts continue well beyond 2100.

Estimates of annualized benefits and costs of the proposed AFUE standards are shown in Table 1.2.3. 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 uses a 3-percent discount rate, *i.e.,* $40.5/t in 2015), the cost of the NWGFs and MHGFs standards proposed in this rule is $701 million per year in increased equipment costs, while the estimated benefits are $1,074 million per year in reduced equipment operating costs, $231 million per year in CO_2 reductions, and $39 million per year in reduced NO_X emissions. In this case, the net benefit would amount to $642 million per year. Using a 3-percent discount rate for all benefits and costs and the average SCC series that uses a 3-percent discount rate ($40.5/t in 2015), the estimated cost of the NWGFs and MHGFs standards proposed in this rule is $709 million per year in increased equipment costs, while the estimated benefits are $1,690 million per year in reduced equipment operating costs, $231 million per year in CO_2 reductions, and $54 million per year in reduced NOx emissions. In this case, the net benefit would amount to $1,264 million per year.

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[7] To convert the time-series of costs and benefits into annualized values, DOE calculated a present value in 2014, the year used for discounting the NPV of total consumer costs and savings. For the benefits, DOE calculated a present value associated with each year's shipments in the year in which the shipments occur (*e.g.,* 2020 or 2030), and then discounted the present value from each year to 2014. The calculation uses discount rates of 3 and 7 percent for all costs and benefits except for the value of CO_2 reductions, for which DOE used case-specific discount rates, as shown in Table 1.2.3. Using the present value, DOE then calculated the fixed annual payment over a 30-year period, starting in the compliance year, that yields the same present value.

Table 1.2.3 Annualized Benefits and Costs of Proposed AFUE Energy Conservation Standards for Non-Weatherized Gas Furnaces and Mobile Home Gas Furnaces (TSL 3)

	Discount Rate %	Primary Estimate*	Low Net Benefits Estimate*	High Net Benefits Estimate*
		million 2013$/year		
Benefits				
Consumer Operating Cost Savings	7	1,074	903	1,174
	3	1,690	1,383	1,887
CO_2 Reduction Monetized Value ($12.0/t case)**	5	64	59	72
CO_2 Reduction Monetized Value ($40.5/t case)**	3	231	211	260
CO_2 Reduction Monetized Value ($62.4/t case)**	2.5	340	311	384
CO_2 Reduction Monetized Value ($119/t case)**	3	715	654	805
NO_X Reduction Monetized Value (at $2,684/ton)**	7	38.50	35.68	42.48
	3	53.52	49.26	59.53
Total Benefits†	7 plus CO_2 range	1,177 to 1,828	998 to 1,593	1,288 to 2,022
	7	1,343	1,150	1,476
	3 plus CO_2 range	1,807 to 2,458	1,491 to 2,087	2,018 to 2,751
	3	1,974	1,643	2,206
Costs				
Consumer Incremental Installed Costs	7	701	750	683
	3	709	766	689
Net Benefits				
Total†	7 plus CO_2 range	476 to 1,127	248 to 843	605 to 1,339
	7	642	400	793
	3 plus CO_2 range	1,098 to 1,749	725 to 1,320	1,329 to 2,062
	3	1,264	877	1,517

* This table presents the annualized costs and benefits associated with NWGFs and MHGFs shipped in 2021–2050. These results include benefits to consumers which accrue after 2050 from the products purchased in 2021–2050. The results account for the incremental variable and fixed costs incurred by manufacturers due to the standard, some of which may be incurred in preparation for the rule. The primary, low benefits, and high benefits estimates utilize projections of energy prices from the *AEO 2014* reference case, low estimate, and high estimate, respectively. In addition, incremental product costs reflect a modest decline rate for projected product price trends in the primary estimate, a constant rate in the low benefits estimate, and a higher decline rate in the high benefits estimate. The methods used to derive projected price trends are explained in chapter 8.

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

† Total benefits for both the 3% and 7% cases are derived using the series corresponding to the average SCC with a 3-percent discount rate ($40.5/t in 2015). 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.

Estimates of annualized benefits and costs of the proposed standby mode and off mode standards are shown in Table 1.2.4. 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 uses a 3-percent discount rate ($40.5/t in 2015), the estimated cost of the NWGFs and MHGFs standby mode and off mode standards proposed in this rule is $40.4 million per year in increased equipment costs, while the estimated benefits are $165.4 million per year in reduced equipment operating costs, $26.9 million per year in CO_2 reductions, and $1.1 million per year in reduced NO_X emissions. In this case, the net benefit would amount to $153.0 million per year. Using a 3-percent discount rate for all benefits and costs and the average SCC series that uses a 3-percent discount rate ($40.5/t in 2015), the estimated cost of the NWGFs and MHGFs standby mode and off mode standards proposed in this rule is $41.0 million per year in increased equipment costs, while the estimated benefits are $240.2 million per year in reduced equipment operating costs, $26.9 million per year in CO_2 reductions, and $1.6 million per year in reduced NO_X emissions. In this case, the net benefit would amount to $227.6 million per year.

Table 1.2.4 Annualized Benefits and Costs of Proposed Standby Mode and Off Mode Energy Conservation Standards for Non-Weatherized Gas Furnaces and Mobile Home Gas Furnaces (TSL 3)

	Discount Rate **%**	**Primary Estimate***	**Low Net Benefits Estimate***	**High Net Benefits Estimate***
		million 2013$/year		
Benefits				
Consumer Operating Cost Savings	7	165.4	149.7	190.8
	3	240.2	214.9	281.5
CO_2 Reduction Monetized Value ($12.0/t case)**	5	7.65	6.94	8.60
CO_2 Reduction Monetized Value ($40.5/t case)**	3	26.87	24.31	30.28
CO_2 Reduction Monetized Value ($62.4/t case)**	2.5	39.46	35.68	44.50
CO_2 Reduction Monetized Value ($119/t case)**	3	83.18	75.26	93.76
NOx Reduction Monetized Value (at $2,684/ton)**	7	1.14	1.04	1.27
	3	1.59	1.44	1.78
Total Benefits†	7 plus CO_2 range	174 to 250	158 to 226	201 to 286
	7	193.4	175.0	222.4
	3 plus CO_2 range	249 to 325	223 to 292	292 to 377
	3	268.6	240.7	313.5
Costs				
Consumer Incremental Installed Costs	7	40.35	45.01	36.86
	3	41.02	46.13	37.19
Net Benefits				
Total†	7 plus CO_2 range	134 to 209	113 to 181	164 to 249
	7	153.0	130.0	185.5
	3 plus CO_2 range	208 to 284	177 to 246	255 to 340
	3	227.6	194.6	276.3

* This table presents the annualized costs and benefits associated with NWGFs and MHGFs shipped in 2021–2050. These results include benefits to consumers which accrue after 2050 from the products purchased in 2021–2050. The results account for the incremental variable and fixed costs incurred by manufacturers due to the standard, some of which may be incurred in preparation for the rule. The primary, low benefits, and high benefits estimates utilize projections of energy prices from the *AEO 2014* reference case, low estimate, and high estimate, respectively.

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

† Total benefits for both the 3% and 7% cases are derived using the series corresponding to the average SCC with a 3-percent discount rate ($40.5/t in 2015). 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.

Estimates of the combined annualized benefits and costs of the proposed AFUE and standby mode and off mode standards are shown in Table 1.2.5. 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 uses a 3-percent discount rate ($40.5/t in 2015), the estimated cost of the NWGFs and MHGFs AFUE and standby mode and off mode standards proposed in this rule is $741.2 million per year in increased equipment costs, while the estimated benefits are $1,240 million per year in reduced equipment operating costs, $257.4 million per year in CO_2 reductions, and $39.6 million per year in reduced NO_X emissions. In this case, the net benefit would amount to $795.5 million per year. Using a 3-percent discount rate for all benefits and costs and the average SCC series that uses a 3-percent discount rate ($40.5/t in 2015), the estimated cost of the NWGFs and MHGFs AFUE and standby mode and off mode standards proposed in this rule is $750.5 million per year in increased equipment costs, while the estimated benefits are $1,930 million per year in reduced equipment operating costs, $257.4 million per year in CO_2 reductions, and $55.1 million per year in reduced NO_X emissions. In this case, the net benefit would amount to $1,492 million per year.

Table 1.2.5 Annualized Benefits and Costs of Proposed AFUE and Standby Mode and Off Mode Energy Conservation Standards for Non-Weatherized Gas Furnaces and Mobile Home Gas Furnaces (TSL 3)

	Discount Rate %	Primary Estimate*	Low Net Benefits Estimate*	High Net Benefits Estimate*
		million 2013$/year		
Benefits				
Consumer Operating Cost Savings	7	1,240	1,053	1,365
	3	1,930	1,598	2,168
CO_2 Reduction Monetized Value ($12.0/t case)**	5	71.49	65.60	80.15
CO_2 Reduction Monetized Value ($40.5/t case)**	3	257.4	235.2	290.0
CO_2 Reduction Monetized Value ($62.4/t case)**	2.5	379.6	346.6	428.0
CO_2 Reduction Monetized Value ($119/t case)**	3	798.1	729.2	898.9
NOx Reduction Monetized Value (at $2,684/ton)**	7	39.64	36.72	43.75
	3	55.11	50.70	61.31
Total Benefits†	7 plus CO_2 range	1,351 to 2,077	1,155 to 1,819	1,489 to 2,308
	7	1,537	1,325	1,699
	3 plus CO_2 range	2,057 to 2,783	1,715 to 2,378	2,310 to 3,128
	3	2,243	1,884	2,519
Costs				
Consumer Incremental Installed Costs	7	741.2	795.0	719.9
	3	750.5	812.4	726.3
Net Benefits				
Total†	7 plus CO_2 range	609.6 to 1,336	360.3 to 1,024	768.9 to 1,588
	7	795.5	529.8	978.7
	3 plus CO_2 range	1,306 to 2,033	0,902 to 1,566	1,583 to 2,402
	3	1,492	1,072	1,793

* This table presents the annualized costs and benefits associated with NWGFs and MHGFs shipped in 2021-2050. These results include benefits to consumers which accrue after 2050 from the products purchased in 2021-2050. The results account for the incremental variable and fixed costs incurred by manufacturers due to the standard, some of which may be incurred in preparation for the rule. The primary, low benefits, and high benefits estimates utilize projections of energy prices from the *AEO 2014* reference case, low estimate, and high estimate, respectively.

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

† Total benefits for both the 3% and 7% cases are derived using the series corresponding to the average SCC with a 3-percent discount rate ($40.5/t in 2015). In the rows labeled "7% plus CO_2 range" and "3% plus CO_2 range," the operating cost and NOx benefits are calculated using the labeled discount rate, and those values are added to the full range of CO_2 values.

1.3 OVERVIEW OF ENERGY CONSERVATION STANDARDS FOR RESIDENTIAL FURNACES

The National Appliance Energy Conservation Act of 1987 (NAECA; Pub. L. 100-12) established EPCA's original energy conservation standards for furnaces, consisting of minimum AFUE levels for mobile home furnaces and for all other furnaces except "small" gas furnaces. (42 U.S.C. 6295(f)(1)-(2)) Pursuant to 42 U.S.C. 6295(f)(1)(B), in November 1989, DOE adopted a mandatory minimum AFUE level for small furnaces. 54 FR 47916 (Nov. 17, 1989). The standards established by NAECA and the November 1989 final rule for small gas furnaces are still in effect for all residential product classes except for non-weatherized oil-fired furnaces, for which the current standards were adopted in a direct final rule published in the *Federal Register* on June 27, 2011 (June 2011 direct final rule). 76 FR 37408. The energy conservation standards for residential furnaces can be found in the Code of Federal Regulations (CFR) at 10 CFR 430.32(e)(1).

Pursuant to EPCA, DOE was required to conduct two rounds of rulemaking to consider amended energy conservation standards for furnaces. (42 U.S.C. 6295(f)(4)(B) and (C)) In satisfaction of this first round of amended standards rulemaking under 42 U.S.C. 6295(f)(4)(B), DOE published a final rule in the *Federal Register* on November 19, 2007 (the November 2007 rule) that revised these standards for most furnaces, but left them in place for two product classes (*i.e.*, mobile home oil-fired furnaces and weatherized oil-fired furnaces; the standards were to apply to furnaces manufactured or imported on and after November 19, 2015). 72 FR 65136.

Following DOE's adoption of the November 2007 final rule, several parties jointly sued DOE in the U. S. Court of Appeals for the Second Circuit (Second Circuit) to invalidate the rule. Petition for Review, *State of New York, et al.* v. *Department of Energy, et al.*, Nos. 08– 0311–ag(L); 08–0312–ag(con) (2d Cir. filed Jan. 17, 2008). The petitioners asserted that the standards for residential furnaces promulgated in the November 2007 rule did not reflect the ''maximum improvement in energy efficiency'' that ''is technologically feasible and economically justified,'' as required under 42 U.S.C. 6295(o)(2)(A). On April 16, 2009, DOE filed with the Court a motion for voluntary remand that the petitioners did not oppose. The motion did not state that the November 2007 rule would be vacated, but indicated that DOE would revisit its initial conclusions outlined in the November 2007 rule in a subsequent rulemaking action. DOE also agreed that the final rule would address both regional standards for furnaces, as well as the effects of alternate standards on natural gas prices. The Second Circuit granted DOE's motion on April 21, 2009.

On June 27, 2011, DOE published the June 2011 direct final rule revising the energy conservation standards for residential furnaces pursuant to the voluntary remand in *State of New York, et al.* v. *Department of Energy, et al.* 76 FR 37408. In the June 2011 direct final rule, DOE considered the amendment of the same six product classes considered in the November 2007 final rule analysis plus electric furnaces. DOE confirmed the standards and compliance dates promulgated in the June 2011 final rule in a notice of effective date and compliance dates published on October 31, 2011. 76 FR 67037. Following DOE's adoption of the June 2011 direct final rule, the American Public Gas Association (APGA) filed a petition for review with the U.S. Court of Appeals for the District of Columbia Circuit to invalidate the DOE rule as it pertained to non-weatherized natural gas furnaces. Petition for Review, *American Public Gas Association, et al.* v. *Department of Energy, et al.*, No. 11-1485 (DC Cir. filed Dec. 23, 2011). On April 24, 2014, the Court granted a motion that approved a settlement agreement that was reached between DOE, APGA, and the various intervenors in the case. In that motion, DOE agreed to a remand of the non-weatherized gas furnace and mobile home gas furnace portions of the June 2011 direct final rule in order to conduct further notice and comment rulemaking. Accordingly, the Court's order vacated the June 2011 direct final rule in part (*i.e.*, those portions relating to non-weatherized gas furnaces and mobile home gas furnaces) and remanded to the agency for further rulemaking.

EPCA, as amended by the Energy Independence and Security Act of 2007 (EISA 2007), also requires that not later than 6 years after issuance of any final rule establishing or amending a standard, DOE must publish either a notice of the determination that standards for the product do not need to be amended, or a notice of proposed rulemaking including proposed energy conservation standards. (42 U.S.C. 6295(m)(1)) This rulemaking will satisfy this statutory provision in addition to the conditions of the settlement agreement.

Furthermore, EISA 2007 amended EPCA to require that any new or amended energy conservation standard adopted after July 1, 2010, shall address standby mode and off mode energy consumption pursuant to 42 U.S.C. 6295(o). (42 U.S.C. 6295(gg)(3)) Consequently, DOE will consider standby mode and off mode energy use as part of this rulemaking for residential furnaces.

1.4 PROCESS FOR SETTING ENERGY CONSERVATION STANDARDS

Under EPCA, when DOE studies 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 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. 6295(o)(2)(B)(i))

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

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

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

The energy conservation standards rulemaking process usually involves three formal public notices (which are published in the *Federal Register*) after the publication of a framework document to initiate the rulemaking. The first of the rulemaking notices is typically a notice of public meeting (NOPM) and availability of a preliminary TSD, which is designed to publicly vet the models and tools used in the preliminary analysis and to facilitate public participation before the NOPR stage. The second notice is usually the NOPR, which presents a discussion of comments received in response to the NOPM and the preliminary analyses and analytical tools; analyses of the impacts of potential amended energy conservation standards on consumers, manufacturers, and the Nation; DOE's weighting of these impacts of amended energy conservation standards; and the proposed energy conservation standards for each product. The third notice is usually 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 compliance dates of the amended energy conservation standards. Table 1.4.1 shows the analyses that occur during each phase of the typical rulemaking process. However, under 42 U.S.C. 6295(p), DOE is only required to publish a notice of proposed rule and accept public comments before amending energy conservation standards in a final rule (*i.e.*, DOE is not required to conduct the earlier rulemaking stages). Due to the extensive and recent rulemaking history for residential furnaces, as well as the associated opportunities for notice and comment described above, DOE is foregoing the typical earlier rulemaking stages (*e.g.*, framework document, preliminary analysis) and has instead developed this NOPR as the first step in the current rulemaking.

Table 1.4.1 Typical Analyses During Each Rulemaking Stage

Preliminary Analyses*	NOPR	Final Rule**
Market and technology assessment	Revised preliminary analyses	Revised NOPR analyses
Screening analysis	Life-cycle cost subgroup analysis	
Engineering analysis	Manufacturer impact analysis	
Energy use characterization	Emissions impact analysis	
Markups to determine equipment price	Monetization of emissions reductions benefits	
Life-cycle cost and payback period analyses	Utility impact analysis	
Shipments analysis	Employment impact analysis	
National impact analysis	Regulatory impact analysis	
Preliminary manufacturer impact analysis		

* For residential furnaces, DOE did not conduct a preliminary analysis due to the recent rulemaking history and shortened rulemaking schedule required by the settlement agreement.

** During the final rule phase, DOE considers the comments submitted by the U.S. Department of Justice in the NOPR phase concerning the impact of any lessening of competition that is likely to result from the imposition of the standard. (42 U.S.C. 6295(o)(2)(B)(v))

As part of the settlement agreement, DOE agreed to issue a notice of proposed rulemaking within one year of the remand, and to issue a final rule within the later of two years of the issuance of remand or one year of the issuance of the proposed rule, including at least a 90-day public comment period. As noted above, due to the extensive and recent rulemaking history for residential furnaces and consistent with EPCA's requirements for conducting rulemakings, DOE has developed this NOPR as the first stage in the rulemaking process.

1.5 STRUCTURE OF THE DOCUMENT

This TSD describes the analytical approaches and data sources used in this rulemaking. The TSD consists of the following chapters and appendices.

Chapter 1	Introduction: provides an overview of the appliance and equipment standards program and how it applies to the residential furnaces rulemaking, and outlines the structure of the document.
Chapter 2	Analytical Framework: describes the rulemaking process step by step and summarizes the major components of DOE's analysis.
Chapter 3	Market and Technology Assessment: characterizes the residential furnaces equipment market and the technologies available for increasing equipment efficiency.
Chapter 4	Screening Analysis: determines which technology options are viable for consideration in the engineering analysis.
Chapter 5	Engineering Analysis: discusses the methods used for developing the relationship between increased manufacturer price and increased efficiency.
Chapter 6	Markups Analysis: discusses the methods used for establishing markups for converting manufacturer prices to customer product costs.
Chapter 7	Energy Use Analysis: discusses the process used for generating energy-use estimates for the considered products as a function of standard levels.
Chapter 8	Life-Cycle Cost and Payback Period Analysis: discusses the methods used to analyze effects of standards on individual customers and users of the products and compares the LCC and PBP of products with and without higher energy conservation standards.
Chapter 9	Shipments Analysis: estimates shipments of the products over the 30-year analysis period that is used in performing the national impact analysis, including how shipments may vary under alternative standard levels.
Chapter 10	National Impact Analyses: assesses the national energy savings, and the national net present value of total consumer costs and savings, expected to result from potential energy conservation standards.
Chapter 11	Consumer Subgroup Analysis: discusses the effects of standards on subgroups of NWGF and MHGF consumers.
Chapter 12	Manufacturer Impact Analysis: discusses the effects of amended standards on the finances and profitability of manufacturers.

Chapter 13	Emissions Impact Analysis: discusses the effects of standards on air-borne emissions, including the impact of emissions of six pollutants or greenhouse gases: sulfur dioxide (SO_2), nitrogen oxides (NOx), carbon dioxide (CO_2), mercury (Hg), methane (CH_4), and nitrous oxide (N_2O).
Chapter 14	Monetization of Emission Reductions Benefits: discusses the monetization of reductions in CO_2 and NOx emissions.
Chapter 15	Utility Impact Analysis: discusses selected effects of standards on electric utilities.
Chapter 16	Employment Impact Analysis: discusses the effects of standards on national employment.
Chapter 17	Regulatory Impact Analysis: discusses the potential impacts of non-regulatory alternatives to setting energy efficiency standards.
Appendix 6A	Detailed Data for Product Price Markups
Appendix 7A	Building Variables
Appendix 7B	Determination of Residential Furnace Energy Use in the LCC Analysis
Appendix 7C	Mapping of Weather Station Data to Residential Energy Consumption Survey and Commercial Building Energy Consumption Survey Buildings
Appendix 7D	Reduced Set of Residential Furnace Models and Characteristics
Appendix 8A	User Instructions for Life-Cycle Cost Analysis Spreadsheet for Residential Furnaces
Appendix 8B	Uncertainty and Variability in the LCC Analysis
Appendix 8C	Forecast of Product Price Trends for Residential Furnaces
Appendix 8D	Installation Cost Determination for Residential Furnaces
Appendix 8E	Energy Price Calculations for Residential Furnaces
Appendix 8F	Maintenance and Repair Cost Determination for Residential Furnaces
Appendix 8G	Residential Furnace Lifetime Determination
Appendix 8H	Distributions Used for Discount Rates

Appendix 8I	Base Case Distribution of Efficiency Levels
Appendix 8J	Product Switching Methodology
Appendix 8K	Life-Cycle Cost Analysis Using Alternative Economic Growth Scenarios for Residential Furnaces
Appendix 8L	Installation Scenario Considering Use of Alternative Venting Technology
Appendix 9A	Additional Residential Furnace Shipments Data
Appendix 10A	User Instructions National Impact Analysis Spreadsheet Model
Appendix 10B	Full-Fuel-Cycle Multipliers
Appendix 10C	National Net Present Value of Consumer Benefits Using Alternative Product Price Forecast
Appendix 10D	National Impact Analysis Using Alternative Economic Growth Scenarios for Residential Furnaces
Appendix 10E	National Impact Analysis Using Alternative Product Switching Scenarios for Residential Furnaces
Appendix 12A	Government Regulatory Impact Model Overview
Appendix 12B	Manufacturer Impact Analysis Interview Guide
Appendix 14A	Social Cost of Carbon for Regulatory Impact Analysis under Executive Order 12866
Appendix 14B	Technical Update of Social Cost of Carbon for Regulatory Impact Analysis under Executive Order 12866
Appendix 17A	Regulatory Impact Analysis: Supporting Materials

CHAPTER 2. ANALYTICAL FRAMEWORK

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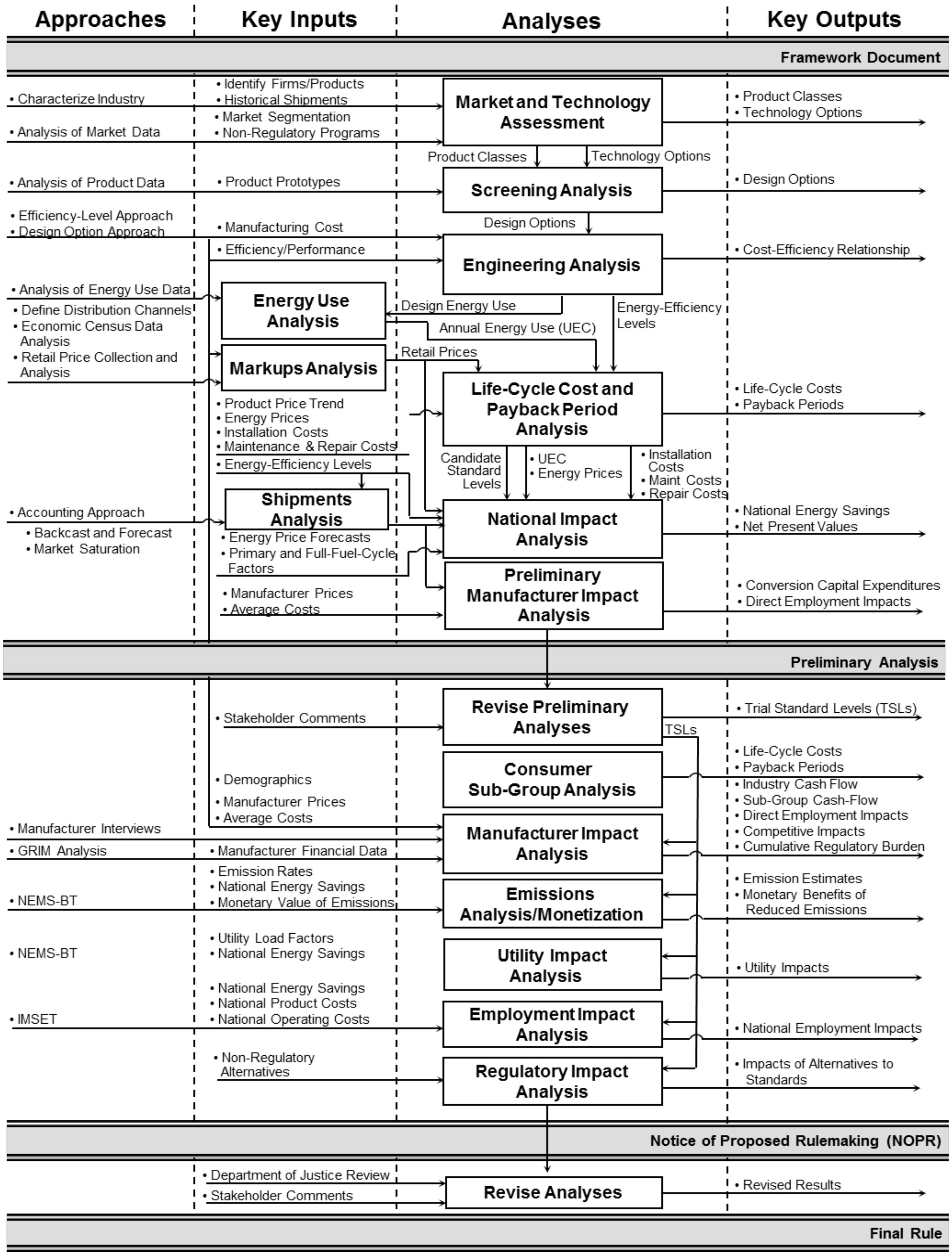
CHAPTER 2. ANALYTICAL FRAMEWORK

2.1 INTRODUCTION

Section 6295(o)(2)(A) of the Energy Policy and Conservation Act (EPCA), as amended, 42 USC 6291 *et. seq.,* requires that when prescribing new or amended energy conservation standards for covered products, the U.S. Department of Energy (DOE) promulgate standards that achieve the maximum improvements in energy efficiency that are technologically feasible and economically justified. This chapter provides a description of the analytical framework that DOE is using to evaluate amended energy conservation standards for non-weatherized gas furnaces (NWGFs) and mobile home gas furnaces (MHGFs). This chapter sets forth the methodology, 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 center column, identified as "Analyses." The columns labeled "Key Inputs" and "Key Outputs" show how the analyses fit into the rulemaking process, and how the analyses relate to each other. Key inputs are the types of data and information that the analyses require. Some key inputs exist in public databases; DOE collects other inputs from 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.


Approaches
Key Inputs
Analyses
Key Outputs
Framework Document
• Characterize Industry
• Analysis of Market Data
• Identify Firms/Products
• Historical Shipments
• Market Segmentation
• Non-Regulatory Programs
Market and Technology Assessment
• Product Classes
• Technology Options
Product Classes
Technology Options
• Analysis of Product Data
• Product Prototypes
Screening Analysis
• Design Options
Design Options
• Efficiency-Level Approach
• Design Option Approach
• Manufacturing Cost
• Efficiency/Performance
Engineering Analysis
• Cost-Efficiency Relationship
• Analysis of Energy Use Data
Energy Use Analysis
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Energy-Efficiency Levels
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Markups Analysis
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Life-Cycle Cost and Payback Period Analysis
• Life-Cycle Costs
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• Energy-Efficiency Levels
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• UEC
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• Installation Costs
• Maint Costs
• Repair Costs
• Accounting Approach
• Backcast and Forecast
• Market Saturation
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National Impact Analysis
• National Energy Savings
• Net Present Values
• Energy Price Forecasts
• Primary and Full-Fuel-Cycle Factors
• Manufacturer Prices
• Average Costs
Preliminary Manufacturer Impact Analysis
• Conversion Capital Expenditures
• Direct Employment Impacts
Preliminary Analysis
• Stakeholder Comments
Revise Preliminary Analyses
• Trial Standard Levels (TSLs)
TSLs
• Demographics
Consumer Sub-Group Analysis
• Life-Cycle Costs
• Payback Periods
• Industry Cash Flow
• Sub-Group Cash-Flow
• Direct Employment Impacts
• Competitive Impacts
• Cumulative Regulatory Burden
• Manufacturer Prices
• Average Costs
• Manufacturer Interviews
• GRIM Analysis
• Manufacturer Financial Data
Manufacturer Impact Analysis
• Emission Rates
• National Energy Savings
• Monetary Value of Emissions
• NEMS-BT
Emissions Analysis/Monetization
• Emission Estimates
• Monetary Benefits of Reduced Emissions
• NEMS-BT
• Utility Load Factors
• National Energy Savings
Utility Impact Analysis
• Utility Impacts
• National Energy Savings
• National Product Costs
• National Operating Costs
• IMSET
Employment Impact Analysis
• National Employment Impacts
• Non-Regulatory Alternatives
Regulatory Impact Analysis
• Impacts of Alternatives to Standards
Notice of Proposed Rulemaking (NOPR)
• Department of Justice Review
• Stakeholder Comments
Revise Analyses
• Revised Results
Final Rule

Figure 2.1.1 Flow Diagram of Analyses for the Rulemaking Process

In this technical support document (TSD), DOE presents results of the following analyses that were performed for this NOPR:

- A market and technology assessment to characterize the relevant products, their markets and technology options for improving their energy efficiency, including prototype designs.
- A screening analysis to review each technology option and determine if it is technologically feasible; is practicable to manufacture, install, and service; would adversely affect product utility or product availability; or would have adverse impacts on health and safety.
- An engineering analysis to develop relationships that show the manufacturer's cost of achieving increased efficiency.
- A markups analysis to develop distribution channel markups that relate the manufacturer production cost (MPC) to the cost to the consumer.
- An energy use analysis to determine the annual energy use of the considered products in a representative set of users.
- Life-cycle cost (LCC) and payback period (PBP) analyses to calculate the savings in operating costs at the consumer level throughout the life of the covered products compared with any increase in the installed cost for the products likely to result directly from imposition of a standard.
- A shipments analysis to forecast product shipments and to assess the impact of potential standards on shipments.
- A national impact analysis (NIA) to assess the aggregate impacts at the national level of potential energy conservation standards for the considered products, as measured by the NPV of total consumer economic impacts and the national energy savings (NES).
- A consumer LCC subgroup analysis to evaluate variations in consumer characteristics that might cause a standard to disproportionately affect particular consumer subpopulations.
- A manufacturer impact analysis (MIA) to estimate the financial impact of standards on manufacturers and calculated impacts on competition, employment, and manufacturing capacity.
- A utility impact analysis to estimate key effects of potential standards on electric utilities.
- An employment impact analysis to assess the aggregate impacts on national employment.
- An emissions analysis to assess the impacts of amended energy conservation standards on CO_2 and other air emissions.

- An emissions monetization to assess the benefits associated with emissions reductions.
- A regulatory impact analysis to examine major alternatives to amended energy conservation standards that potentially could achieve substantially the same regulatory goal at a lower cost.

2.2 BACKGROUND

On June 27, 2011, DOE published in the *Federal Register* a direct final rule (DFR) revising the energy conservation standard for residential furnaces. The standards set forth in the DFR were confirmed in a notice of effective date and compliance dates published in the *Federal Register* on October 31, 2011. 76 FR 67037. Following DOE's adoption of these amended furnace standards, the American Public Gas Association (APGA) sued DOE in the U. S. Court of Appeals for the District of Columbia Circuit (D.C. Circuit) to invalidate the rule as it pertained to non-weatherized natural gas furnaces. On March 11, 2014, DOE and APGA, as well as the various interveners in the case, filed a joint motion for approval of a settlement with the court, in which DOE agreed to seek a remand of the non-weatherized gas furnace portions of the June 2011 DFR, and to conduct notice and comment rulemaking proceedings. The settlement agreement was approved by the D.C. Circuit in an order filed April 24, 2014, through which the court vacated the rule in part (*i.e.,* the provisions related to non-weatherized gas furnaces (NWGF) and mobile home gas furnaces (MHGF)) and remanded for further rulemaking. DOE has undertaken this rulemaking pursuant to terms of the March 2014 settlement agreement. Accordingly, DOE has agreed to issue a notice of proposed rulemaking within one year of issuance of the remand, including at least a 90-day public comment period, and to issue a final rule within the later of two years of the issuance of the remand or one year of the issuance of the proposed rule.

The following sections provide a brief overview of the different analytical approaches used for analyzing amended standards for NWGF and MHGF. DOE used the most reliable data available at the time of each analysis in this rulemaking.

2.3 REGIONS FOR ANALYSIS

The Energy Independence and Security Act of 2007 (EISA 2007) amended EPCA to allow for the establishment of a single, more restrictive regional standard in addition to the base national standard for furnaces. (42 U.S.C. 6295(o)(6)(B)) Further, EPCA mandates that a regional standard must produce significant energy savings compared to the national standard, and provides that DOE must determine that the additional standards are economically justified and consider the impact of the additional regional standards on consumers, manufacturers, and other market participants, including product distributors, dealers, contractors, and installers. Accordingly, DOE has addressed the potential impacts from regional standards in the relevant NOPR analyses, including the mark-ups to determine product price, the LCC and payback period analyses, the national impact analysis (NIA), and the manufacturer impact analysis (MIA).

The allocation of individual states to the regions was done using the same evaluation methodology DOE used in exploring regional standards in the June 2011 direct final rule, which was based on whether a state's annual heating degree days (HDD)[a] average is above or below 5,000. 76 FR 37422, 37427-37429 (Jun. 27, 2011). This level offers a rough threshold point at which space heating demands are significant enough to require longer operation of heating systems, which provides a basis for utilization of higher efficiency systems. Table 2.3.1 and Figure 2.3.1 show the regions analyzed for this rulemaking.

Table 2.3.1 Regions for NOPR Analysis of Furnace Standards

Northern Region		**National Standard**
Alaska	Pennsylvania	Alabama
Colorado	Rhode Island	Arizona
Connecticut	South Dakota	Arkansas
Idaho	Utah	California
Illinois	Vermont	Delaware
Indiana	Washington	Dist. of Columbia
Iowa	West Virginia	Florida
Kansas	Wisconsin	Georgia
Maine	Wyoming	Hawaii
Massachusetts		Kentucky
Michigan		Louisiana
Minnesota		Maryland
Missouri		Mississippi
Montana		Nevada
Nebraska		New Mexico
New Hampshire		North Carolina
New Jersey		Oklahoma
New York		South Carolina
North Dakota		Tennessee
Ohio		Texas
Oregon		Virginia

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[a] DOE used the population weighted state HDD as determined by the National Oceanic and Atmospheric Administration (NOAA) in its 1971-2000 United States Climate Normals report, available at http://hurricane.ncdc.noaa.gov/climatenormals/hcs/HCS_51.pdf (last accessed July 28, 2014).

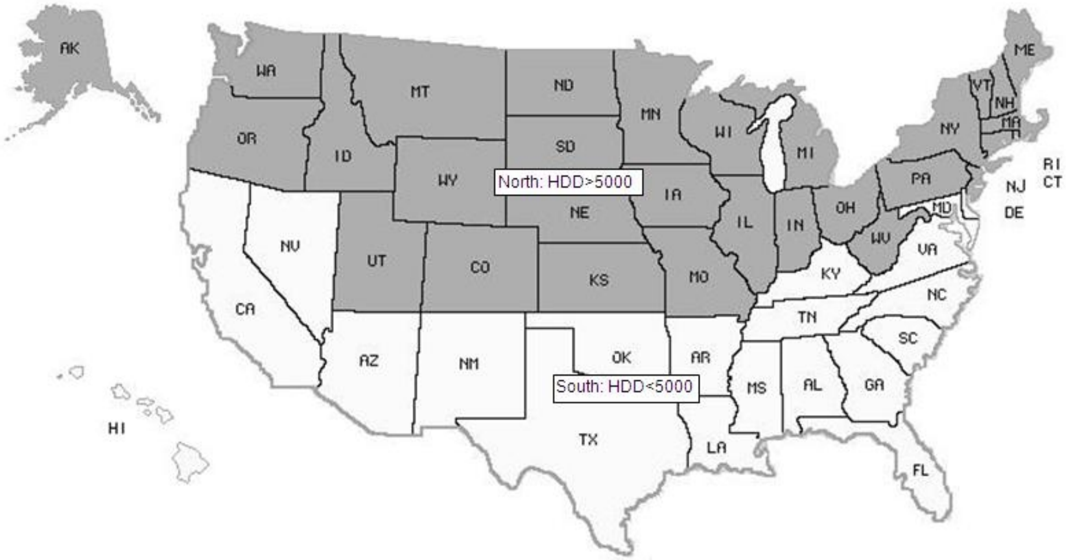

Figure 2.3.1 Map of the Regions for the NOPR Analysis of Furnace Standards

2.4 MARKET AND TECHNOLOGY ASSESSMENT

When DOE begins an energy conservation standards rulemaking, it develops information that provides an overall picture of the market for the products considered, including the nature of the products, 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 products sold and offered for sale.

DOE reviewed relevant literature and interviewed manufacturers to develop an overall picture of the residential furnaces industry in the United States. Industry publications and trade journals, government agencies, and trade organizations provided the bulk of the information, including (1) manufacturers and their market shares, (2) shipments by product type and cooling capacity, (3) product information, and (4) industry trends. The analyses developed as part of the market and technology assessment are described in chapter 3 of this TSD.

2.4.1 Product Classes and Scope of Coverage

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

DOE considered the following residential furnace product classes in this rulemaking: (1) non-weatherized gas-fired furnaces and (2) mobile home gas-fired furnaces.

2.4.2 Technology Assessment

As part of the market and technology assessment, DOE developed a list of technologies to consider for improving the annual fuel utilization efficiency (AFUE) or reducing the standby and off mode power consumption of furnaces. DOE removed from consideration those technology options whose energy consumption could not be adequately measured by the existing DOE test procedure. Then DOE removed technologies that do not change or affect the energy efficiency metrics of furnaces. Chapter 3 of this TSD includes the detailed list of all technology options DOE identified for this rulemaking.

2.5 SCREENING ANALYSIS

The purpose of the screening analysis is to evaluate the technologies identified in the technology assessment to determine which options to consider further in the analysis and which options to screen out. DOE consulted with industry, technical experts, and other interested parties in developing a list of energy-saving technologies for the technology assessment. DOE then applied the screening criteria to determine which technologies were unsuitable for further consideration in this rulemaking. Chapter 4 of this TSD, the screening analysis, contains details about DOE's screening criteria.

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 product utility or availability; and (4) have adverse impacts on health and safety. In consultation with interested parties, DOE reviewed the list of residential furnace 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.

2.6 ENGINEERING ANALYSIS

The engineering analysis (chapter 5 of this TSD) establishes the relationship between the manufacturing production cost and the efficiency for each residential furnace. This relationship serves as the basis for cost-benefit calculations in terms of individual consumers, manufacturers, and the nation. Chapter 5 discusses the product classes analyzed, representative baseline units, incremental efficiency levels, methodology used to develop manufacturing production costs, cost-efficiency relationships, impact of efficiency improvements on the considered products, and methodology used to extend the analysis to products with input capacities outside the representative input. To determine the cost to consumers of furnaces, DOE estimated manufacturing costs, markups in the distribution chain, installation costs, and maintenance costs. Efficiency levels (both AFUE and standby and off mode levels) for furnaces included in this rulemaking were calculated according to the applicable sections of DOE test procedure, 10 CFR Part 430, subpart B, Appendix N, Uniform Test Method for Measuring the Energy Consumption of Furnaces and Boilers.

In the engineering analysis, DOE evaluated a range of product efficiency levels and associated manufacturing costs. The purpose of the analysis is to estimate the incremental increase to selling prices that would result from increasing efficiency levels above the baseline model in each product class. The engineering analysis considers technologies not eliminated in the screening analysis. The LCC analysis uses the cost-efficiency relationships developed in the engineering analysis.

2.6.1 Baseline Models

In order to analyze design options for energy efficiency improvements, DOE defined a baseline model unit for both product classes. DOE defined baseline models as appliances with the most popular and cost-effective features that just meet the current energy conservation standard. For standby and off mode, the baseline model was the model with the highest standby and off mode power consumption. In its selection process, DOE considered technical descriptions of the covered equipment, definitions of the product classes as described in the framework document, results of the market assessment, and suggestions from interested parties.

2.6.2 Manufacturing Cost Analysis

There are several ways to develop the relationship between cost and performance. DOE chose to use a component-based engineering analysis, or teardown analysis. This approach identifies potential technological paths manufacturers could use to achieve increased equipment energy efficiency. DOE purchased off-the-shelf units commercially available on the market and dismantled them component-by-component to determine what technologies and designs manufacturers currently employ to increase energy efficiency. DOE then used independent costing methods, along with manufacturer and component-supplier data, to estimate the costs of the components.

DOE determined the efficiency levels corresponding to various design options from commercially available information on products, data submitted by manufacturers, engineering calculations, and/or product testing. DOE obtained cost estimates from detailed incremental manufacturer cost data, which include the cost of the equipment components, labor, purchased parts and materials, shipping/packaging, and investment. DOE estimated manufacturing costs using a combination of teardown analysis, manufacturer-supplied estimates, and direct estimates. See chapter 5 for details on DOE’s engineering analysis.

2.7 MARKUPS ANALYSIS

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

To develop markups, DOE identified how the products are distributed from the manufacturer to the consumer. After establishing appropriate distribution channels, DOE relied on economic data from the U.S. Census Bureau and other sources to determine how prices are marked up as the products pass from the manufacturer to the consumer. Chapter 6 of the NOPR TSD provides details on DOE's development of markups for NWGFs and MHGFs.

2.8 ENERGY USE ANALYSIS

The purpose of the energy use analysis is to determine the annual energy consumption of NWGFs and MHGFs used in representative U.S. single-family homes, multi-family residences, and commercial buildings. Additionally, the energy use analysis assesses the energy savings potential of increased furnace efficiency. DOE estimated the annual energy consumption of NWGFs and MHGFs at specified energy efficiency levels across a range of climate zones. The annual energy consumption includes the natural gas, liquid petroleum gas, oil fuel, and/or electricity use by the furnace. The annual energy consumption of NWGFs and MHGFs is used in subsequent analyses, including the LCC and PBP analyses and the national impact analysis.

DOE used the Residential Energy Consumption Survey (RECS) 2009,[1] Commercial Building Energy Consumption Survey (CBECS) 2003,[2] and energy and weather data from the National Oceanic and Atmospheric Administration [3] to estimate weather-normalized energy use. The RECS 2009 data provide information on the home characteristics, as well as heating energy use in each household. The survey includes household information such as the physical characteristics of housing units, household demographics, information about other heating and cooling products installed in the household, fuel types used, energy consumption and expenditures, and other relevant data. For NWGFs used in commercial applications, DOE used the CBECS 2003 buildings sample.

To estimate the annual energy consumption of furnaces meeting higher efficiency levels, DOE calculated the heating load based on the RECS and CBECS estimates of the annual energy consumption of the furnace for each household. DOE then used the house heating load to determine the burner operating hours, which are needed to calculate the fuel consumption and electricity consumption based on the DOE residential furnace and boiler test procedure. To calculate fan and other auxiliary components' electricity consumption, DOE utilized data from manufacturer product literature.

DOE also determined furnace electricity consumption during standby mode and off mode based on input from the engineering analysis (chapter 5).

Chapter 7 describes the details of the energy use analysis methodology.

2.9 LIFE-CYCLE COST AND PAYBACK PERIOD ANALYSES

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 used the following two metrics to measure consumer impacts:

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

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

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

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

2.10 SHIPMENTS ANALYSIS

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

The shipments models take an accounting approach, tracking market shares of each product class and the vintage of units in the existing stock. Stock accounting uses product shipments as inputs to estimate the age distribution of in-service product stocks for all years. The age distribution of in-service product stocks is a key input to calculations of both the NES and NPV, because operating costs for any year depend on the age distribution of the stock.

DOE also considers the impacts on equipment switching from changes in product purchase price and operating cost associated with higher energy efficiency levels. For NWGFs, owners may choose to use other products such as electric space heating products if the energy conservation standard of gas furnaces is increased. Chapter 9 of the NOPR TSD provides additional details on the shipments analysis.

2.11 NATIONAL IMPACT ANALYSIS

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

Several of the inputs for determining NES and NPV depend on the forecast trends in product energy efficiency. For the base case—without new or amended standards—DOE uses the efficiency distributions developed for the LCC analysis, and assumes some rate of change over the forecast period. In this analysis, DOE used a roll-up scenario in developing its forecasts of efficiency trends after standards take effect. Under a roll-up scenario, all products that perform at levels below a prospective standard are moved, or rolled-up, to the minimum performance level allowed under the standard. Product efficiencies above the standard level under consideration would remain the same as before the revised standard takes effect.

2.11.1 National Energy Savings Analysis

The inputs for determining the national energy savings for each product class are: (1) annual energy consumption per unit, (2) shipments, (3) product stock, (4) national energy consumption, and (5) site-to-source conversion factors for energy. DOE calculated national energy consumption by multiplying the number of units, or stock, of each product class (by vintage, or age) by the unit energy consumption (also by vintage). DOE calculated annual NES based on the difference in national energy consumption for the base case and for each energy conservation standard being considered. DOE estimated energy consumption and savings based on site energy consumption, which it then converted to source energy. Cumulative energy savings are the sum of the NES for each year.

2.11.2 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 determined the net savings for each year as the difference between the base 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 products shipped in the forecast period. DOE calculated NPV as the difference between the present value of operating cost savings and the present value of total installed costs. DOE used a discount factor based on real discount rates of 3 and 7 percent to discount future costs and savings to present values.

For the NPV analysis, DOE calculates increases in total installed costs as the difference in total installed cost between the base case and standards case (*i.e.*, once the standards take effect). Because the more efficient products bought in the standards case usually cost more than products bought in the base case, cost increases appear as negative values in the NPV.

DOE expresses savings in operating costs as decreases associated with the lower energy consumption of products bought in the standards case compared to the base case. Total savings in operating costs are the product of savings per unit and the number of units of each vintage that survive in a given year. DOE used the Energy Information Administration's (EIA's) *Annual Energy Outlook 2014* (*AEO 2014*) as the source of projections for future energy prices.

DOE estimates the NPV of consumer benefits using both a 3-percent and a 7-percent real discount rate. DOE uses these discount rates in accordance with guidance provided by the Office of Management and Budget (OMB) to federal agencies on the development of regulatory analysis. (OMB Circular A-4 (Sept. 17, 2003), section E, "Identifying and Measuring Benefits and Costs".)

2.12 CONSUMER SUBGROUP ANALYSIS

In analyzing the potential impacts of new or amended standards on consumers, DOE evaluates the potential impact of new or amended standards on identifiable groups of consumers (*i.e.*, subgroups), such as low-income consumers and senior citizens (*e.g.*, senior-only households), that may be disproportionately affected by a national energy conservation standard. Accordingly, DOE evaluated impacts on low-income households and senior-only households using the LCC and payback period spreadsheet model, using inputs appropriate to these subgroups to the extent possible. The NWGF and MHGF subgroup analysis is discussed in detail in chapter 11 of this TSD.

2.13 MANUACTURER IMPACT ANALYSIS

DOE performed an MIA to determine the potential financial impact of higher energy conservation standards on residential furnace manufacturers, as well as to estimate the impact of such standards on employment and manufacturing capacity. The MIA has both quantitative and qualitative aspects. The quantitative part of the MIA relies on the government regulatory impact model (GRIM), an industry cash-flow model customized for the residential furnace industry. The GRIM inputs include manufacturer production costs, manufacturer selling prices, industry shipments, and industry financial parameters. This includes information from many of the analyses described above, such as manufacturing production costs and manufacturer selling prices from the engineering analysis and shipments forecasts from the shipments analysis. The key GRIM output is the industry net present value (INPV). Different sets of assumptions (scenarios) will produce different results. The qualitative part of the MIA includes factors such as impacts on industry competition, impacts on manufacturing capacity, industry consolidation, employment, and identification of manufacturer key issues.

DOE conducts each MIA in three phases. In Phase I, DOE creates an industry profile to characterize the industry and identify important issues that require consideration. In Phase II, DOE prepares an industry cash-flow model and interview questionnaire to guide subsequent discussions. In Phase III, DOE interviews manufacturers and assesses the impacts of standards quantitatively and qualitatively. DOE assesses industry and subgroup cash flow and NPV using the GRIM. DOE then assesses impacts on competition, manufacturing capacity, employment, and regulatory burden based on manufacturer interview feedback and discussions. Chapter 12 of this TSD describes the complete MIA.

2.14 EMISSIONS IMPACT ANALYSIS

In the emissions analysis, DOE estimated the impact on power sector emissions of carbon dioxide (CO_2), nitrogen oxides (NOx), sulfur dioxide (SO_2) and mercury (Hg) from potential energy conservation standards for the considered products. In addition, DOE estimated emissions impacts in production activities (extracting, processing, and transporting fuels) that provide the energy inputs to power plants. These are referred to as "upstream" emissions. Together, these emissions account for the full-fuel-cycle (FFC). In accordance with DOE's FFC Statement of Policy (76 FR 51282 (Aug. 18, 2011)), the FFC analysis includes impacts on emissions of methane and nitrous oxide, both of which are recognized as greenhouse gases.

Because the on-site operation of NWGFs and MHGFs requires use of fossil fuels and results in emissions of CO_2, NOx, 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.

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

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

Sulfur dioxide 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

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

an annual emissions cap on SO_2 for affected EGUs in the 48 contiguous states and the District of Columbia (D.C.). Sulfur dioxide emissions from 28 eastern states and D.C. were also limited under the Clean Air Interstate Rule (CAIR), which created an allowance-based trading program that operates along with the Title IV program in those states and D.C. 70 FR 25162 (May 12, 2005). CAIR was remanded to EPA by the U.S. Court of Appeals for the District of Columbia Circuit (D.C. Circuit), but it remained in effect.[c] On July 6, 2011 EPA issued a replacement for CAIR, the Cross-State Air Pollution Rule (CSAPR). 76 FR 48208 (August 8, 2011). On August 21, 2012, the D.C. Circuit issued a decision to vacate CSAPR.[d] The court ordered EPA to continue administering CAIR. *AEO 2014* assumes that CAIR remains a binding regulation through 2040.[e]

The attainment of emissions caps is typically flexible among EGUs and is enforced through the use of emissions allowances and tradable permits. Under EPA regulations, any excess SO_2 emissions allowances resulting from the lower electricity demand caused by the adoption of an energy conservation 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 energy conservation 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 such standards.

Beginning in 2016, however, SO_2 emissions will fall as a result of the Mercury and Air Toxics Standards (MATS) for power plants. 77 FR 9304 (Feb. 16, 2012). In the final MATS rule, EPA established a standard for hydrogen chloride (HCl) as a surrogate for acid gas hazardous air pollutants (HAP), and also established a standard for SO_2 (a non-HAP acid gas) as an alternative equivalent surrogate standard for acid gas HAP. The same controls are used to reduce HAP and non-HAP acid gas; thus, SO_2 emissions will be reduced as a result of the control technologies installed on coal-fired power plants to comply with the MATS requirements for acid gas. *AEO 2014* assumes that, in order to continue operating, coal plants must have either flue gas desulfurization or dry sorbent injection systems installed by 2016. Both technologies, which are used to reduce acid gas emissions, also reduce SO_2 emissions. Under the MATS, emissions will be far below the cap that would be established by CAIR, so it is unlikely that excess SO_2 emissions allowances resulting from the lower electricity demand would be needed

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

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

[e] On April 29, 2014, the U.S. Supreme Court reversed the judgment of the D.C. Circuit and remanded the case for further proceedings consistent with the Supreme Court's opinion. The Supreme Court held in part that EPA's methodology for quantifying emissions that must be eliminated in certain states due to their impacts in other downwind states was based on a permissible, workable, and equitable interpretation of the Clean Air Act provision that provides statutory authority for CSAPR. See *EPA v. EME Homer City Generation*, No 12-1182, slip op. at 32 (U.S. April 29, 2014). 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. Because DOE is using emissions factors based on *AEO 2014*, the analysis assumes that CAIR, not CSAPR, is the regulation in force. The difference between CAIR and CSAPR is not relevant for the purpose of DOE's analysis of SO_2 emissions.

or used to permit offsetting increases in SO_2 emissions by any regulated EGU. Therefore, energy conservation standards will reduce SO_2 emissions in 2016 and beyond.

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

The MATS limit mercury emissions from power plants, but they do not include emissions caps and, as such, DOE's energy conservation standards would likely reduce mercury emissions. DOE estimated mercury emissions reduction using emissions factors based on *AEO 2014*, which incorporates the MATS.

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

Further detail is provided in chapter 13 of this TSD.

2.15 MONETIZING REDUCED CARBON DIOXIDE AND OTHER EMISSIONS

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

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

The Interagency Working Group on Social Cost of Carbon released an update of its previous report in 2013.[4] The most recent estimates of the SCC in 2015, expressed in 2013$, are $12.0, $40.5, $62.4, and $119 per metric ton of CO_2 avoided. For emissions reductions that occur in later years, these values grow in real terms over time. Additionally, the interagency group determined that a range of values from 7 percent to 23 percent should be used to adjust the global SCC to calculate domestic effects, although DOE gives preference to consideration of the global benefits of reducing CO_2 emissions.

DOE multiplied the CO_2 emissions reduction estimated for each year by the SCC value for that year in each of the four cases. To calculate a present value of the stream of monetary values, DOE discounted the values in each of the four cases using the discount rates that had been used to obtain the SCC values in each case.

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

DOE also estimated the potential monetary benefit of reduced NOx emissions resulting from the standard levels it considers. Estimates of monetary value for reducing NOx from stationary sources range from $476 to $4,893 per ton in 2013$.[5] DOE calculated monetary benefits using a medium value for NOx emissions of $2,684 per short ton (2013$), and real discount rates of 3 and 7 percent.

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

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

2.16 UTILITY IMPACT ANALYSIS

In the utility impact analysis, DOE analyzes the changes in electric installed capacity and generation that result for each trial standard level (TSL). The utility impact analysis is based on output of the NEMS. NEMS is a public domain, multi-sectored, partial equilibrium model of the U.S. energy sector. Each year, DOE/EIA uses NEMS to produce an energy forecast for the United States, the *Annual Energy Outlook*. The EIA publishes a reference case, which incorporates all existing energy-related policies at the time of publication, and a variety of side cases which analyze the impact of different policies, energy price and market trends. As of 2014, DOE is using a new methodology based on results published for the *AEO 2014* reference case and a set of side cases that implement a variety of efficiency-related policies. Further detail is provided in chapter 15 of this TSD.

2.17 EMPLOYMENT IMPACT ANALYSIS

The adoption of energy conservation standards can affect employment both directly and indirectly. Direct employment impacts are changes in the number of employees at the plants that produce the covered products. DOE evaluates direct employment impacts in the MIA. Indirect employment impacts may result from expenditures shifting between goods (the substitution effect) and changes in income and overall expenditure levels (the income effect) that occur due to standards. DOE defines indirect employment impacts from standards as net jobs eliminated or created in the general economy as a result of increased spending driven by increased product prices and reduced spending on energy.

Indirect employment impacts are investigated in the employment impact analysis using the Pacific Northwest National Laboratory's "Impact of Sector Energy Technologies" (ImSET) model.[6] The ImSET model was developed for DOE's Office of Planning, Budget, and Analysis to estimate the employment and income effects of energy-saving technologies in buildings, industry, and transportation. Compared with simple economic multiplier approaches, ImSET allows for more complete and automated analysis of the economic impacts of energy conservation investments. Further detail is provided in chapter 16 of this TSD.

2.18 REGULATORY IMPACT ANALYSIS

In the NOPR stage, DOE prepared a regulatory impact analysis (RIA) pursuant to Executive Order 12866, Regulatory Planning and Review, 58 FR 51735, October 4, 1993. The RIA addresses the potential for non-regulatory approaches to supplant or augment energy conservation standards in order to improve the energy efficiency or reduce the energy consumption of the product covered under this rulemaking. DOE bases its assessment on the actual impacts of any such initiatives to date, and also considers information presented by interested parties regarding the impacts existing initiatives might have in the future. Further detail is provided in chapter 17 of this TSD.

REFERENCES

[1] U.S. Department of Energy: Energy Information Administration, Residential Energy Consumption Survey: 2009 RECS Survey Data (2013) (Available at: www.eia.gov/consumption/residential/data/2009/) (Last accessed March, 2013).

[2] U.S. Department of Energy: Energy Information Administration, Commercial Buildings Energy Consumption Survey (2003) (Available at: www.eia.gov/consumption/commercial/data/2003/index.cfm?view=microdata) (Last accessed November, 2013).

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

[4] *Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866*. Interagency Working Group on Social Cost of Carbon, United States Government; revised November 2013. www.whitehouse.gov/sites/default/files/omb/assets/inforeg/technical-update-social-cost-of-carbon-for-regulator-impact-analysis.pdf

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

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

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 carried out in support of this notice of proposed rulemaking (NOPR) for energy conservation standards for non-weatherized gas-fired (NWGF) and mobile-home gas-fired (MHGF) residential furnaces. This chapter consists of two sections: the market assessment and the technology assessment.

The goal of the market assessment is to develop a qualitative and quantitative characterization of the residential furnace industry and market structure, based on publicly available information and data and information submitted by manufacturers and other stakeholders. The technology assessment is a list of technologies that can improve the efficiency of residential furnaces. These technologies are considered in the screening analysis.

DOE examined publicly available information from its Compliance Certification Management System (CCMS)[a] database and the Air-Conditioning, Heating, and Refrigeration Institute (AHRI) Consumers' *Directory of Certified Efficiency Ratings for Furnaces* to identify the types and characteristics of furnaces on the market. DOE determined that the CCMS database provided the most comprehensive list of furnace products on the market and chose to base its analysis off of this database. DOE determined by analyzing manufacturer product literature and the AHRI database that due to multiple brand names assigned to identical units from common parent manufacturers, the CCMS database contained duplicate listings of furnaces that were otherwise the same. DOE consolidated the data it gathered from its CCMS database by eliminating all duplicate product listings as well as all discontinued models.

DOE also examined Current Industrial Reports (CIR) and the from the U.S. Census Bureau. Issues addressed include: manufacturer characteristics and market shares;, existing regulatory and non-regulatory efficiency improvement initiatives, product classes, and trends in the equipment markets and characteristics.

Following DOE's publication in the *Federal Register* on June 27, 2011, of a direct final rule (DFR; 76 FR 37408) revising the energy conservation standard for residential furnaces, the American Public Gas Association (APGA) sued DOE in the U. S. Court of Appeals for the District of Columbia Circuit (D.C. Circuit) to invalidate the rule as it pertained to non-weatherized natural gas furnaces. On March 11, 2014, DOE and APGA, as well as the various intervenors in the case, filed a joint motion for approval of a settlement with the court, in which DOE agreed to seek a remand of the non-weatherized gas furnace portions of the June 2011 DFR, and to conduct notice and comment rulemaking proceedings. The settlement agreement was approved by the D.C. Circuit in an order filed April 24, 2014, through which the court

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[a] DOE requires all manufacturers of residential furnaces for sale in the United States to certify each model with the DOE. The CCMS database lists all models that have met this certification, and as such is a comprehensive listing of furnace models for sale in the United States.

vacated the rule in part (*i.e.,* the provisions related to non-weatherized gas furnaces and mobile home gas furnaces) and remanded for further rulemaking.

As such, DOE only considered non-weatherized gas and mobile home gas furnaces in its analysis of amended annual fuel utilization efficiencies (AFUE) standards.

This rulemaking will also establish energy conservation standards for energy consumption of NWGF and MHGF furnaces operating in standby mode and off mode. Section 310(3) of the Energy Independence and Security Act of 2007 (EISA 2007; Pub. L. 110-140) amended EPCA to require that energy conservation standards published after July 1, 2010, address standby mode and off mode energy use (42 U.S.C. 6295(gg)), if justified by the criteria for adoption of standards in section 325(o) of EPCA (42 U.S.C. 6295(o)).

DOE's current standards for furnaces are expressed as minimum AFUE. AFUE is an annualized fuel efficiency metric that fully accounts for fuel consumption in active, standby, and off modes. DOE published a test procedure final rule in the *Federal Register* on October 20, 2010 (the October 2010 TP Rule), that amended DOE's test procedure for furnaces and boilers to establish a method for measuring the electrical energy use in standby mode and off mode for gas and oil-fired furnaces. On December 31, 2012, DOE published a final rule in the *Federal Register* that updated the standby mode and off mode test procedure provisions to incorporate by reference the latest edition of International Electrotechnical Commission (IEC) Standard 62301 (second edition). For this rulemaking, DOE has determined that homeowners are unlikely to switch their furnaces to off mode in the non-heating season, and therefore the power consumed in off mode is equivalent to the power consumed in standby mode. As such, DOE is analyzing separate but equivalent standards for maximum standby and off mode electrical energy consumption for all residential furnaces covered in this rulemaking.

3.1.1 Product Definitions

A residential, or warm-air, furnace is an integral part of a home's central heating and cooling system that provides heated air to the conditioned space through ductwork. A fuel-burning furnace provides heat by passing the combustion products through an air-to-air heat exchanger. The furnace uses a blower to propel circulation air over the outside of the heat exchanger, transferring heat from the hot combustion gases to the cool circulation air. The heated air is then distributed via ductwork to the conditioned space, and the products of combustion are exhausted from the heat exchanger to the atmosphere through the flue passage.

The Energy Policy and Conservation Act (42 U.S.C. 6291 *et seq*.; EPCA) defines a residential "furnace" as a product that utilizes only single-phase electric current, or single-phase electric current or DC current, in conjunction with natural gas, propane, or home heating oil, and which:

(1) is designed to be the principal heating source for the living space of a residence;
(2) is not contained within the same cabinet with a central air conditioner whose rated cooling capacity is above 65,000 Btu per hour;

(3) is an electric central furnace, electric boiler, forced-air central furnace, gravity central furnace, or low-pressure steam or hot water boiler; and
(4) has a heat input rate of less than 300,000 Btu per hour for electric boilers and low-pressure steam or hot water boilers and less than 225,000 Btu per hour for forced-air central furnaces, gravity central furnaces, and electric central furnaces. (42 U.S.C. 6291(23))

3.1.2 Product Classes

3.1.2.1 Furnaces

DOE categorized furnaces into two product classes and analyzed a separate amended energy conservation standard for both product classes in this rulemaking. EPCA specifies the criteria for product class separation, which include: (1) the type of energy consumed; (2) capacity; or (3) other performance-related features, such as those that provide utility to the consumer or other features deemed appropriate by the Secretary that would justify the establishment of a separate energy conservation standard. (42 U.S.C. 6295(q))

The 2011 DFR divided furnaces into seven product classes for analysis: (1) non-weatherized gas-fired furnaces, (2) mobile home gas-fired furnaces, (3) non-weatherized oil-fired furnaces, (4) weatherized gas-fired furnaces, (5) mobile home oil-fired furnaces, (6) weatherized oil-fired furnaces, and (7) electric furnaces. Following the lawsuit filed against DOE by APGA in response to the 2011 DFR (as discussed in section 3.1.1), DOE and APGA, as well as the various intervenors in the case, filed a joint motion for approval of a settlement with the court (filed on March 11, 2014), in which DOE agreed to seek a remand of the non-weatherized gas furnace portions of the June 2011 DFR, and to conduct notice and comment rulemaking proceedings. In the settlement agreement approved on April 24, 2014, the court vacated the 2011 DFR in part (*i.e.,* the provisions related to NWGF and MHGF) and remanded for further rulemaking (see section 3.1.1). Therefore, the product classes that DOE is considering in this rulemaking for amended AFUE energy conservation standards are non-weatherized gas furnaces and mobile home gas furnaces. These product classes and their characteristics are shown in Table 3.1.1.

Table 3.1.1 Product Classes for Residential Furnaces Used in this Rulemaking

Product Class	Characteristics
Non-weatherized gas furnace	Intended for indoor installation; fueled by natural gas
Mobile home gas furnace	Intended for mobile home installation; require direct vent; subject to space constraints; fueled by natural gas

3.1.3 Test Procedures

EPCA, as amended by EISA 2007, requires that DOE review test procedures for all covered products at least once every 7 years. (42 U.S.C 6293(b)(1)(A)) Accordingly, DOE must complete the ongoing residential furnaces and boilers test procedure rulemaking no later than

December 19, 2014 (*i.e.,* 7 years after the enactment of EISA 2007), which is before the expected completion of this energy conservation standards rulemaking for furnaces.

The energy conservation standards for residential furnaces are represented in terms of the AFUE as measured by the current DOE test procedure. (42 U.S.C. 6295(f)(1-2)) DOE's current test procedure for residential furnaces is described in 10 CFR part 430 subpart B appendix N, which incorporates by reference American National Standards Institute/American Society of Heating, Refrigerating and Air-Conditioning Engineers (ANSI/ASHRAE) Standard 103-1993, *Method of Testing for Annual Fuel Utilization Efficiency of Residential Central Furnaces and Boilers*. AFUE is the ratio of annual output of useful heat to annual fuel input energy, and it includes active mode, standby, and off mode fuel consumption (including non-heating-season pilot input loss if applicable).

AFUE does not account for electrical energy consumption in standby mode and off mode, although it does address fossil fuel use in these modes. To satisfy the requirements of EPCA as amended by EISA, the DOE test procedure for residential furnaces and boilers was amended by a final rule published on October 20, 2010, to account for standby and off mode electrical energy consumption. 75 FR 64621. The amended DOE test procedure incorporates by reference provisions of the IEC Standard 62301, *Household electrical appliances—Measurement of standby power* . It also adds new calculations to determine the annual energy consumption associated with standby mode and off mode measured power, and it modifies the existing energy consumption equations to integrate standby mode and off mode electrical energy consumption into the calculation of overall annual energy consumption of these products.

3.2 MARKET ASSESSMENT

The following market assessment identifies manufacturer trade associations, domestic and international manufacturers of residential warm air furnaces, and their corresponding market shares, and regulatory and non-regulatory programs.

3.2.1 Trade Associations

AHRI is a national trade association of manufacturers of residential, commercial, and industrial appliances, equipment, components, and related products. AHRI was established in January 2008 when the Air-Conditioning and Refrigeration Institute (ARI) merged with the Gas Appliance Manufacturers Association (GAMA). AHRI's member companies are responsible for more than 90 percent of the residential and commercial air conditioning and space heating equipment sold in North America.[1] AHRI develops and publishes technical standards for residential and commercial equipment using rating criteria and procedures for measuring and certifying equipment performance. AHRI also participates in developing international standards and has established a policy of adopting international standards for use in the United States when technologically and economically feasible.

AHRI administers a certification[b] program that tests and certifies the performance of gas- and oil-fired central furnaces that use single-phase electric current or direct current (DC) and that

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have a heat input rate of less than 225,000 Btu per hour. AHRI maintains the AHRI *Directory of Certified Product Performance* that lists all products that it has certified.

3.2.2 Manufacturers and Market Share

For residential furnaces, DOE examined its CCMS database of residential furnaces, the AHRI product listings, manufacturers' websites, and product catalogs to identify residential furnace manufacturers. All manufacturers of NWGF and MHGF furnaces that DOE identified are shown in Table 3.2.1. Manufacturers may offer multiple brand names. DOE identified more than 50 brands under which furnaces are manufactured and marketed.

Table 3.2.1: Manufacturers Whose Products are Included in DOE's Database

Manufacturer	Parent Company (if applicable)	NWGF	MHGF
Allied Air Enterprises, LLC	Lennox International, Inc.	X	
Carrier Corporation	United Technologies Corporation	X	X
GD Midea Heating & Ventilating Equipment Co., Ltd	Midea Group	X	
Goodman Manufacturing Co., LP.	Daikin Industries, Ltd.	X	
Heat Controller	N/A		X
International Comfort Products	United Technologies Corporation	X	X
Lennox Industries, Inc.	Lennox International, Inc.	X	
Mortex	Mortex Products, Inc.		X
Nordyne, LLC.	Nortek, Inc.	X	X
Rheem Manufactuing Company	Paloma Group	X	
Texas Furnace, LLC	AllStyle Coil Company, L.P.	X	
Trane	Ingersoll Rand	X	
Wolf Steele, Ltd.	Napoleon Systems and Development, Ltd.	X	
York International Corporation	Johnson Controls, Inc.	X	X

Seven U.S. manufacturers hold the domestic gas furnace market almost entirely : Carrier, Goodman, Lennox, Trane,[c] Rheem, York, and Nordyne.[2] Figure 3.2.1 shows the 2008 market shares for residential furnace manufacturers as depicted in the September 2009 issue of *Appliance Magazine*. This was the most recent year for which data was available.

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[c] Prior to 2007, Trane was a subsidiary of American Standard Companies. On November 28, 2007 Trane separated from the two other branches of American Standard Companies. On June 5, 2008, Ingersoll Rand acquired Trane. For more information, visit www.trane.com/Corporate/About/history.asp.

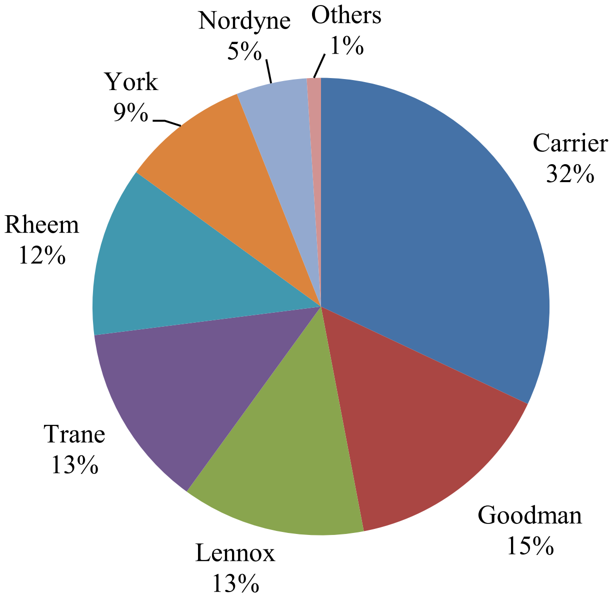

Figure 3.2.1 2008 Market Shares for U.S. Manufacturers of Residential Gas Furnaces[3]

Three of these major manufacturers, Carrier, Nordyne, and York, also have large market share in the market for mobile home gas furnaces. Other manufacturers of mobile home gas furnaces include Mortex, Heat Controller, and Hamilton Home Products.

3.2.2.1 Mergers and Acquisitions

A trend in the residential furnace industry over the past decades has been the consolidation of major manufacturers. A brief summary of the recent history of each of the seven largest manufacturers is as follows:

- Goodman Global, Inc., was founded and purchased Janitrol in 1982. In 1997, Goodman acquired Amana, which was then sold to Maytag in 2001, and later to Whirlpool when Whirlpool acquired Maytag in 2006. Goodman was then bought by Daikin Industries, Inc., of Japan in 2012. Product lines manufactured by Goodman prior to the consolidation into Daikin are still sold under the Goodman brand.
- Lennox Industries is a subsidiary of Lennox International, Inc., a holding company that was created in 1984. Lennox International acquired Armstrong Air Conditioning Inc., in 1988. In 1999, Lennox International completed an initial public offering and became a public company.[4] Around this time, Lennox also acquired Service Experts and other equipment service companies.
- Carrier has been a wholly-owned subsidiary of United Technologies Corporation since 1979. In 1999, Carrier Corporation acquired International Comfort Products (ICP). [5]
- York Unitary Products Group and York International are subsidiaries of Johnson Controls, Inc. Johnson Controls, Inc., purchased York in 2005. [6]

- Rheem is a privately held firm that was acquired by Paloma Industries of Japan in 1987. Paloma Industries also acquired Rheem Australia (Solahart) in 2002. [7]
- Nordyne is a subsidiary of the privately held Nortek, Inc. [8]
- Trane Inc. was acquired by American Standard Companies in 1984. In 2007, American Standard sold off two of its three corporate segments, retained Trane, and then renamed itself Trane, Inc. In 2008, Trane was bought by Ingersoll Rand.[9,10]

3.2.2.2 Small Businesses

DOE considers the possibility of small businesses being particularly affected by the promulgation of energy conservation standards for residential furnaces. The Small Business Administration (SBA) defines small business manufacturing enterprises for residential furnaces as having 750 employees or fewer. SBA lists small business size standards that are matched to industries as they are described in the North American Industry Classification System (NAICS). A size standard is the largest that a for-profit business can be and still qualify as a small business for federal government programs. These size standards are generally the average annual receipts or the average employment of a firm. For residential furnaces, the size standard is matched to NAICS code 333415, Air-Conditioning and Warm Air Heating Equipment and Commercial and Industrial Refrigeration Equipment Manufacturing, which has a size standard of 750 employees.

DOE further studied the potential impacts on these small businesses in detail and presented the results in the manufacturer impact analysis (MIA; chapter 12 of this TSD). DOE has identified Texas Furnace, LLC (subsidiary of AllStyle Coil Company) as the only domestic small business furnace manufacturer of NWGF. DOE identified Heat Controller, Inc. and Mortex as the only domestic small business manufacturers of MHGF.

3.2.3 Distribution Channels

A single distribution channel represents the vast majority of the heating, ventilating, and air conditioning (HVAC) market. Simply, the original equipment manufacturer (OEM) assembles the system and sells it to a wholesaler; the wholesaler warehouses and sells the unit to a mechanical contractor; and the mechanical contractor sells the unit to the final consumer (see Figure 3.2.2). In the replacement market, the mechanical contractor installsthe furnace upon sale to the consumer (the homeowner). This replacement distribution channel applies to sales of both NWGF and MHGF units.

In the new site-built home construction market, the mechanical contractor sells the furnace to the general contractor building the home, but the installation of the furnace for the final consumer is still carried out by the mechanical contractor (see Figure 3.2.3). For mobile home gas-fired units installed in brand new manufactured homes, a different distribution channel is used. In this distribution channel, the OEM sells the mobile home furnace to the mobile home manufacturer, who then installs the furnace in the mobile home and sells the mobile home to a mobile home dealer, and the mobile home dealer then sells the furnace to the final consumer (see Figure 3.2.4). In addition to the replacement and new home distribution channels discussed for residential applications, some non-weatherized gas-fired units are used in commercial applications and use a more direct distribution model. In this model, the manufacturer sells to a wholesaler and the wholesaler then sells the unit to the final consumer on a national account the consumer holds with the wholesaler (see Figure 3.2.5).

The final consumer varies in the replacement and in the new construction market. In the replacement market, the final consumer is usually the homeowner, as illustrated in Figure 3.2.2, and is very influential in product selection. Replacements in kind" (replacing a unit with a similar or identical product) are common, although premium products are also commonly sold in this market. Replacements represent approximately 75 percent of non-weatherized gas furnace sales and 70 percent of mobile home gas furnace sales in the United States. In the new construction market, a builder or general contractor is effectively the final purchaser, as shown in Figure 3.2.3. In the new construction market, the home builder has a much stronger influence than the homeowner, who typically has little choice in what kind of system is installed. The new construction market tends to be a low-cost, low-efficiency market, as the decision makers are not the beneficiary of the system installed. After installation, mechanical contractors typically perform additional lifecycle service on the system, including inspection, maintenance, and repair.

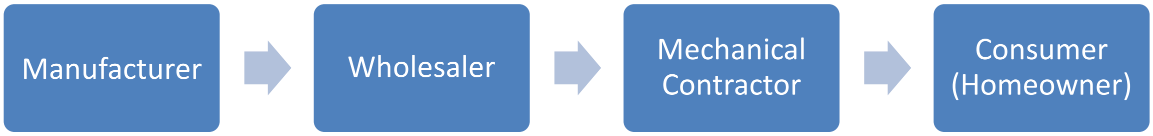

Figure 3.2.2 Distribution Channel in NWGF and MHGF Replacement Market

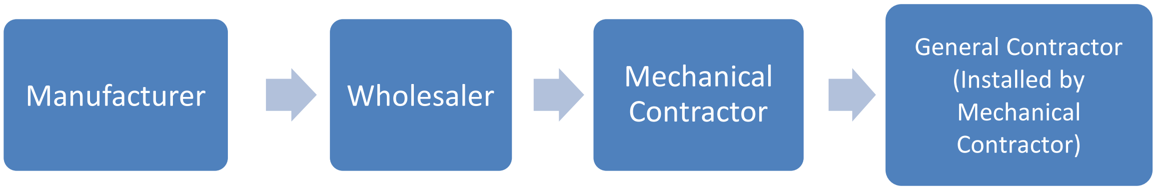

Figure 3.2.3 Distribution Channel in NWGF New Construction Market

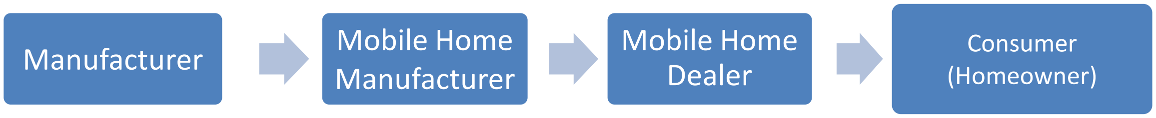

Figure 3.2.4 Distribution Channel in MHGF New Construction Market

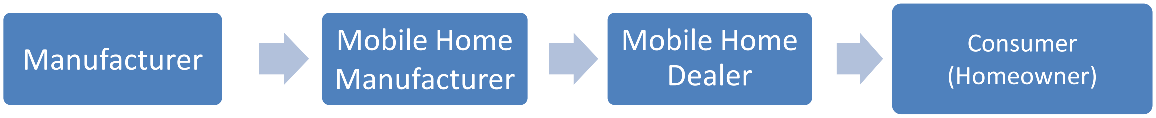

Figure 3.2.5 Distribution Channel in NWGF National Account Market

3.2.4 Regulatory Programs

The following section details current regulatory programs mandating energy conservation standards for residential furnaces. Section 3.2.4.1 discusses current federal energy conservation standards. Section 3.2.4.2 reviews standards in Canada that may affect companies servicing the North American market.

3.2.4.1 Current Federal Energy Conservation Standards

Part A of Title III of EPCA addresses the energy conservation standards for consumer products other than automobiles, which include residential furnaces.(42 U.S.C. 6291-6309) The current federal standards prescribed by EPCA have applied since January 1, 1990, for mobile home furnaces, and January 1, 1992, for all other furnaces except "small" furnaces. (42 U.S.C. 6295(f)(1)–(2)) Table 3.2.2 presents the current federal energy conservation standards for residential furnaces as prescribed by section 325(f) of EPCA.

Table 3.2.2 Current Federal Energy Conservation Standards Established by EPCA, as Amended by National Appliance Energy Conservation Act

Product Class	Minimum AFUE %
Furnaces (excluding classes noted below)	78
Mobile home furnaces	75
Small furnaces (having an input rate of less than 45,000 Btu/h)	78

Pursuant to 42 U.S.C. 6295(f)(4)(B), DOE amended the energy conservation standards for residential furnaces in a final rule issued on November 19, 2007 (hereafter referred to as the November 2007 Rule). 72 FR 65135. These standards, shown in Table 3.2.3 for non-weatherized gas-fired and mobile home gas-fired furnaces, have a compliance date of November 19, 2015, prior to the compliance date of this rulemaking. Because these standards for NWGF and MHGF will be the energy efficiency standard at the time of this rulemaking's compliance date, DOE has adopted them as the baseline efficiency levels for its analyses, as discussed in the NOPR.

Table 3.2.3 Federal Energy Conservation Standards for NWGF and MHGF Established by the November 2007 Rule

Product Class	Minimum AFUE %
Non-weatherized gas-fired furnaces	80
Mobile home gas-fired furnaces	80

3.2.4.2 Canadian Energy Conservation Standards

The Natural Resources Canada (NRCan) Office of Energy Efficiency regulation mandates energy conservation standards for residential furnaces that apply to imports and interprovincial trade. The standards for furnaces are expressed as minimum AFUEs), rated according to the Canadian test standard CAN/CSA P.2-2007, *Testing method for measuring annual fuel utilization efficiency of residential gas-fired furnaces and boilers;* (*CSA P.2*). These standards apply to automatic operating gas-fired central forced-air furnaces that use propane or natural gas and have an input rate not exceeding 225,000 Btu per hour, but do not apply to furnaces for mobile homes or recreational vehicles. The furnace standards and their compliance dates are shown in Table 3.2.4.

Table 3.2.4 Canadian Energy Conservation Standards for Residential Gas Furnaces[11]

Product	Minimum AFUE Standard %	Compliance Date
Non-weatherized gas furnaces, that have an input rate no greater than 225,000 Btu/h and use single-phase electric current	90	On or after December 31, 2012
Gas furnaces, other than those with an integrated cooling component, that are outdoor or through-the-wall* gas furnace, that have an input rate no greater than 225,000 Btu/h and that use single-phase electric current	90	On or after December 31, 2012
Gas furnaces that are outdoor furnaces with an integrated cooling component, that have an input rate no greater than 225,000 Btu/h and that use single-phase electric current	78	On or after December 31, 2009
Gas furnaces that are through-the-wall with an integrated cooling component, that have an input rate no greater than 225,000 Btu/h and that use single-phase electric current	78	On or after December 31, 2012
All gas furnaces that have an input rate less than 225,000 Btu/h that use three-phase electric current	78	December 31, 2012

*With respect to gas furnaces, through-the-wall refers to gas furnaces that are designed and marketed to be installed in an opening in an exterior wall that is fitted with a weatherized sleeve.

3.2.5 Non-Regulatory Programs

DOE identified several non-regulatory programs aimed at improving the energy efficiency of residential furnaces.

3.2.5.1 ENERGY STAR

ENERGY STAR®[d] is a voluntary labeling program conducted by the U.S. Environmental Protection Agency (EPA) and DOE, which identifies and promotes energy efficient products. To qualify, a product must usually exceed federal standards by a specified amount, or if no federal standard exists, it must meet efficiency levels set by the program and/or exhibit selected energy saving features. ENERGY STAR creates energy efficiency specifications for various products, including residential gas-fired furnaces. ENERGY STAR originally set specifications for residential furnaces in 1995; these levels were revised in 2011 and are shown in Table 3.2.5.

Table 3.2.5 ENERGY STAR Levels for Gas-Fired Furnaces[12]

Equipment	Specification
Gas furnace AFUE product criteria	90% for U.S. South
	95% for U.S. North
Gas furnace other product criteria	Less than or equal to 2.0% furnace fan efficiency
	Less than or equal to 2.0% air leakage

Regions	States per Region
U.S. North	Alaska, Colorado, Connecticut, Idaho, Illinois, Indiana, Iowa, Kansas, Maine, Massachusetts, Michigan, Minnesota, Missouri, Montana, Nebraska, New Hampshire, New Jersey, New York, North Dakota, Ohio, Oregon, Pennsylvania, Rhode Island, South Dakota, Utah, Vermont, Washington, West Virginia, Wisconsin and Wyoming.
U.S. South	Alabama, American Samoa, Arizona, Arkansas, California, Delaware, District of Columbia, Florida, Georgia, Guam, Hawaii, Kentucky, Louisiana, Maryland, Mississippi, Nevada, New Mexico, North Carolina, Oklahoma, Puerto Rico, South Carolina, Tennessee, Texas and Virginia.

3.2.5.2 Consortium for Energy Efficiency

The Consortium for Energy Efficiency (CEE) is a coalition of energy efficiency programs in the United States and Canada, including state energy efficiency offices, energy efficiency advocacy groups, and utilities engaged in establishing common goals and methods for promoting energy efficiency across a broad range of products.

The CEE Residential Gas Heating Initiative promotes the use of high-efficiency residential furnaces. CEE identifies three tiers of annual fuel utilization efficiency for gas furnaces. Table 3.2.6 shows the AFUE requirements for gas furnaces at each CEE tier. The CEE also promotes the use of high-efficiency indoor blower fan technology by setting a furnace fan efficiency performance level. To meet the CEE furnace fan standard, the furnace fan efficiency

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

ratio (e) must be less than or equal to 2.0 percent (on a furnace with a minimum AFUE of 90 percent).[13]

Table 3.2.6 CEE Fuel Use Performance Levels for Residential Gas Furnaces

CEE Tier	AFUE Requirement %
1	90
2	95
3	97

Source: Consortium for Energy Efficiency. *CEE High-Efficiency Specifications for Gas Furnaces and Boilers.* (Last Accessed September 4, 2014) <http://library.cee1.org/content/natural-gas-residential-furnaces-qualifying-products-list/>

3.2.5.3 Consumer Rebate Programs

In addition to the state tax credits available for purchasers of residential furnaces, many states and local utility companies offer rebates for high-efficiency products, typically for existing home retrofits only. DOE maintains a database of such rebates, called the Database of State Incentives for Renewables & Efficiency (DSIRE), in addition to information on other state, local, utility, and federal incentives and policies that promote renewable energy and energy efficiency.[e]

3.2.5.4 State Tax Credits

DOE identified three states that have tax credits for residential furnaces: Montana, Oregon, and Kentucky.

Montana has had an Energy Conservation Tax Credit for residential energy conservation measures since 1998.[14],[15] The tax credit covers a variety of residential energy and water efficiency installations, including ENERGY STAR heating and cooling equipment. The amount of the credit increased in 2002 from five percent of equipment costs (up to $150) to 25 percent (up to $500 per taxpayer). The Energy Conservation Tax Credit can be used for equipment installed in new construction or remodeling projects, with the tax credit allowed only for the portion of the cost and materials above “established standards of construction.”

Oregon’s Residential Energy Tax Credit (RETC) was created in 1977 to encourage the use of renewable resources in households. The Oregon legislature expanded the RETC program in 1997 to include residential refrigerators, clothes washers, and dishwashers; participation in the program increased significantly after they became eligible. The program subsequently added credits for furnaces and boilers in 2002.[16]

Kentucky offers a 30 percent state income tax credit through December 31, 2015, for taxpayers who install certain energy efficiency measures on their principal residence or

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[e] For more information on individual rebate programs, please visit the DSIRE website at www.dsireusa.org.

residential rental property. These energy efficiency measures include "qualified energy property unstallation," which includes gas-fired furnaces. Equipment must meet the efficiency guidelines specified in the federal tax credit for residential energy property (see Table 3.2.7). These credits apply to equipment purchased in taxable years 2009 to 2015 and may be carried forward for one year.[17],[18]

Table 3.2.7 State Tax Credits for Residential Gas Furnaces[19]

State	AFUE Requirement %	Other Requirements	Available Tax Credit
Oregon	95	Electrically-efficient fan motor, direct vent, installed after 1/1/13	$352
	97	Electrically-efficient fan motor, direct vent, installed after 1/1/13	$492
Montana	95 for natural gas or propane furnaces	N/A	25% of cost, up to $500 for individual and $1,000 for married couple filing jointly
Kentucky	95	Must be equipment purchased from 2009 through 2015	30% of installed cost, $500 maximum

Source: DSIRE, Database of State Incentives for Renewables and Efficiency. Personal Tax Credit, Montana, Energy Conservation Installation Credit. (Last accessed September 4, 2014.) <http://www.dsireusa.org/incentives/incentive.cfm?Incentive_Code=MT24F&re=0&ee=0>

3.2.5.5 Federal Energy Management Program Procurement Guidelines

DOE reviewed the Federal Energy Management Program (FEMP) procurement guidelines for federal government equipment purchasing. The mission of DOE's FEMP[f] is "to

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

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."[20] FEMP helps federal buyers identify and purchase energy efficient equipment.

FEMP designates standards for residential gas furnaces purchased by the federal government. The designated FEMP gas furnace standard level is the ENERGY STAR level specific to the jurisdiction of the government facility.[21]

3.2.6 Industry Cost Structure

DOE developed an industry cost structure for residential furnaces from publicly available information from the Census Bureau's *ASM* and the Security and Exchange Commission (SEC) 10-K[g] reports filed by publicly owned manufacturers. Companies subject to SEC regulations must report sales, costs of goods sold, gross profits, and various overhead costs, in addition to overall performance and operations for the year. DOE analyzed SEC 10-K reports from 2007 to 2013 and developed a representative cost structure for the furnace industry. The cost of materials as a percentage of revenue for each product can fluctuate as raw material costs change from year to year. For more information on the furnace industry cost structure derived using SEC 10-K data, see chapter 12 of this TSD.

The Census Bureau collects industrywide employment data based on NAICS codes. As stated previously, manufacturers of residential furnaces are grouped into NAICS code 333415. Table 3.2.8 presents the residential air conditioning and warm air heating equipment and commercial and industrial refrigeration equipment manufacturing employment levels and earnings from 1997 to 2011 according to the NAICS.

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[h] See DOE's residential furnace fan webpage for more information, available at www.eere.energy.gov/buildings/appliance_standards/residential/furnace_fans.html.

Table 3.2.8 Air Conditioning and Warm Air Heating Equipment and Commercial and Industrial Refrigeration Equipment Manufacturing Industry Employment and Payroll Data [22,23,24]

Year	Production Workers	Total Number of Employees	Payroll for All Employees *$, thousands*
2011	62,009	83,969	3,763,853
2010	61,668	83,361	3,778,633
2009	60,259	85,475	3,768,643
2008	70,772	96,502	4,010,045
2007	74,728	101,485	4,034,043
2006	74,909	98,097	4,019,813
2005	76,011	102,354	3,942,808
2004	73,106	99,035	3,691,029
2003	77,488	104,668	3,776,417
2002	80,417	108,274	3,815,747
2001	88,978	118,876	3,950,483
2000	97,978	127,384	4,267,872
1999	95,904	123,962	4,043,064
1998	91,994	120,011	3,844,667
1997	90,968	119,386	3,678,996

The statistics illustrate a generally declining trend in both the number of production and non-production workers in the industry after the year 2000. The overall decline in employment may be a result of industry consolidation, increased automation in production, manufacturers moving their facilities outside of the United States to reduce labor costs, or economic downturn leading to decreased demand. The increase in employment in 2005 may have resulted from manufacturers of residential central air conditioners and heat pumps augmenting the number of production workers to deal with the increased demand for central air conditioners and heat pumps that occurred prior to the most recent federal standards for those products, which became effective in 2006.

Table 3.2.9 presents the costs of materials and industry payroll as a percentage of value of shipments from 1997 to 2009.

Table 3.2.9 Air Conditioning and Warm Air Heating Equipment and Commercial and Industrial Refrigeration Equipment Industry Cost Data [22,22,22]

	Percent of Value of Shipments		
Year	**Cost of Materials %**	**Cost of Payroll for Production Workers %**	**Cost of Total Payroll %**
2009	55.1	7.9	13.9
2008	54.8	8.1	13.5
2007	55.6	8.2	13.4
2006	53.2	8.9	13.8
2005	53.8	8.5	13.8
2004	51.1	8.8	14.2
2003	50.6	9.5	15.4
2002	49.4	9.8	15.9
2001	52.6	9.8	15.8
2000	53.0	10.1	16.0
1999	53.4	9.8	15.4
1998	54.9	9.9	15.4
1997	54.2	10.1	16.0

The cost of materials as a percentage of value of shipments has fluctuated slightly over the 13-year period. The cost of payroll for production workers as a percentage of value of shipments has followed a declining pattern since 2000, with the exception of 2006, during which the cost of payroll for production workers increased from the previous year. Finally, the cost of total payroll as a percentage of value of shipments has generally declined since 2000, illustrating a reduction in industry non-production or administrative employees, possibly the product of selling, general, and administrative cost-cutting measures.

A detailed financial analysis of the manufacturers of each of the product types covered by this rulemaking is presented in the MIA (chapter 12 of this TSD). This analysis identifies key financial inputs including cost of capital, working capital, depreciation, capital expenditures, etc.

3.2.7 Product Lifetime

The lifetime of residential furnaces can vary greatly depending on how often the system is used (which is dependent upon the climate of the region where the product is installed and the personal preferences of the consumer) and how regularly it is maintained and serviced. Generally, most sources estimate the lifetime of residential furnaces to be in the range of 10 to 20 years. *Appliance Magazine* publishes an *Annual Portrait of the U.S. Appliance Industry*, in which it estimates low, high, and average lifetimes for a range of home appliances, including gas-fired furnaces, based on input from appliance experts and additional sources. In 2009, *Appliance Magazine* estimated the typical service lifetime range of a gas furnace is 12 to 17 years, and the average lifetime of a gas furnace is 15 years.[25] DOE's methodology for determining the lifetime of the products under analysis is described in detail in chapter 8 of this

TSD. Using a combination of Residential Energy Consumption Survey (RECS) data, large-scale surveys of commercially available products, and manufacturer information about historical shipments and stock, DOE estimated that the median lifetime of non-weatherized gas-fired furnaces and mobile home gas-fired furnaces is 21.7 years. Additional information about product lifetimes is contained in chapter 8 (life-cycle cost and payback period analyses) of this TSD.

3.2.8 Market Performance Data

As noted in section 3.1, DOE primarily examined the CCMS database to develop an understanding of the residential furnace industry and market. This database contains information such as brand name, model number, input capacity, and efficiency. DOE only examined products that meet EPCA's definition of a residential furnace (see section 3.1.1 of this chapter). In addition, DOE excluded from its analysis any products that were manufactured for installation in Canada or for export only, and any products in the AHRI *Directory of Certified Product Performance* that were not labeled as "active," meaning that they are not currently being manufactured. Table 3.2.10 shows the number of models in the CCMS database for both equipment classes of furnaces analyzed in this rulemaking. The number of models studied in this analysis is a consolidation of the total quantity actually listed in the CCMS database. DOE consolidated the database by removing duplicate models of furnaces that had identical model numbers as other furnaces, but were originally counted separately due to brand name differences. As Table 3.2.10 indicates, the large majority of residential furnaces are non-weatherized gas-fired furnaces and there are comparatively few mobile home gas-fired models.

Table 3.2.10 Number of Furnace Models Listed in the CCMS Database by Product Class[26]

Product Class	Number of Models*
Non-weatherized gas furnaces	1,215
Mobile home gas furnaces	113

* The number of models studied in this analysis is a consolidation of the total quantity actually listed in the CCMS database. DOE consolidated the database by removing duplicate models of furnaces that had identical model numbers as other furnaces, but were originally counted separately due to brand name differences.

3.2.8.1 Efficiency Data

DOE characterized the distribution of furnace efficiencies currently available to consumers by dividing the products listed in the DOE database into bins based on their efficiency and counting the number of models in each efficiency bin. The efficiency ratings were separated into bins in sizes of 1.0 percent AFUE. Each bin is named by a center-point integer AFUE value, and each bin's range represents the range of AFUE values that round to that integer value of AFUE (*e.g.*, the 80 percent AFUE bin includes all values 79.5 percent AFUE through 80.4 percent AFUE). Figure 3.2.6 and Figure 3.2.7 show histograms of the efficiency data for each product class.

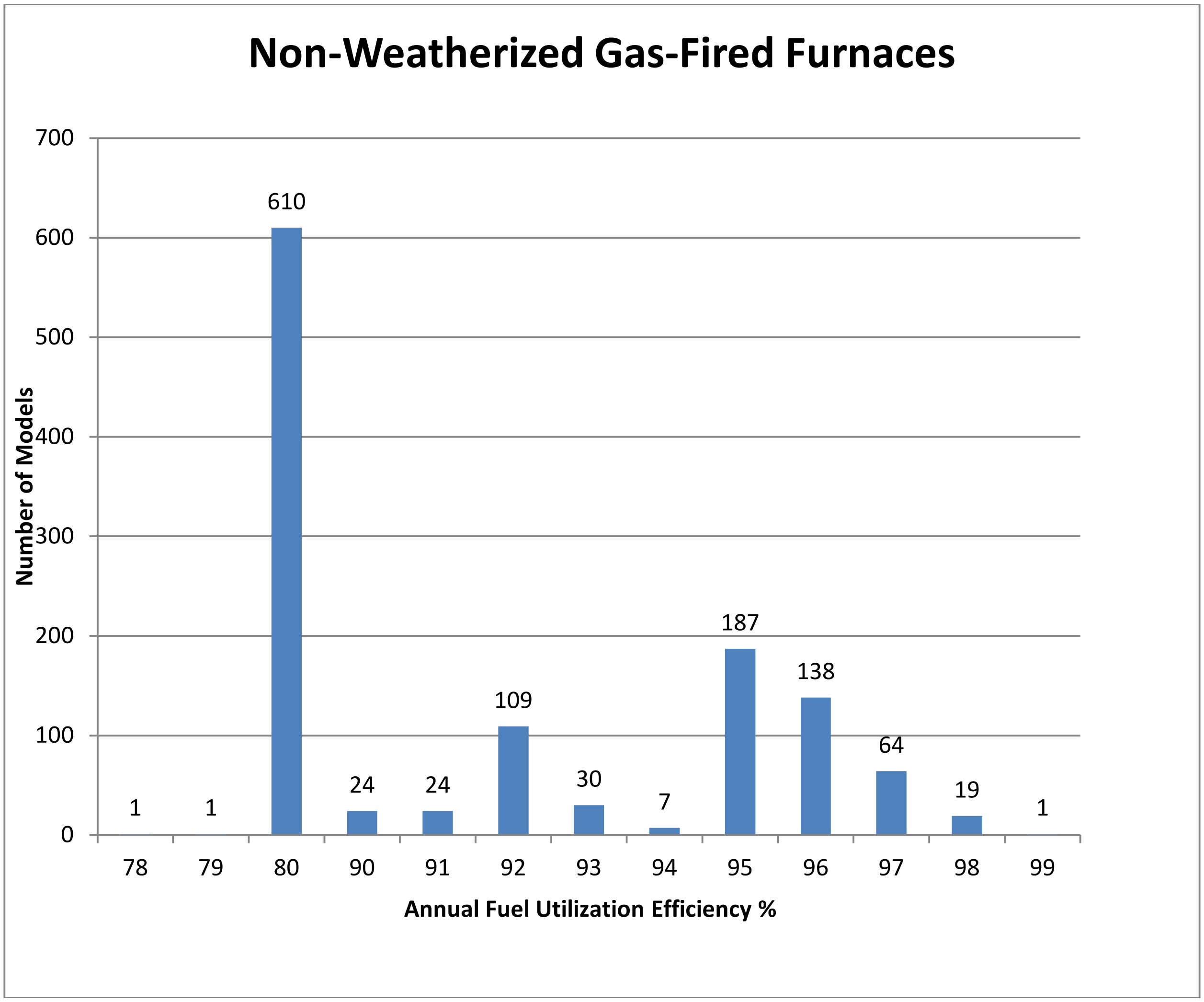

Figure 3.2.6 Distribution of Non-Weatherized Gas-Fired Furnace Models by AFUE

As Figure 3.2.6 shows, non-weatherized gas furnace efficiencies typically fall into two ranges: non-condensing (between 78 percent and 80 percent AFUE) and condensing (at or above 90 percent AFUE). The vast majority of non-condensing models are at 80 percent AFUE, while the largest number of condensing models is at 95 percent AFUE.

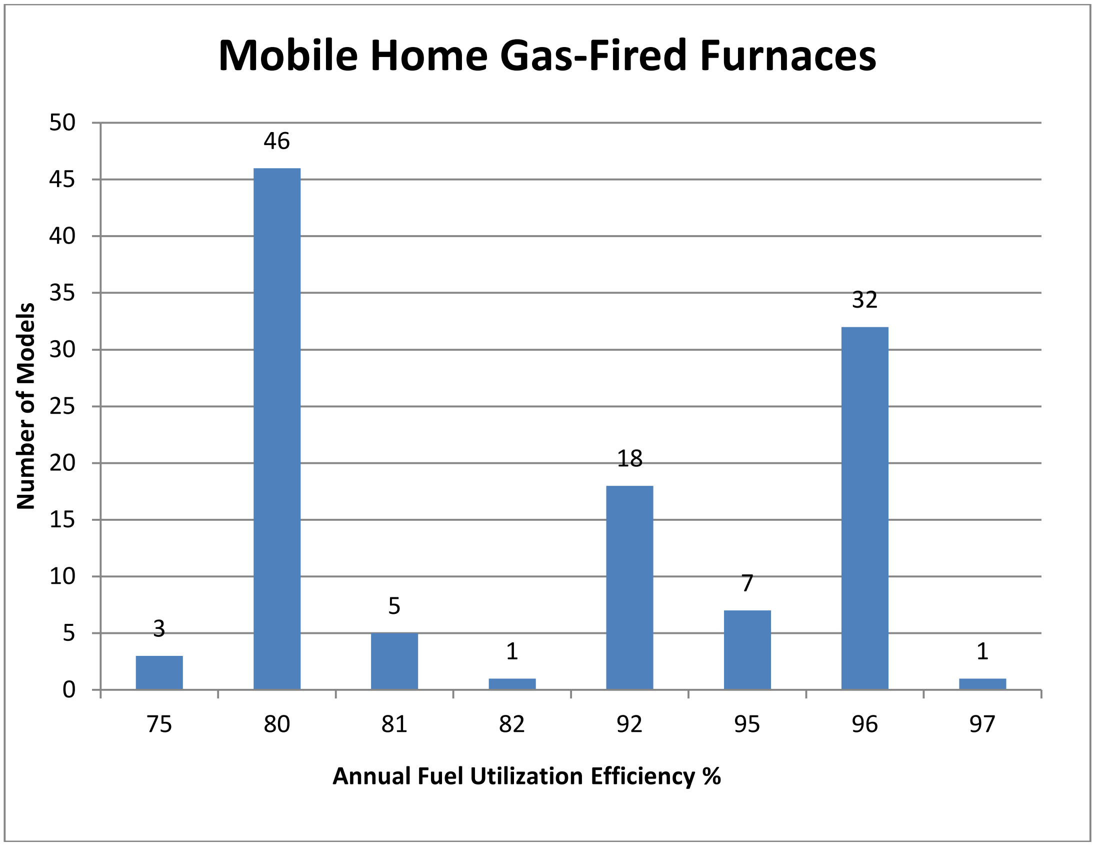

Figure 3.2.7 Distribution of Mobile Home Gas-Fired Furnace Models by AFUE

As shown in Figure 3.2.7, the distribution of mobile home gas furnaces is similar to that of non-weatherized gas furnaces in that the majority of models fall into one of two ranges – non-condensing (*i.e.*, 78 to 82 percent AFUE) or condensing (*i.e.*, at or above 92 percent AFUE). As with non-weatherized gas furnaces, most non-condensing mobile home gas furnaces are concentrated at 80 percent AFUE, and most condensing mobile home gas furnaces are at 96 percent AFUE.

3.2.8.2 Capacity Data

In characterizing the residential furnace market, DOE also examined the distribution of models by their input capacity ratings. DOE divided the products into bins based on their input capacities and counted the number of models in each input capacity bin. The capacities were separated into bins in sizes of 10,000 Btu per hour. Each bin is named by its midpoint, and each bin's range is defined by furnaces with input capacities no less than 5,000 Btu per hour less than the midpoint, and no greater than 4,999 Btu per hour higher than the midpoint (*e.g.*, the 80,000 Btu per hour bin includes all values 75,000 Btu/h through 84,999 Btu/h). Figure 3.2.8 and Figure 3.2.9 show these distributions for both the NWGF and MHGF product classes covered in this rulemaking, respectively. Based on the model distributions by input capacity, DOE determined that 80,000 Btu per hour is the representative input heating capacity for both the non-weatherized gas and mobile home gas product classes, because in both of these product classes, the distribution of units across input heating capacities is centered around 80,000 Btu per hour heating input.

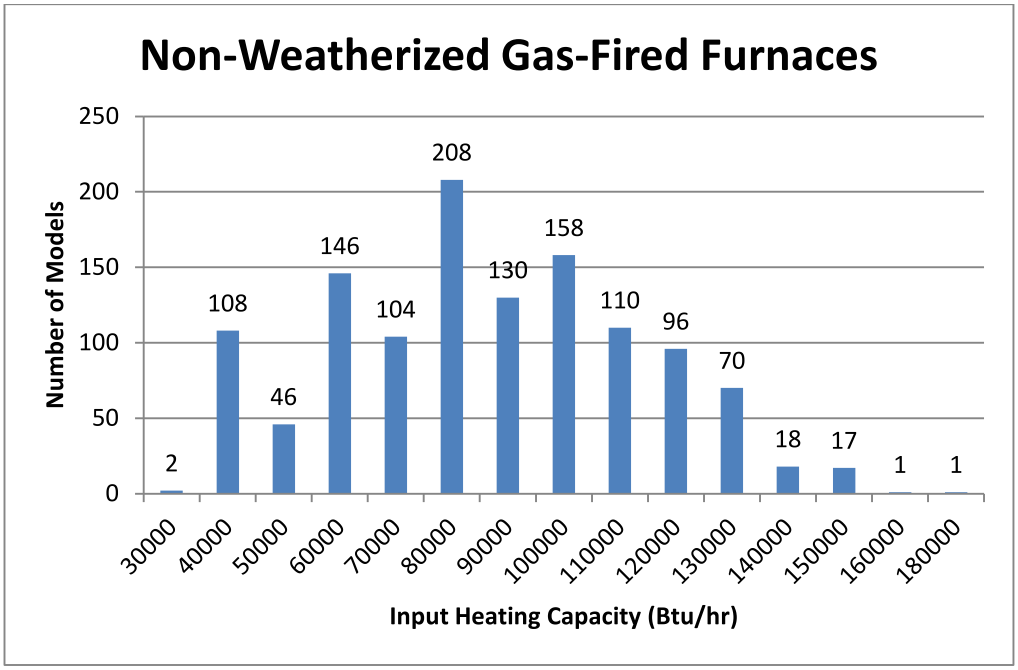

Figure 3.2.8 Distribution of Non-Weatherized Gas Furnace Models by Input Capacity

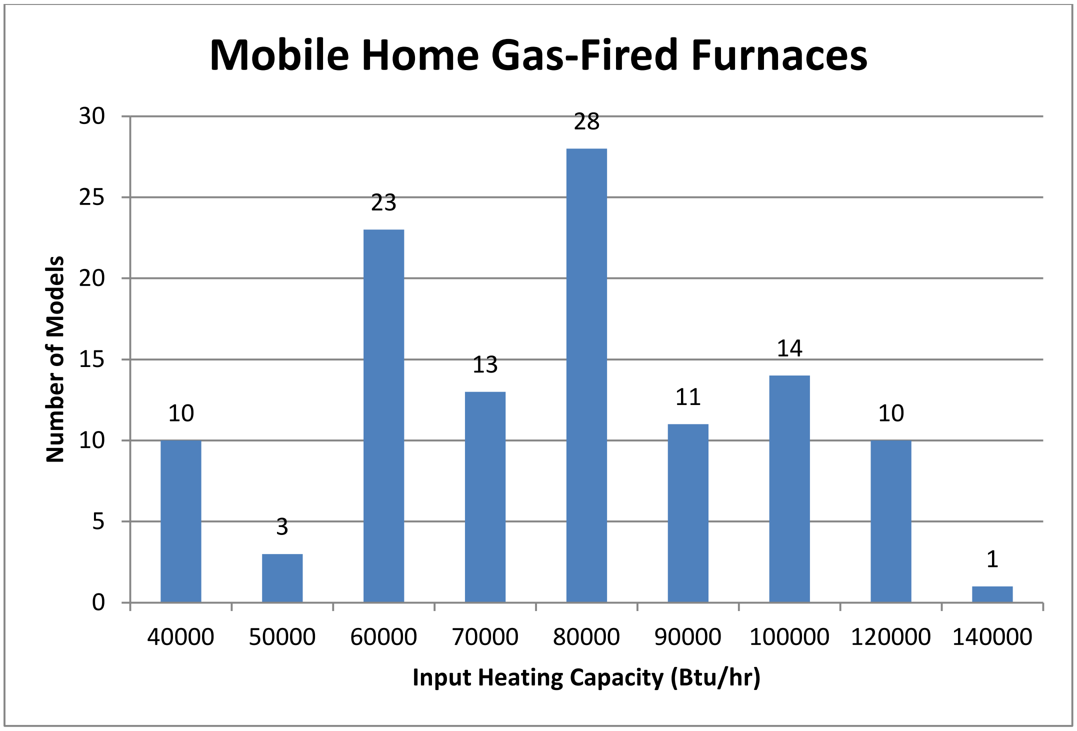

Figure 3.2.9 Distribution of Mobile Home Gas Furnace Models by Input Capacity

3.2.9 Historical Shipments and Efficiencies

3.2.9.1 Historical Shipments

Information about annual furnace shipment trends allows DOE to estimate the impacts of energy conservation standards on the residential furnace industry. DOE has examined unit shipments and value of shipments using publicly available data from the ASM and CIR, and estimates from AHRI and *Appliance Magazine*.

AHRI tracks shipment data of the warm air furnaces manufactured by AHRI member companies, which manufacture the vast majority of the furnaces shipped in the United States each year. Figure 3.2.10 presents annual shipments of gas (both NWGF and MHGF units) and oil-fired residential furnaces (excluding exports) from 1994 through 2013 based on AHRI data. Although oil-fired furnace standards are not being analyzed in this rulemaking, DOE presents shipments and fuel price data for oil-fired furnaces because they compete for sales with the gas-fired furnaces in this rulemaking.

From the data, it is apparent that gas furnaces comprise the vast majority of the residential furnace industry. Shipments of gas furnaces grew steadily until 2005, then plunged in the subsequent four years to 30 percent below the unit shipments at the beginning of the decade. This trend mirrors that of new housing starts over the same time period, indicating that gas furnace shipments may be driven, in part, by the new construction market. Shipments of oil-fired furnaces remained relatively steady over the first part of the decade, before dropping by more than half between 2005 and 2009. This directly corresponds with rising heating oil prices, shown in Figure 3.2.11, which more than doubled in the same period. This strong correlation between shipments and fuel prices indicates that the oil warm-air heating market may be driven, in part, by the replacement market.

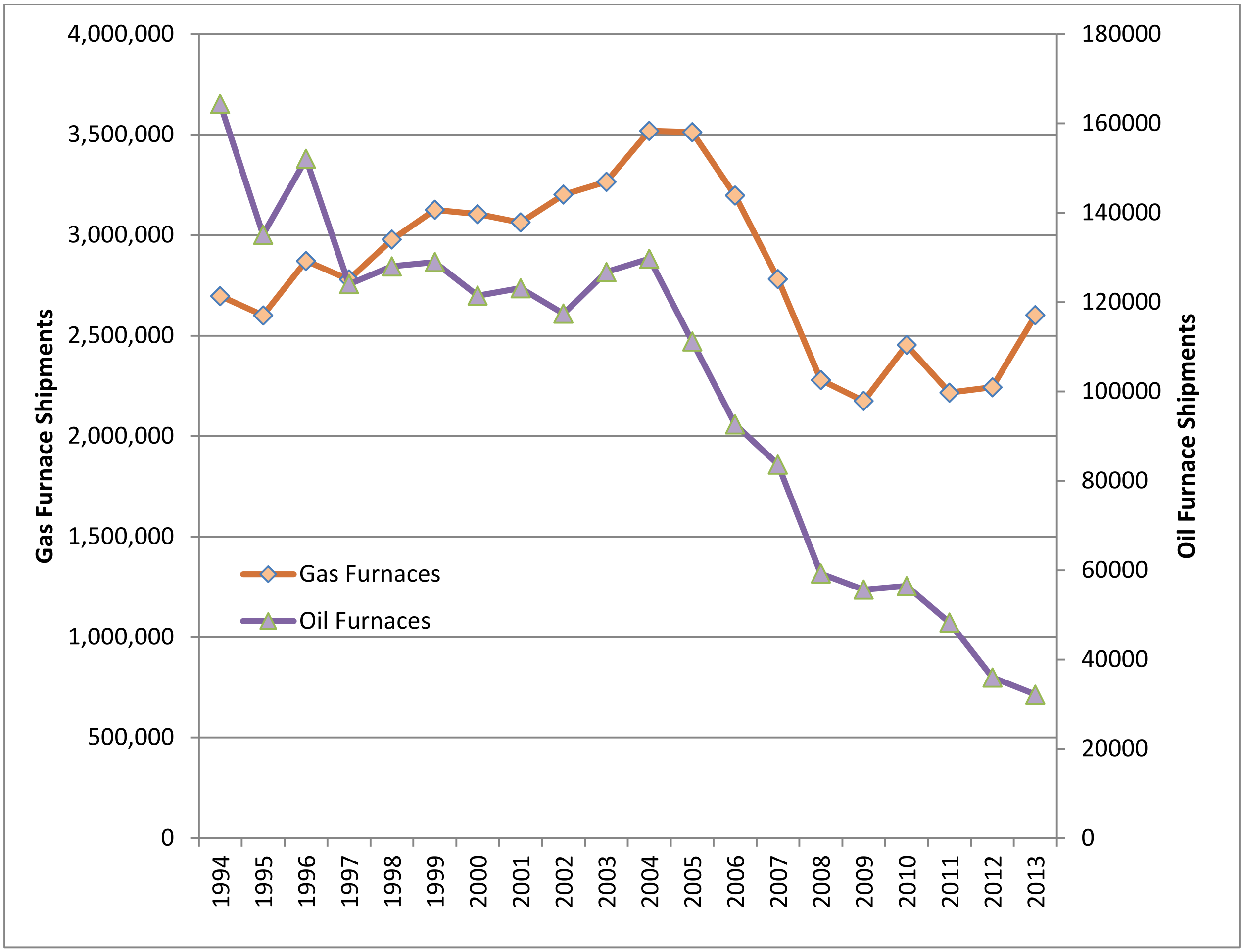

Figure 3.2.10 Residential Furnace Industry Shipments (Domestic and Imported), 1994 to 2013[27]

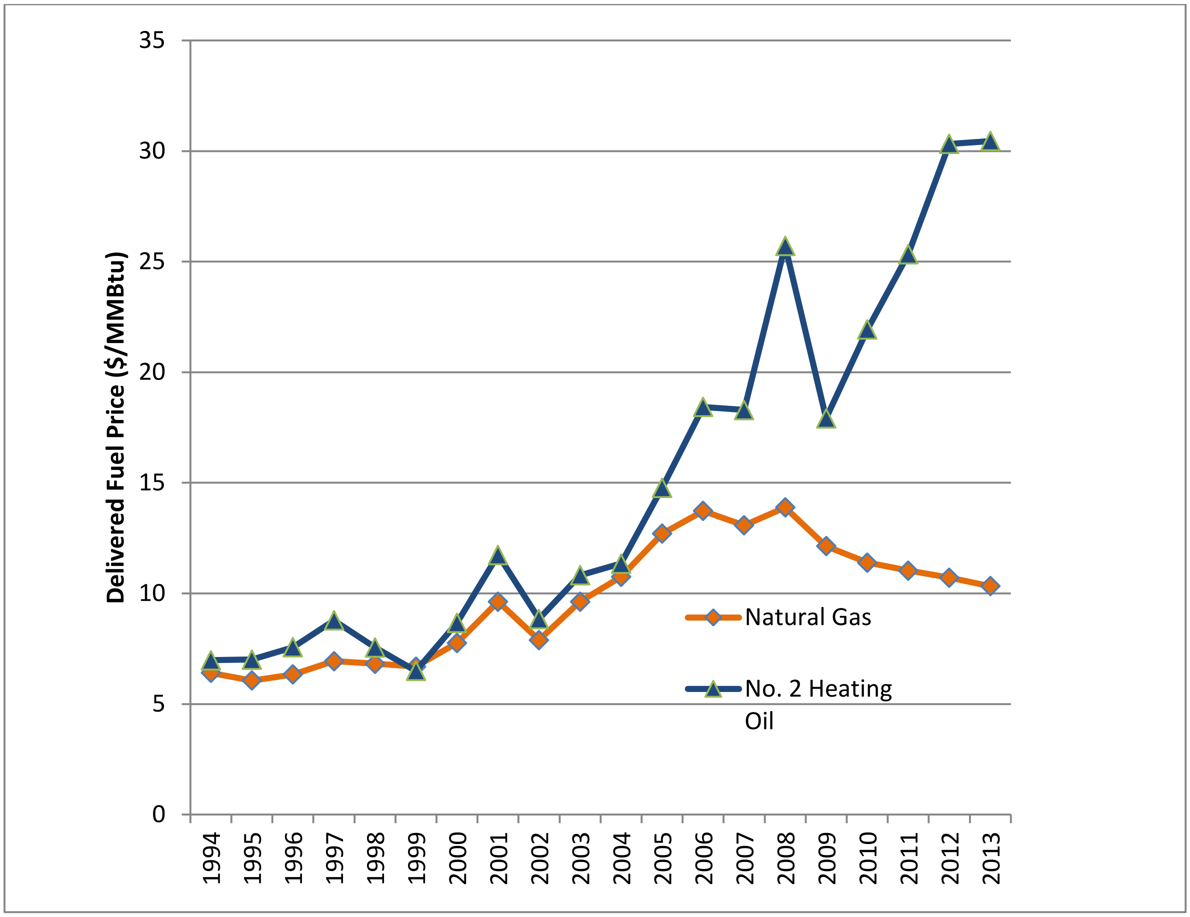

Figure 3.2.11 Average Fuel Prices[28,29], 1994 to 2013

3.2.9.2 Value of Shipments

Table 3.2.11 provides the value of shipments for the residential furnace industry from 2005 to 2010 using the Census Bureau CIRs.[30] The CIR expresses all dollar values in current dollars (*e.g.*, 2005 data are expressed in 2005$). Using the gross domestic product deflator, DOE converted each year's shipment values to 2010$; 2010 was the last year included in the CIR data set.

Table 3.2.11 Value of Residential Furnace Shipments by Year[31]

Year	**Value of Shipments** ***$, millions***	**Value of Shipments in 2010$** ***$, millions***
2010	1,999	1,999
2009	1,828	1,850
2008	1,829	1,865
2007	2,090	2,173
2006	2,205	2,353
2005	2,268	2,495

From this data it is apparent that the residential furnace industry gradually shrank between 2005 and 2009, but saw growth in 2010.

3.2.9.3 Saturations in U.S. Households

Stock saturation refers to the percentage of housing stock equipped with a given product or exhibiting a certain feature. As of 2009, 44.8 percent (50.9 million) of homes in the United States have central warm-air furnaces.[32] Of these furnaces, 44.3 million are gas furnaces, 2.7 million are oil-fired furnaces, and 3.9 million are liquid petroleum gas furnaces. Within individual homes, warm-air space heating represents, on average, 50.8 percent (5.169 quadrillion Btu) of total annual household energy consumption.[32]

3.3 FURNACE TECHNOLOGY ASSESSMENT

The purpose of the technology assessment is to develop a list of technology options that manufacturers can use to improve the efficiency of residential furnaces. The following assessment provides descriptions of those technology options that apply to all product classes.

In preparation for the screening and engineering analyses, DOE identified possible technology options for improving furnace efficiency and examined the most common efficiency-improving technologies used today. These technology options provide insight into the technological improvements typically used to increase the energy efficiency of residential furnaces.

3.3.1 Furnace Characterization

At a basic level, furnaces are characterized based on fuel type, whether they are weatherized, whether they are designed for condensing operation, and the physical configuration of the heat exchanger and blower.

3.3.1.1 Weatherization

Residential furnaces can be described as either weatherized or non-weatherized furnaces. Weatherized furnaces are generally installed outdoors (often on rooftops), and non-weatherized furnaces are installed indoors. The main difference between a weatherized furnace and a non-weatherized furnace is that the weatherized furnace has a weather-resistant external case, while the non-weatherized furnace does not. Weatherized furnaces are only used as part of unitary heating and cooling units, which means that an air conditioner is contained in the same package. DOE is not aware of any manufacturer that presently sells a stand-alone furnace approved for outdoor installation. Manufacturers produce few weatherized oil-fired furnaces.

Because weatherized furnaces are subject to adverse weather conditions, the heat loss through the jacket of a weatherized furnace is higher than that of a non-weatherized furnace. To account for this, the DOE test procedure requires manufacturers to rate weatherized furnaces for outdoor installation; they do so by applying a higher multiplication factor to the jacket losses in order to simulate outdoor conditions.

The DOE test procedure specifies that all non-weatherized furnaces shall be rated and tested as isolated combustion systems , which means that the furnace is isolated from the heated space and draws combustion and dilution air, if applicable, from the outdoors. Because all non-weatherized furnaces are rated under the same conditions, those that are installed in the heated space do not have a rated AFUE advantage over those that are installed outside of the heated space, such as non-weatherized furnaces installed in garages, due to their jacket losses. However, in real-world applications, conductive heat transfer through the jacket of a non-weatherized furnace installed in the heated space will dissipate as useful heat to the heated space. This means that non-weatherized furnaces installed in the heated space may be able to realize higher operational efficiencies compared with their ratings. This rulemaking only considers non-weatherized furnaces, as both of the product classes being analyzed (NWGF and MHGF) include only non-weatherized products.

3.3.1.2 Condensing Operation

Non-weatherized furnaces can be either non-condensing or condensing. When the flue gas temperature is substantially higher than the water vapor dew point and the latent heat (the heat from condensation of water vapor in the combustion products) is not recovered in the appliance's heat exchanger, the furnace is classified as non-condensing. The AFUE of such furnaces is generally below 82 percent AFUE for natural gas furnaces and 88 percent AFUE for oil-fired furnaces. Condensing furnaces recover more heat from the combustion products by condensing the water vapor in the flue gases. There are relatively few weatherized condensing furnaces available on the market compared to non-weatherized models, primarily because of concerns that the condensate could freeze and damage the furnace under cold, outdoor winter temperatures.

As water vapor begins to condense in the furnace's heat exchanger, the latent heat recovered from the vapor raises the furnace's AFUE to above 90 percent, with a higher AFUE indicating a greater amount of condensation being formed. Condensing furnaces typically require additional components, such as a corrosion-resistant secondary heat exchanger and a condensate drain device. Condensing furnaces also cannot use a natural draft venting system, because the buoyancy of the cooler flue gases is not sufficient to draw the gases up a regular chimney. Forced and induced draft blowers are used in conjunction with condensing furnaces to draw air into the combustion zone and exhaust the flue gases through the vents.

Furnaces generally are not manufactured in the 82 to 89 percent AFUE range. In this range, corrosive condensate can form in the vent system under certain operating conditions, which can cause safety concerns in venting systems used for non-condensing furnaces. However, the temperature of the flue gases is still too high at these efficiencies to allow for the use of polyvinylchloride for the venting system. Proper venting of such a furnace requires a special stainless steel venting system, which is often cost prohibitive. As a result, manufacturers typically do not offer products in this range of efficiencies.

3.3.1.3 Configurations

Three different airflow configurations are commonly used in residential furnaces: 1) horizontal; 2) upflow; and 3) downflow or counterflow. A fourth design, called multipoise or multiple direction, allows the furnaces to be set up in two or three of the previously listed configurations depending on the installation requirements. Each configuration requires a different arrangement of the furnace's basic components.

The horizontal furnace configuration is commonly used in attics, crawl spaces, and other locations where the height of the furnace is the constraining dimension. Air enters at one end of the unit through the blower compartment, is forced horizontally over the heat exchanger, and then exits the furnace at the opposite end through installed ductwork that distributes it to the heated space. Horizontal furnaces are most common in weatherized (especially rooftop) units.

The upflow "highboy" configuration is most commonly used for basement or first-floor equipment room installations where floor space is at a premium. In this configuration, the blower is located below the heat exchanger. Air enters at the bottom or lower side of the unit and leaves at the top through a warm-air outlet (plenum). The upflow "lowboy" furnace configuration occupies more floor space and is lower in height than the upflow highboy design, which makes it suited for basement installations where both floor space and height are constraints. In the upflow lowboy configuration, manufacturers place the blower alongside the heat exchanger. A return-air plenum is installed above the blower compartment, and a supply-air plenum is installed above the heat exchanger compartment. The upflow highboy configuration is most common in non-weatherized gas and oil-fired furnaces.

The downflow, or counterflow, configuration is used in houses that have an under-the-floor type of heat distribution system, where the ductwork that delivers heated air is located beneath the conditioned space. In this configuration, the blower assembly is located above the heat exchanger, and the return-air plenum is connected to the top of the unit. Most mobile home furnaces are installed in the downflow configuration.

The multipoise, or multiple-direction, furnace design allows for the unit to be configured as upflow, horizontal, or downflow, depending on the requirements of the particular installation. Some multipoise furnaces are able to be configured in all three configurations (*i.e.*, upflow, horizontal, and downflow), while others are only designed to be set up in two of the three configurations (*e.g.,* upflow and horizontal). Demand is growing for these products because they allow for more flexibility and can accommodate different types of installations. Multipoise appliances are more expensive to manufacture because they require extensive testing and more complicated controls. The majority of modern non-weatherized furnaces are multipoise.

3.3.2 Baseline Product Components and Operation

A basic residential gas furnace comprises a hot surface or direct spark ignition system, tubular inshot burners, non-condensing heat exchanger, single-speed air blower assembly with permanent split capacitor (PSC) motor and forward swept blades, single-speed mechanical draft combustion fan assembly, and automatic controls.

3.3.2.1 Heat Exchanger

The heat exchanger's function is to transfer heat from the combustion gases to the circulating air, which is then distributed to the heated space. The heat exchanger of a baseline unit is usually constructed from aluminized, cold-rolled steel or stainless steel with welded or crimped seams. There are two types of primary heat exchangers commonly used in residential furnaces: individual section and drum.

Individual-section heat exchangers consist of a number of separate heat exchanger sections. Each section has an individual fuel-burning device. The sections are typically joined together at the upstream end of the heat exchanger so that a common ignition device can light all of the burners. The sections are also joined together at the downstream end to direct flue gases to a common flue. The individual-section type of heat exchanger is used primarily in gas-burning products.

Tubular and clamshell heat exchangers are different types of individual-section heat exchangers. A tubular heat exchanger comprises several metal tubes bent in shape, while the clamshell, or serpentine, heat exchanger is manufactured by folding specially formed sheets of metal. Heat exchanger designs differ from manufacturer to manufacturer, but are typically similar across all product lines for a specific manufacturer. Tubular heat exchangers require a smaller initial investment than clamshell types, but can be more costly if produced in high volume.

Drum heat exchangers have a single combustion chamber and use a single-port fuel-burning device. The drum heat exchanger is used primarily in oil-firing units and occasionally in mobile home gas furnace designs.

3.3.2.2 Burner Assembly

The gas burner assembly in a residential furnace functions to: (1) control and regulate the flow of gas, (2) ensure the proper mixture of gas with air, and (3) ignite the gas under safe conditions. To accomplish these functions, a gas burner assembly consists of four major parts or sections: a gas valve, an ignition device, a manifold and orifice(s), and gas burners and adjustments.

The gas valve consists of a number of parts—a hand shutoff valve, a pressure-reducing valve, safety shutoff equipment, and an operator-controlled automatic gas valve—each performing a different function. In modern units, these parts are all contained in a combination gas valve.

The manifold connects the gas supply from the gas valve to the burners and delivers gas in equal proportions to each burner. The orifices permit a high-velocity stream of gas to enter the burners and meter the gas flow.

Gas-burning devices require the correct mixture of air (*i.e.*, oxygen) and gas to be supplied to ensure complete combustion. Primary air, which is mixed with the gas prior to combustion, accounts for 30 to 50 percent of the total air required for stoichiometric combustion. Secondary air, which is supplied to the flame at the time of combustion, provides the remaining

50 to 70 percent of the total air supply to prevent the formation of noxious carbon monoxide. To produce efficient and safe combustion, it is essential to maintain the proper ratio of primary to secondary air. In gas furnaces, the burners are typically "inshot" (*i.e.*, single-port), which means that one long flame is directed into the heat exchanger section after ignition. The fuel enters the burner through a venturi tube that accelerates the gas stream. In turn, the high velocity of the gas stream creates a suction effect that entrains the primary air into the tube and mixes it with gas from the gas service line. This mixture of gas and primary air oxidizes in the first stage of combustion. In the second stage of combustion, secondary air is introduced to the combustion zone in excess to burn the remaining gas.

3.3.2.3 Electronic Ignition

Modern furnaces are equipped with electronic ignition systems, which light the burner with an electrical component upon a call for heat. Unlike standing pilot ignition systems that consume fuel continuously, electronic devices and their control modules (which house electronic circuitry required to control the ignition system) operate only during the active mode. The different types of electronic ignition systems are discussed in greater detail below.

Hot Surface Ignition. Hot surface ignition (HSI) is the most common form of electronic ignition in gas furnaces and the baseline ignition component for non-weatherized gas-fired furnaces and mobile home gas-fired furnaces. The igniter in this system is an electrically heated resistance element that thermally ignites the main burner directly, without use of a pilot light. Hot surface igniters use simpler controls and are regarded in the industry as being more reliable than other types of electronic ignition. In HSI operation, a voltage is applied to the igniter until its surface is sufficiently hot to light the system's main burner directly. Silicon nitride igniters offer a durability advantage over silicon carbide, and as a result they have largely replaced silicon carbide igniters in most modern furnaces.[33]

Direct Spark Ignition. A direct spark ignition (DSI) system provides the same functionality as a hot surface igniter: it serves to ignite the main burner and acts as a flame sensor. As its name implies, the DSI lights the main burner directly by generating a spark. There is no pilot light. Flame rectification is used to detect flame presence: if a flame is present, the control module will hold the gas valve open and cut off power to the igniter. If a flame has not been established within the trial-for-ignition period (approximately 4 to 7 seconds), the system will go into lockout and must be reset. Direct spark igniters are the baseline ignition component for weatherized gas furnaces, which DOE is not analyzing in this rulemaking, as discussed in the NOPR, as well as in section 3.3.1.1 of this chapter.

Intermittent Pilot Ignition. This is a device that lights a pilot by generating a spark. The pilot light in turn lights the main burner. This type of ignition is uncommon in residential furnaces currently on the market.

3.3.2.4 Mechanical Draft

Modern furnaces in all product classes commonly employ mechanical draft, in which motorized fans supply and regulate air for combustion and create sufficient draft to exhaust the flue gases. The fan is typically driven by a single-speed, two-speed, or variable-speed motor in the 75 to 90 watt range. [34]

Mechanical draft systems can be designed as either induced draft (*i.e.*, power vent) or forced draft (*i.e.*, power burner of power combustion) systems. An induced draft fan is located downstream of the heat exchanger in the venting system and pulls flue gases through the gas pathway, creating negative pressure in the heat exchanger. A forced draft fan is located upstream of the heat exchanger and creates positive pressure in the heat exchanger that pushes products of combustion through the vent system. Both methods improve efficiency over natural draft systems by providing the correct fuel-to-air ratio to optimize combustion efficiency and by regulating draft to optimize heat transfer in the heat exchanger.

Induced draft combustions systems also have a safety benefit as compared with forced and natural draft systems. Because airflow through the vents is created by inducing a negative pressure in the heat exchanger, air is pulled through the furnace. This suction mechanism ensures that carbon monoxide and other toxic flue gases cannot leak into the heated space in the case of a cracked heat exchanger or venting system.

3.3.2.5 Blower Assembly

The circulating air blower of a residential furnace is typically a centrifugal fan-impeller with a shaft-mounted motor. The assembly with the fan shroud is mounted in an enclosure at the base of an upflow furnace, the return-air end of a horizontal unit, or the top of a downflow furnace.

Air blowers in residential furnaces generally use multi-speed induction motors, typically PSC designs. Furnaces with premium components may offer brushless permanent magnet (BPM) motors, which have a higher efficiency, and other features, such as modulating capacity controlled by the thermostat.

The blower motor is typically sized for a residential HVAC system based on the quantity of air being moved and the resistance of the system. Because the airflow requirements of central air conditioners are typically higher than those of furnaces, the requirements of the air conditioning system frequently determine the size and electricity consumption of the blower fan motor. However, energy consumed by the blower is not accounted for by the AFUE calculation. DOE has promulgated energy conservation standards for furnace fan electricity consumption in a separate rulemaking published in the *Federal Register* on July 3, 2014.[h] 79 FR 38129.

3.3.3 Technology Options That Improve AFUE

DOE identified the following technology options as having the potential to improve the efficiency of furnaces:

1. Condensing secondary heat exchanger

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[h] See DOE's residential furnace fan webpage for more information, available at www.eere.energy.gov/buildings/appliance_standards/residential/furnace_fans.html.

2. Heat exchanger improvements
3. Two-stage and modulating combustion
4. Pulse combustion
5. Low NOxNOx premix burners
6. Burner derating
7. Insulation improvements
    - increased jacket insulation
    - advanced forms of insulation
8. Off-cycle dampers
9. Direct venting
10. Concentric venting

DOE considered these technology options further in the screening analysis.

3.3.3.1 Condensing Secondary Heat Exchanger

The energy efficiency of gas-fired furnaces can be improved by increasing the amount of heat extracted from the combustion gases so that the water vapor within the gasses begins to condense. Condensation of the vapor in the flue gases signals an efficient transfer of energy from combustion gases to circulation air and is usually achieved by the addition of a secondary heat exchanger. The secondary heat exchanger is typically a tube-fin type heat exchanger constructed from corrosion-resistant stainless steel. The secondary heat exchanger allows more heat to be extracted from the flue gases before the products of combustion exit through the flue to the vent system. Flue gas condensate is acidic and corrosive. Corrosion due to condensation of combustion gases limits the AFUE that can be achieved by a non-condensing furnace to ratings below 82 percent AFUE. Using corrosion-resistant heat exchangers and lining the vent system with corrosion-resistant material allows for AFUE improvements while reducing the risk of corrosion damage to the heat exchanger and venting system.

3.3.3.2 Heat Exchanger Improvements for Non-Weatherized Furnaces

Improving the heat exchanger for furnaces can increase the rate of heat transfer from the hot combustion gases to the circulation air that is distributed to the heated space. This improved heat transfer increases thermal efficiency and AFUE.

Improvements to the heat exchanger can be achieved by modifying baseline designs of standard furnaces to incorporate any combination of (1) increased heat exchanger surface area, (2) heat exchanger surface features, and (3) heat exchanger baffles and turbulators.

Increased heat exchanger surface area. The performance of the heat exchanger can be improved by increasing surface area. An increase in surface area provides a larger surface over which heat transfer can occur. This increases the overall rate of heat transfer occurring in the furnace, thereby improving the furnace's ability to efficiently extract heat from the hot combustion gases. The result is an increase in the steady-state efficiency of the unit, and thus, the AFUE.

Generally, manufacturers increase the surface area of the heat exchanger by increasing the size of the secondary heat exchanger. If the gas temperature is too low, the gases will begin to condense inside the primary heat exchanger, which is usually not corrosion-resistant. Areas where condensation occurs in the primary heat exchanger are sometimes known as “cold spots” and are detrimental to the integrity of the heat exchanger. Manufacturers thus limit the surface area of the primary heat exchanger in order to avoid the formation of cold spots and instead increase surface area in the corrosion-resistant secondary heat exchanger.

Heat exchanger surface features. An alternative to increasing the size of the heat exchanger is enhancing the effectiveness of the heat exchanger surfaces. One way this may be done is by adding surface features to the heat exchanger. Incorporating surface features, such as dimples, increases turbulence in the air passing close to the heat exchanger’s surface, which can enhance heat transfer when correctly designed.

Heat exchanger baffles and turbulators. Turbulators and baffles are pieces of metal that are incorporated into the heat exchanger to improve heat transfer through the walls of the heat exchanger. Turbulators are typically very thin, twisted strips of stainless steel inserted longitudinally into the tubes of the secondary heat exchanger, parallel to air flow. They improve heat transfer by restricting flow in the heat exchanger tubes and increasing turbulence in the combustion gases. Baffles are simply fins or extrusions from the combustion-air side of the heat exchanger wall. Baffles enhance heat transfer primarily by deflecting the products of combustion toward the heat exchanger wall.

3.3.3.3 Two-Stage and Modulating Combustion

Two-stage and modulating combustion allows furnaces to meet heating load requirements more precisely. When low heating load conditions exist, a two-stage or modulating furnace can operate at a reduced input rate for an extended period of burner on-time to meet the reduced heating load. This improves comfort by reducing large fluctuations in room temperature. Because burner on-time increases, however, fuel use does not drastically decrease, and with combustion air supply held constant, there is minimal effect on AFUE.[35] When the combustion air supply is modulated to match the fuel input rate, however, the burner is essentially derated, making the heat exchanger more effective during periods of lower heat demand and significantly raising AFUE. Two-stage and modulating combustion is common in gas furnaces.

Two-stage and modulating gas burners reduce cycling of the furnace by reducing the flow rate of gas at lower heating loads. These burners regulate gas flow but not airflow. When a modulating or two-stage burner is paired with a single-stage combustion fan, a greater percentage of excess air is induced at the lower gas flow rate, resulting in lower combustion efficiencies when compared to the normal or maximum gas flow rate. Because of this, furnaces equipped with two-stage or modulating burners but without two-stage or modulating combustion fans will likely have lower energy efficiency, as measured by the DOE test procedure, than furnaces equipped with single-stage burners.

To overcome this lower efficiency and achieve efficient two-stage or modulating combustion, an induced draft or forced draft system using a two-speed or variable speed combustion fan should be paired with the two-stage or modulating burner. With the multi-speed combustion fan, the excess air drawn into the burner at low gas flow rates can be reduced in order to improve the steady-state efficiency of the furnace.

3.3.3.4 Pulse Combustion

Pulse combustion burners operate on self-sustaining resonating pressure waves that alternately rarefy the combustion chamber (drawing a fresh fuel-air mixture into the chamber) and pressurize it (causing ignition by compression heating of the mixture to its flash point). This process is initiated by a blower that supplies an initial fuel and air mixture to the combustion chamber. A spark ignites the mixture. Once resonance is initiated, the process becomes self-sustaining. Pulse frequencies are on the order of 60 to 70 cycles per second.[36] The turbulent nature of the pulse combustion process requires no mechanical devices (*e.g.,* induced draft fans or power burners) to vent the combustion products to the outside.

Pulse combustion systems feature high heat transfer rates, can self-vent, and can operate as isolated combustion systems. Because the pulse combustion process is highly efficient, the burners are generally used with condensing appliances.

In contrast to furnaces that utilize natural draft and induced draft technologies, pulse combustion furnaces generate positive pressure in the heat exchanger. This creates a potential safety problem because any breach in the heat exchanger would result in a leak of toxic combustion products into the circulation air stream.

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

3.3.3.5 Low Nitrogen Oxide Premix Burners

Low NOx premix burners reduce emissions in two ways: by reducing peak flame temperature and by reducing levels of excess air. They achieve this by completely premixing the primary air and fuel prior to combustion, thereby eliminating the need for secondary air. The greater level of primary air in the lean, premixed air-fuel mixture creates a uniform flame shape that ensures oxygen availability to all regions of the flame. This eliminates the interior region of an inshot burner flame, where sub-stoichiometric, fuel-rich “hot spots” form “thermal NOx” at a rate that increases exponentially with flame temperatures above 2,800 °F. In addition, the absence of secondary air reduces the amount of free oxygen and nitrogen available to the flame exterior, thereby reducing “prompt NOx formation.” Aside from NOx reductions, the leaner, premixed flames also have a higher overall flame temperature than flames with secondary air. The hotter, leaner, premixed flame improves heat transfer and AFUE. It also raises the water vapor dew point, which facilitates condensation and further improves AFUE in condensing mode. The use of low NOx premix burners in a residential furnace would require a major redesign. As such, low NOx premix burners have not yet been successfully incorporated into a residential furnace design.

3.3.3.6 Burner Derating

Reducing burner firing rate while keeping heat exchanger geometry and surface area the same will increase the ratio of heat transfer surface area to energy input, thereby increasing the annual fuel utilization efficiency. However, the lower energy input means that less heat, and thus lower utility, would be provided to building occupants than with conventional burner firing rates.

3.3.3.7 Insulation Improvements

The DOE test procedure requires that all non-weatherized furnaces be rated as isolated combustion systems. The test procedure specifies that the jacket loss for units intended for installation outdoors or in an unheated space may either be assigned a fixed value of 1 percent or a jacket loss measurement may be performed. If the jacket loss test is performed, insulation improvements may realize AFUE gains. Insulation can be improved by modifying the baseline furnace design through the use of increased jacket insulation or advanced forms of insulation.

Increased jacket insulation. Manufacturers insulate furnaces by adding insulation to the inside wall of the cabinet. Most residential furnaces on the market today have half--inch thick fiberglass insulation. Increasing the thickness of the jacket insulation could reduce standby losses by reducing heat loss through the jacket. Some manufacturers produce furnaces with slightly increased insulation thickness.

Advanced forms of insulation. Alternate ways of reducing the jacket losses without increasing the footprint of furnaces include using advanced insulation materials or evacuated panels. Some of the advanced materials or methods of insulation considered here involve using foam insulation, vacuum insulation, inert gases, aerogel insulation, or partial vacuums.

Foam insulation. Foam insulation can be used as an alternative to fiberglass insulation. Chlorofluorocarbon-free, water-blown polyurethane foam is a common alternative to high-density fiberglass blankets. Incorporating foam insulation of the same thickness in place of fiberglass insulation can increase the overall efficiency of a furnace. Foam typically has an R-value up to two to three times greater than fiberglass. Additionally, foam can be blown into small spaces and constrictive geometries where the potential for heat loss still exists, and which would be difficult to fill with fiberglass batts. Finally, manufacturing processes that use foam-blowing techniques are better suited for production line changes due to the shape-conforming characteristics of the foam. This allows additional technology options, methods, and advances to be incorporated into current designs with minimal impacts on insulation installation techniques.

Vacuum insulation panels. A “hard” vacuum between internal reflective surfaces is a very good insulator. It has been used for years in Thermos® bottles and dewar tanks for cryogenic applications. Durability and the difficulty of maintaining the seal over the life of the furnace are some of the manufacturing problems that remain unresolved. This technology has not been demonstrated for use with furnaces.

Gas-Filled Panels. Gas-filled panels are thermal insulating devices that retain a high concentration of a low-conductivity gas at atmospheric pressure within a multilayer infrared reflective baffle. The thermal performance of the panels depends on the type of gas fill and the baffle configuration. Gas-filled panels are flexible and self-supporting and can be made in a variety of shapes and sizes to thoroughly fill most types of cavities. This technology has not been demonstrated for furnace applications.[37]

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

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

3.3.3.8 Off-Cycle 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 furnace loses heat by natural convection and conduction through the combustion air inlet and flue. Installing a damper at these points can prevent heat from escaping and minimize off-cycle heat losses.

Dampers have no effect on the steady-state performance of the furnace; however, they can reduce standby losses. The AFUE metric captures both steady-state and standby performance of the furnace, and thus any heated air that is retained in the system during the standby mode improves the system's annual fuel utilization efficiency.

The safety standard for gas-fired central furnaces, ANSI/AGA Z21.10.1-1993, *Gas-Fired Central Furnaces,* requires the burner to shut off if the flue gets blocked. Thus, the effects of a failure of the flue damper to open should be mitigated by the burner controls.

Electro-mechanical flue damper. A damper that is installed downstream of the heat exchanger is called a flue damper. Electro-mechanical flue dampers are activated by an external source of electricity. These dampers open when combustion starts and close immediately after combustion stops. When the damper reaches the open position, an interlock switch energizes the solenoid and enables the gas ignition circuit. Therefore, as a safety measure, the burner cannot be ignited when the damper is in the closed position. Because the dampers open and close immediately, no bypass is needed. The electro-mechanical flue damper needs an electrical connection and consumes a nominal amount of power during opening and closing.

Electro-mechanical burner inlet damper. Inlet dampers are installed at the combustion-air inlet to the burner box and are designed to automatically close off the air passage and restrict the airflow through the heat exchanger when the burner is off. The principlemeans of operation of an electro-mechanical inlet damper are identical to those of an electro-mechanical flue damper.

3.3.3.9 Direct Venting

In some furnace installations, consumers may elect to use a direct venting system on their furnace. A direct venting system consists of a pipe that provides the burner with a direct connection to a combustion air source on the exterior of the building. This external connection allows the furnace to utilize outdoor air for combustion, which results in an improvement in AFUE. The use of an outdoor air source for combustion air ensures a more stoichiometric (complete) combustion of heating fuel than in installations which draw combustion air from the interior of the building. The relative purity of the outdoor air compared to indoor air ensures a more complete combustion of the heating fuel, because the composition of oxygen in outdoor combustion air is increased in the absence of the various household air contaminates found in indoor air. In addition, direct venting systems reduce infiltration losses, as conditioned air from the space is not used for combustion, but rather unconditioned air is brought in from outside. Direct venting can be achieved through either a two-pipe system, which includes one pipe for bringing combustion air to the burner and one for exhausting the products of combustion, or a single, concentric vent. Concentric direct venting is further discussed in section 3.3.3.10.

Direct venting also provides improvements to product lifetime and safety, in addition to efficiency improvements. Indoor combustion air can contain various particulates which are corrosive to the heat exchanger, such as chemicals originating from cleaning products, paint, and adhesives. As such, not using indoor air for combustion effectively extends the product lifetime of the furnace by preventing these corrosive chemicals from interacting with the inside of the heat exchanger. When the furnace is starting up or shutting down, there is also the risk that hazardous by-products of combustion, as well as natural gas, may seep into the living space through the combustion air opening if the furnace utilizes indoor air for combustion. Direct venting eliminates this risk by ensuring that the combustion air stream is completely sealed from the indoor environment.

3.3.3.10 Concentric Venting

Furnaces using direct venting may use a combustion air preheat venting system that passes the outdoor combustion air through a heat exchanger in contact with the flue gases. The combustion air does not mix with the flue gases. Manufacturers accomplish this preheat design by running the inlet and exhaust vents concentrically. The flue gases are exhausted through a central vent pipe and the intake combustion air passes through a concentric duct surrounding it. This arrangement creates a counter-flow heat exchanger that recovers some heat from the flue gases to preheat the combustion air.

Concentric venting provides an efficiency advantage compared to conventional venting systems, as the concentric vent essentially serves as a shell-in-tube heat exchanger. Some furnace manufacturers report separate AFUE ratings for each model with both concentric and conventional venting. In such cases, models tested with concentric venting show an efficiency enhancement of a few tenths of a percent AFUE over those with conventional venting configurations.

3.3.4 Technologies Options That Do Not Improve AFUE

DOE preliminarily determined that the following technology options do not improve the rated AFUE of furnaces, and as a result, these technologies were not carried forward to the screening analysis:

1. Infrared burner
2. Improved blower efficiency
3. Micro combined heat and power (icro-CHP)

3.3.4.1 Infrared Burner

Infrared (IR) burners are typically premix burners that produce a high radiant heat flux with low NOx emissions. The primary mechanism of heat transfer in infrared burners is radiation, in which heat is emitted in the form of a wave. The infrared waves emitted by the burner are transmitted at the speed of light in a straight line without heating the air. When the waves strike an opaque object, they are absorbed and converted back to heat. The heated object can then dissipate its heat via conduction or convection.

Infrared burners have higher combustion efficiencies than traditional gas inshot burners. Gas and primary air flow through the porous material or fiber mesh of the burner without need for secondary air. Because they are able to operate at lower levels of excess air, infrared burners have a small combustion efficiency advantage over traditional blue-flame burners.

Several infrared burner materials have been developed, including ceramic, stainless steel, and glass fiber. Most ceramic burners are flat plates, which have not been used in residential gas furnaces. Several ceramic burner designs consisting of ceramic fibers formed into a mat structure have been manufactured.[38] This design satisfies the heating load requirements for residential furnaces, has very low NOx emissions, and is capable of operating within a very wide turndown ratio (the ratio of the maximum to minimum output). Another burner design incorporates perforated high-temperature stainless steel and woven high-temperature wire. These burners are formable and adaptable to various configurations; however, they are not very durable because the metal gets brittle with time, creeps out of shape, and cracks. Glass fiber is the most successful material because it can be formed and will reliably maintain its shape.

Infrared burners made out of these materials are commonly used in industrial processing furnaces, room heaters, cooktop appliances, and other applications that require direct heating of an object. The application of IR burners to a residential furnace would require a major redesign of the heat exchanger to take advantage of radiative heat transfer from the burner. To DOE's knowledge, IR burners have not been incorporated into a warm-air furnace design, and as such, it has not been demonstrated that IR burners can improve overall system efficiency.

3.3.4.2 Improved Blower Efficiency

All furnaces come equipped with blower fans to circulate the heated air over the heat exchanger and through the plenum for distribution to the conditioned space. The efficiency of the air circulating blower can be increased by improving the blower motor efficiency and/or blower impeller efficiency to reduce the electrical energy consumption of the unit. However, electrical energy consumption of the furnace fan does not affect AFUE and therefore DOE did not consider improved blower efficiency in this rulemaking.

3.3.4.3 Micro Combined Heat and Power (Micro-CHP)

It is possible to use the heat generated by a furnace's combustion system to generate electricity opportunistically.[39, 40] Self-generated electricity can be used to operate the electrical components of the furnace or can be sold back to the grid. Known methods of micro-CHP include fuel cell generators, thermophotovoltaic generators, thermoelectric generators, and thermionic conversion. Other techniques use engines based on the Rankine cycle, Brayton cycle, Stirling cycle, or Otto cycle, where the engine drives an electrical generator or provides direct mechanical power and the waste heat from the engine is used for space heating. Neither the furnace's electricity use nor the heat generated by its electrical components, however, contribute to the calculation of its seasonal efficiency. Therefore, this technology option will not affect AFUE and was not considered in the screening analysis.

3.4 STANDBY MODE AND OFF MODE TECHNOLOGY ASSESSMENT

For furnaces, the standby and off modes are in effect when the furnace is connected to the power source, and neither the burner, electric resistance elements, nor any electrical auxiliaries such as blowers, are activated. Because the AFUE rating does not account for the electrical energy used in standby and off mode, and it is not feasible to integrate the standby and off mode electrical energy use into the AFUE metric, DOE is analyzing separate standby and off mode standards that are maximum wattage levels, which address such energy use.

The following assessment provides descriptions of technologies and designs that reduce the standby mode and off mode power consumption of residential furnaces.

DOE identified the following design options as having the potential to reduce the electrical power consumption of a furnace operating in standby and off modes:

1. Transformer improvements
2. BPM cielay
3. Switching mode power supply

3.4.1 Transformer Improvements

DOE has identified two types of transformers that offer improvement over the current typical laminated core transformer technology: toroidal transformers and low-loss transformers (LLTX).

A toroidal transformer operates more quietly and efficiently than a typical laminated core power transformer and has lower noise-inducing stray magnetic fields and smaller size and weight. A toroidal transformer has an annular core made of very tightly wound, grain-oriented, silicon steel ribbons. The steel ribbons are arranged such that all their molecules are aligned with the direction of flux. This allows better performance than a traditional laminated transformer in which unaligned molecules increase the core's reluctance, or capacity for opposing magnetic induction.[41]

Toroidal transformers also have virtually no air gap because they are made of continuously wound ribbon. Eliminating the air gap minimizes flux leakage, which is the principle source of power loss in a laminate transformer, such that nearly all flux is utilized. Additionally, toroidal transformers have a copper coating that reduces heat (*i.e.*, power) loss. These improvements in efficiency allow an up to 50 percent reduction in size and weight, such that they can be used in new, innovative applications. Overall efficiency of toroidal transformers is 90 to 95 percent.

Research also has shown that LLTX use four times less energy in standby mode than do typical transformers that are in use in the majority of furnaces on the market. LLTX utilize a thinner(0.35 millimeter) iron core sheet material than standard transformers, which utilize the more typical 0.50 millimeter sheet iron material. The 0.35 millimeter sheet core material is marginally more expensive than the .50 millimeter material, but offers reduced alternating current (AC)-core losses per kilogram. AC-core losses are energy losses that occur in a magnetic material due to hysteresis, eddy current, and residual losses in the core material. Core material at 0.50 millimeter sheds useful electrical energy into heat at a rate of 1.7 watt per kilogram of core material at a peak flux density of 1 Tesla magnetic field strength, whereas .35 millimeter core material only loses energy at a rate of 1watt per kiligram of core material, at 1 Tesla peak flux density. Drawbacks of LLTX compared to more typical transformers are their larger size and increased manufacturing cost due to the larger core dimensions needed to compensate for the reduced density of the iron core sheet material. However, this increase in cost is only approximately 10 to 15 percent greater than the cost of standard off-the-shelf transformers.[42]

Because transformers continue to supply power to the control board in all modes of operation, including standby mode, increasing their operating efficiency will reduce the furnace's standby electrical power consumption. However, although toroidal and low-loss transformers have significant advantages over laminated transformers in efficiency, they are also more expensive to manufacture.

3.4.2 Brushless Permanent Magnet Control Relay

During testing of standby and off mode components, DOE found that BPM motors and their associated controls consumed 3 watts in off mode, while PSC motors did not have any off mode power draw. Therefore, the BPM motor could be disconnected to further reduce a system's off mode power consumption. To accomplish this task, a control relay would need to be added to the circuit. A typical control relay activates a switch when current runs through it, and when there is no current, a spring holds the switch in the open position. However, DOE has not found any products which completely disconnect the BPM fan motor. Additionally, manufacturer feedback indicated that BPM motors subjected to large currents upon start up and using a control relay to completely depower them could reduce the lifetime of the motors, leading to a reduction in utility of the product.

3.4.3 Switching Mode Power Supply

DOE identified switch mode power supplies as having the potential to reduce the electrical power consumption of a furnace operating in standby mode. While linear power supplies regulate voltage supply to the dc circuit with a series element, switching mode power supplies (SMPS) do so in an alternative, more effective way. In a switching mode power supply, power handling electronics switch on and off (where "on" means switch is closed and voltage drop is negligible and "off" means the switch is open and current is negligible) with high frequency, effectively connecting and disconnecting the output (load) to the input source. Continuous power flow to the load can be maintained or controlled by varying the duty cycle or frequency of the SMPS.

Linear power supplies experience significant heat losses because they use resistance elements, which convert electrical energy to heat energy, to regulate power supply. By using a switch to control energy flow instead, switching mode power supplies avoid such heat losses and have higher efficiency. SMPS do introduce transient losses that increase with frequency, but these losses are negligible in comparison to the energy saved.

Switching mode power supplies also allow the use of a smaller transformer than the transformer used in a linear power supply. This is because the size of the transformer (*i.e.,* the number of turns) is inversely related to power frequency. In one respect, switching mode power supplies are at a relative disadvantage in comparison to linear power supplies, which regulate voltage with greater precision and have simpler controls.

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CHAPTER 4. SCREENING ANALYSIS

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CHAPTER 4. SCREENING ANALYSIS

4.1 INTRODUCTION

This chapter details the screening analysis that the U.S. Department of Energy (DOE) conducted in support of this rulemaking for energy conservation standards for residential furnaces.

The purpose of the screening analysis is to evaluate the technologies that improve furnace energy efficiency or reduce standby and off mode energy consumption to determine which technologies DOE should consider further in the rulemaking analyses. In the market and technology assessment (MTA; chapter 3), DOE presents an initial list of technologies that manufacturers can use to improve the energy efficiency of residential furnaces or reduce their standby and off mode electrical power consumption. DOE consulted a range of parties, including industry and technical experts and others, to develop a list of technologies for consideration in the market assessment (see chapter 3 of this technical support document (TSD)). Some of these technologies can reduce annual energy consumption of products in actual applications but may not improve the annual fuel utilization efficiency (AFUE) or reduce standby and off mode electrical power consumption. These rating metrics are measured according to DOE regulations at 10 CFR 430 subpart B, appendix N, which incorporates by reference industry standards ASHRAE 103-1993 and IEC 63201 (second edition). DOE removed from consideration those technologies that do not increase AFUE or reduce standby and off mode electrical power consumption per the DOE test procedures. DOE evaluated the remaining technologies pursuant to the criteria described below.

Section 325(o) of the Energy Policy and Conservation Act (EPCA) establishes criteria for prescribing new or amended standards designed to achieve the maximum improvement in energy efficiency. Furthermore, EPCA directs the Secretary of Energy to determine whether a standard is technologically feasible and economically justified. (42 U.S.C. 6295(o)(2)(A)(B)) In view of this requirement, 10 CFR part 430 subpart C, appendix A, *Procedures, Interpretations and Policies for Consideration of New or Revised Energy Conservation Standards for Consumer Products*, guides DOE in its consideration and promulgation of new or revised product efficiency standards. These procedures elaborate on the statutory criteria provided in 42 U.S.C. 6295(o) and in part, eliminate problematic technologies early in the process of prescribing or amending an energy conservation standard. In particular, DOE determines whether to eliminate from consideration any technology that presents unacceptable problems with respect to the following four criteria:

1. Technological feasibility. Technologies that are not incorporated in commercial products or in working prototypes will not be considered further.

2. Practicability to manufacture, install, and service. If it is determined that mass production of a technology in commercial products and reliable installation and servicing of the technology could not be achieved on the scale necessary to serve the

relevant market at the time of the effective date of the standard, then DOE will not consider that technology further.

3. Impacts on product utility to consumers. If DOE determines that a technology would have 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 that technology further.

4. Safety of technologies. If DOE determines that a technology will have significant adverse impacts on health or safety, it will not consider that technology further.

In sum, if DOE determines that a technology, or a combination of technologies, has unacceptable impacts on the policies stated in section 5(b) of the Process Rule, 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 from further consideration in the engineering analysis. 61 FR 36974-36987; 10 CFR part 430, subpart C, appendix A, section (5)(b). The reasons for eliminating any technology are documented in section 4.2 of this TSD.

4.2 SCREENED-OUT TECHNOLOGIES

This section describes the technologies that DOE eliminated based on consideration of the four criteria described above.

4.2.1 Furnace AFUE Standards

DOE eliminated the following technology options from further consideration: pulse combustion; low nitrogen oxide (NOx) premix burners; burner derating; and advanced forms of insulation.

4.2.1.1 Pulse Combustion

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

In contrast to natural draft and induced draft furnaces, pulse combustion furnaces generate positive pressure in the heat exchanger. Although these products are generally safe, this could create a potential safety problem if the heat exchanger breeches, because combustion products can contaminate the circulation air stream.

Pulse combustion gas furnaces were available in the United States for more than two decades. However, they were withdrawn from the market within the past 20 years because manufacturers found that competing technologies, such as condensing secondary heat exchangers, cost significantly less to manufacture and operate. In light of the ability of furnace manufacturers to cost-effectively achieve high efficiencies without the use of pulse combustion, the technology's risks do not outweigh its benefits. DOE did not further analyze this technology option as part of this rulemaking.

4.2.1.2 Low Nitrogen Oxide Premix Burners

Premix burners work by completely mixing primary air and fuel prior to combustion, eliminating the need for secondary air. However, atmospheric burners cannot entrain sufficient primary air to completely premix the air and gas. Therefore, to ensure sufficient and complete mixing, the burner incorporates a fan to deliver combustion air at positive pressure. To DOE's knowledge, low-NOx premix burners have not yet been successfully incorporated into a residential furnace design and technological feasibility in a furnace has not been proven. For this reason, DOE did not consider this technology option further in the rulemaking analyses.

4.2.1.3 Burner Derating

Decreasing the burner size to increase the ratio of heat transfer area to fuel input, or burner derating, can increase the AFUE rating of gas-fired furnaces. However, because heat output rate is directly related to burner size, derating also reduces the amount of heated air available to the consumer. This reduction in heat output adversely affects the utility to consumers. Therefore, DOE did not consider this technology option.

4.2.1.4 Advanced Forms of Insulation

Insulating furnaces with foam, a vacuum, inert gases, aerogel, or evacuated panels is an alternative to increasing the thickness of the insulation to decrease jacket heat loss. Manufacturers may elect to use alternative types of insulation because increasing the thickness of insulation may create shipping and installation problems if the footprint exceeds typical dimensions. However, none of these technologies has been applied to residential furnaces, and as a result, DOE has insufficient information to judge the merits and practicability of incorporating advanced forms of insulation into residential furnaces. DOE eliminated this technology option from further consideration.

4.2.2 Standby Mode and Off Mode Power Consumption Standards

DOE screened out from consideration brushless permanent magnet (BPM) motor control relays in its residential furnaces standby power consumption standards analysis.

4.2.2.1 Brushless Permanent Magnet Control Relay

While permanent split capacitor blower motors do not draw any power when off, BPM blower motors and their associated controls consume an average of three watts in standby mode and off mode in order to provide power to an integral control board for modulating the fan speed. To reduce standby power consumption of a furnace equipped with a BPM blower motor, DOE considered adding a relay to the circuit to disconnect the blower motor's control circuit when not in use. A typical relay activates a switch when current runs through it, and a spring holds the switch open when there is no current flow. Manufacturer feedback provided during the interview process (see chapter 12 of this TSD) indicated that BPM motors are subject to an inrush of current upon startup. The power supply on the BPM motor's control board, which is typically a switching mode power supply, cannot withstand the repeated surge of current that occurs at BPM motor startup and, therefore, completely depowering and reactivating the motor by use of a control relay would significantly shorten the motor's lifetime. DOE considers a premature failure of the blower to be a reliability issue that adversely affects product utility to the consumer. Therefore, DOE did not consider in the engineering analysis disconnection of a BPM fan motor when the blower is not in use. In addition, DOE has not found any HVAC products that utilize a control relay or other mechanism to disconnect the BPM motor fan when the product is in standby or off mode. Therefore, DOE did not consider this technology option for this rulemaking.

4.3 REMAINING TECHNOLOGIES

After eliminating those technologies that have no effect on or do not increase energy efficiency and screening out those technologies that do not meet the four screening criteria described in section 4.1, DOE considered the following technologies:

4.3.1 Furnace AFUE Standards

For its analysis of furnace energy conservation standards with regard to the AFUE efficiency metric, DOE considered the following technology options in the engineering analysis (see chapter 5 of this TSD):

- Condensing secondary heat exchanger
- Heat exchanger improvements
    - increased heat exchanger surface area
    - heat exchanger surface features
    - heat exchanger baffles and turbulators
- Two-stage and modulating combustion
- Increased jacket insulation
- Off-cycle dampers
    - electro-mechanical flue damper
    - electro-mechanical burner inlet damper
- Direct venting
    - concentric venting

4.3.2 Standby Mode and Off Mode Power Consumption Standards

Because DOE is required by EPCA, as amended by the Energy Independence and Security Act of 2007 (EISA 2007), to include a descriptor for standby mode and off mode energy consumption for residential furnaces, DOE conducted a separate screening analysis for standby and off mode design options. (42 U.S.C. 6295(gg)(2)(A))

DOE identified the following design options that are capable of reducing the standby and off mode electrical power consumption of residential furnaces:

- Transformer improvements
- Switching mode power supply

CHAPTER 5. ENGINEERING ANALYSIS

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5.1 INTRODUCTION

The engineering analysis establishes the relationship between manufacturer selling price (MSP) and energy-efficiency (*i.e.*, annual fuel utilization efficiency, abbreviated as AFUE) for the furnaces covered in this rulemaking. The cost-efficiency relationship serves as the basis for subsequent cost/benefit calculations for individual consumers, manufacturers, and the Nation. In determining this relationship, the U.S. Department of Energy (DOE) estimates the increase in the manufacturer selling price associated with technological changes that reduce the energy consumption of the baseline models.

The primary inputs to the engineering analysis are data from the market and technology assessment (chapter 3 in the TSD), input from manufacturers, baseline specifications, and production cost estimates developed using a cost model. The primary output of the engineering analysis is a set of cost-efficiency relationships that represent the average incremental cost of increasing product efficiency above the baseline levels. In the subsequent markups analysis (chapter 6 in the TSD), DOE determines consumer prices by applying distribution chain markups and sales tax to the manufacturer sales prices (MSPs) developed in the engineering analysis. After applying these markups, the data serve as inputs to the energy use characterization (chapter 7 in the TSD) and the life-cycle cost and payback period analyses (chapter 8 in the TSD).

In this chapter, DOE discusses: (1) the identification of representative baseline units for each product class, (2) the methodology used to develop bills of materials (BOMs) and MSPs, (3) the process for constructing the industry cost-efficiency relationships, (4) the cost-efficiency relationship outputs, (5) the scaling of the representative analysis to other capacities, (6) the development of an engineering examination for analysis of standby mode and off mode energy consumption, and (7) the results of the engineering analysis.

5.2 METHODOLOGY OVERVIEW

This section describes the analytical methodology used in the engineering analysis. In this rulemaking, DOE adopted a combination of an efficiency-level approach (to identify incremental improvements in efficiency for each product class) and a cost-assessment approach (to develop a cost for each efficiency level) for the analysis of the AFUE efficiency levels, which estimates the incremental cost of increasing product efficiency. (The standby and off mode analysis was performed using a design option approach, which is discussed further in section 5.10 of this chapter). In combination with the efficiency-level approach, the cost-assessment approach allowed DOE to determine the manufacturing production cost (MPC) at each efficiency level identified for analysis.

The cost-assessment is based on teardown (see section 5.5) data and was validated by manufacturer input. First, DOE used information gathered from manufacturers and/or data from the market and technology assessment and screening analysis to identify baseline units and representative models and selected a set of units at the baseline and higher efficiencies for teardown analysis. The baseline unit serves as a starting point for comparison with higher efficiency equipment, and the units selected for teardown analysis span a range of manufacturers, functionality, and efficiencies for commercially available products. A teardown analysis was also conducted for several units outside the representative capacities determined by DOE, so DOE could accurately scale its analysis at the representative capacity to other capacities. DOE developed a unit cost estimate for each of the units selected for teardown by disassembling each unit, developing a bill of materials, and inputting the results into a manufacturing cost model (see section 5.6), which calculated the MPC.

To determine the MSP of a unit at each efficiency level, DOE applied derived manufacturer markups (see section 5.7.1) to the MPC and added the estimated shipping cost. To derive the manufacturer markup, DOE added a typical profit to the fully absorbed cost of production by using publicly available industry financial data and manufacturer feedback. DOE developed shipping costs for each product based on the product's shipping dimensions and the size and cost of a typical trailer. DOE added the shipping costs to the marked-up MPC to get the total MSP. The results of the engineering analysis are a set of cost-efficiency relationships, in the form of MSP versus energy-efficiency, for each product class. The methodology for the engineering analysis is a logical, concise, and reproducible process, as illustrated in Figure 5.2.1.

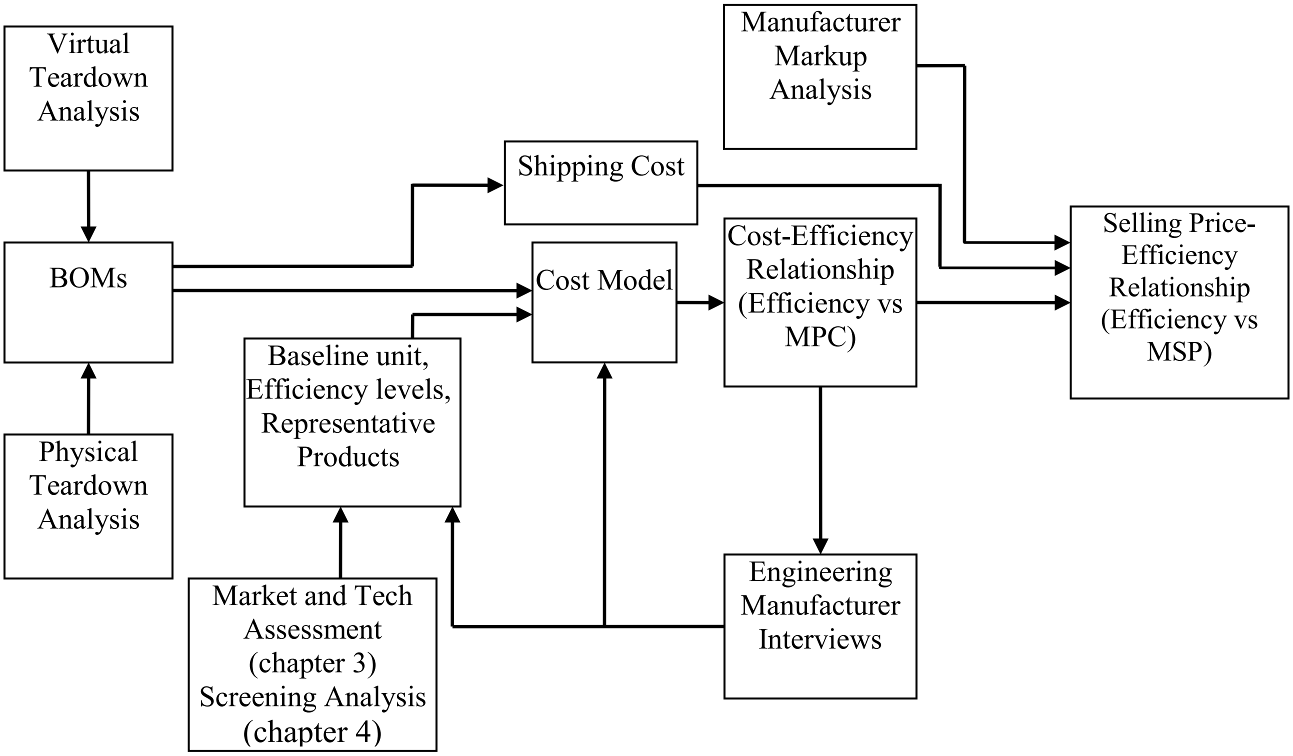


Figure 5.2.1 Engineering Analysis Methodology

5.3 PRODUCT CLASSES

As discussed in chapter 3 of this TSD (market and technology assessment), this rulemaking was initiated as part of a settlement agreement that required DOE to remand energy conservation standards for non-weatherized gas-fired furnaces (NWGF) and mobile home gas-fired furnaces (MHGF). Accordingly, DOE analyzed amended AFUE standards for these two product classes. Additionally, DOE analyzed new standby and off mode requirements for both of the product classes listed above, as discussed in section 5.10 of this chapter.

5.4 EFFICIENCY LEVELS ANALYZED

DOE analyzed multiple efficiency levels for both the NWGF and MHGF product classes and estimated the MPC and MSP at those levels. The following subsections explain the design options used to improve furnace efficiency across the full efficiency range from the baseline to the maximum technologically feasible ("max-tech") efficiency for both product classes. DOE identified the highest efficiency level by reviewing product literature for commercially available products. DOE presents the technologies used to cost-effectively increase energy efficiency above the baseline efficiency level for both NWGF and MHGF furnaces in Table 5.4.1 and Table 5.4.2, respectively.

Table 5.4.1 Efficiency Levels and Technologies Used at Each Efficiency Level Above Baseline for Non-Weatherized Gas-Fired Furnaces

Efficiency Level	AFUE %	Description of Technologies Incorporated
0 – Baseline	80	-
1	90	Baseline Efficiency Level + Addition of condensing secondary heat exchanger
2	92	Efficiency Level 1 + Increased secondary heat exchanger area
3	95	Efficiency Level 2 + Increased secondary heat exchanger area
4 – Max-tech	98	Efficiency Level 3 + Increased secondary heat exchanger area + Step-modulating combustion + Constant-airflow BPM blower motor

Table 5.4.2 Efficiency Levels and Technologies Used at Each Efficiency Level Above Baseline for Mobile Home Gas-Fired Furnaces

Efficiency Level	AFUE %	Description of Technologies Incorporated
0 – Baseline	80	-
1	92	Baseline Efficiency Level + Addition of condensing secondary heat exchanger
2	95	Efficiency Level 1 + Increased secondary heat exchanger area
3 – Max-tech	97	Efficiency Level 2 + Increased secondary heat exchanger area

5.4.1 Baseline Efficiency Levels

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

DOE used the baseline units for comparison in several analyses, including the engineering analysis, life-cycle cost (LCC) analysis, payback period (PBP) analysis, and national impacts analysis (NIA). To determine energy savings that will result from an amended energy conservation standard, DOE compared energy use at each of the higher energy efficiency levels to the energy consumption of the baseline unit. Similarly, to determine the changes in price to the consumer that will result from an amended energy conservation standard, DOE compared the price of a baseline unit to the price of a unit at each higher efficiency level.

The identification of baseline units requires establishing the baseline efficiency level. In cases where there is an existing standard, DOE defines baseline units as units with efficiencies equal to the current Federal energy conservation standards. The current Federal energy conservation standards for NWGF and MHGF, as measured by AFUE, became effective on January 1, 1992 and September 1, 1990, respectively. (42 U.S.C. 6295(f)(1)-(2)). However, the November 2007 final rule for furnaces and boilers amended those standards with a compliance date of November 19, 2015. Due to EPCA's anti-backsliding clause, DOE is prohibited from adopting levels below those previously adopted in the November 2007 final rule. As a result, DOE used those levels as the baseline efficiency levels in the analysis. Table 5.4.3 presents the AFUE at the baseline efficiency level for each product class of residential furnaces analyzed in this rulemaking, as well as the typical characteristics of products at the baseline efficiency level.

Table 5.4.3 Baseline Unit AFUE for Residential Furnaces

Product Class	Minimum AFUE Rating %	Typical Characteristics
Non-weatherized Gas-Fired (NWGF)	80	- Draft inducer - Single-stage burner - Hot surface igniter - Aluminized steel, clamshell or tubular primary heat exchanger - Constant-torque BPM blower motor* with forward-curved blower impeller
Mobile Home Gas-Fired (MHGF)	80	- Draft inducer

		- Single-stage burner - Hot surface igniter - Aluminized steel, clamshell or tubular primary heat exchanger - Improved PSC blower motor* with forward-curved blower impeller - Direct venting system - Built-in evaporator coil cabinet

*The current baseline blower motor design option for furnaces is a permanent split capacitance (PSC) motor; however, following the 2014 furnace fan rulemaking, the baseline blower motor design options for NWGF and MHGF units will be a constant-torque BPM motor, and an improved PSC motor, respectively.

Typically, the baseline units are representative of the minimum technology and lowest cost product that manufacturers can produce. In the teardown analysis (see section 5.5) the baseline units were a reference point for determining the cost-efficiency relationship of units with higher energy efficiencies. DOE compared the design features incorporated into products at the baseline efficiency to units with higher energy efficiencies to determine the change in manufacturing, installation, and operating costs.

5.4.2 Intermediate Efficiency Levels

DOE established intermediate energy efficiency levels for both product classes. The intermediate efficiency levels are representative of either the most common efficiency levels available on the market or efficiency levels where major technological changes occur (*e.g.*, condensing operation). DOE reviewed its own product certification directory,[1] as well as AHRI's product certification directories,[2] manufacturer catalogs, and other publicly available literature to determine which efficiency levels are the most prevalent for each product class and which technologies are used to increase efficiency. For each of the product classes, DOE analyzed multiple efficiency levels and estimated manufacturer production costs at each efficiency level. Section 5.11 contains cost efficiency data for the full range of efficiency levels that DOE analyzed from the baseline efficiency level to the max tech efficiency level for both product classes of furnaces.

For NWGF, DOE analyzed three efficiency levels in addition to the baseline and the max-tech. The efficiency levels were determined by the most commonly shipped furnace AFUEs and major technology changes (such as the switch to condensing technology at 90% AFUE). The representative units selected for analysis at each efficiency level have the most commonly used efficiency-related technologies and characteristics. DOE chose each of these efficiency levels because the incremental gains in efficiency correspond to common techniques and technologies manufacturers use to increase energy efficiency. For NWGF, manufacturers use a condensing, secondary heat exchanger to reach efficiency levels 1 and higher. To further improve efficiency, manufacturers increase the surface area of the secondary heat exchanger, which allows manufacturers to achieve efficiency levels 2 and 3.

For MHGF, DOE selected two efficiency levels between the baseline and max-tech levels. As with the intermediate efficiency levels selected for the analysis of NWGF units, the efficiency levels for MHGF were determined by the most commonly shipped furnace AFUEs. The representative units selected for analysis at each efficiency level have the most commonly used efficiency-related technologies and characteristics, and DOE chose each of these efficiency levels because the incremental gains in efficiency correspond to common techniques and technologies manufacturers use to increase energy efficiency. At efficiency level 1, manufacturers incorporate a condensing secondary heat exchanger into the furnace design. At efficiency level 2, manufacturers enlarge the condensing secondary heat exchanger in order to increase heat transfer area, which improves thermal efficiency and thus, AFUE.

5.4.3 Max-tech Efficiency Levels

As part of the engineering analysis, DOE determined the maximum technologically feasible improvement in energy efficiency for the covered products, as required by section 325(o) of EPCA. (42 U.S.C. 6295(o)) In the market and technology assessment (chapter 3 of this TSD), DOE conducted a survey of the markets for the covered products and their supporting research areas. The max-tech product in each product class was the highest efficiency product and no working products or prototypes are currently available at efficiency levels above that of the max-tech product. For NWGF, DOE identified a max-tech efficiency level design which achieves an AFUE of 98 percent. For MHGF, DOE identified a design which achieves a max-tech efficiency level of 97 percent AFUE. The max-tech levels identified for NWGF and MHGF are shown in Table 5.4.4.

For NWGF, the max-tech efficiency level is not currently achieved solely by use of a larger secondary heat exchanger, which is the design option used to achieve efficiency levels 2 and 3 in NWGF. DOE believes this is due to cabinet size restrictions (primarily a concern for retrofit installations) which constrain the heat exchanger to a certain degree of enlargement. In addition, furnaces offered at such high efficiency are often considered as “premium” furnaces and packaged with additional features such as 2-stage and step-modulating combustion and variable speed fan motors. Manufacturers indicated during interviews that modulating operation can boost AFUE, because operation at a reduced input has the same effect as increasing heat exchanger area and improves efficiency as long as other modulating components are used to maintain proper airflow and air to fuel ratio. As a result, manufacturers currently use designs that incorporate step-modulation in combination with a larger secondary heat exchanger to achieve the max-tech AFUE efficiency level. As described in the market and technology assessment (chapter 3 of this TSD), step-modulation allows products to match the actual heating load more closely. To achieve modulation, manufacturers must implement several components, including a modulating gas valve, multi-speed inducer fan, and additional controls. At the max-tech efficiency level, manufacturers will also typically utilize a constant-airflow brushless permanent magnet (BPM) blower fan motor in place of a standard permanent split capacitance (PSC) motor to precisely adjust the airflow to the conditioned space to better match the multitude of variations in heating capacity offered by a modulating furnace.

For MHGF, DOE determined that the max-tech efficiency level of 97% AFUE is achieved by enlarging the condensing secondary heat exchanger beyond its size at efficiency level 2 (95% AFUE). The larger secondary heat exchanger needed to reach an efficiency of 97% AFUE requires an increase in cabinet size, but does not require the cabinet to grow beyond size constraints for typical installations.

Table 5.4.4 Max-Tech Efficiency Levels for NWGF and MHGF

Product Class	Representative Input Capacity (Btu/h)	Max-Tech Efficiency Level (AFUE)
Non-Weatherized Gas-Fired (NWGF)	80,000	98
Mobile Home Gas-Fired (MHGF)	80,000	97

5.5 TEARDOWN ANALYSIS

Other than obtaining detailed manufacturing costs directly from a manufacturer, the most accurate method for determining the production cost of a product is to disassemble it piece-by-piece, compile a bill of materials (BOM), and estimate the material and labor cost of each component. DOE refers to this practice as a physical teardown. A supplementary method, called a catalog teardown (or “virtual teardown”), uses published manufacturer product literature and supplementary component data to estimate the major physical differences between the catalog teardown unit and a similar physical teardown unit. One alternative to the teardown method is to instead conduct price surveys to determine the production cost, but this price survey approach only provides insight into costs under the current standards, whereas the teardown approach provides insight into how products may change due to amended energy conservation standards.

Units selected for physical teardowns were dismantled, and each part was characterized according to weight, manufacturing processes, dimensions, material, and quantity, in order to facilitate the creation of a complete BOM for the product. Bills of materials for virtual teardowns are generated by modifying the BOM of a similar unit that has been physically torn down to reflect major physical differences. These modifications are based on data taken from manufacturer specification sheets and supplementary component data.

5.5.1 Selection of Units

For the teardown analysis, DOE had recent data for 31 physical teardowns and 29 additional virtual teardowns from the June 2011 direct final rule. In that rule, DOE identified and selected representative units across the entire range of efficiencies available to consumers. DOE confirmed that the designs of furnaces currently sold on the market are unchanged from the designs found in the models previously examined. DOE also added one additional physical teardown and 3 virtual teardowns to the set of teardown data from the June 2011 direct final rule. DOE used the BOMs generated from the teardown analyses with an updated cost model (which included updates to the purchase part prices, raw material prices, labor wage rates, etc.) to generate new MPC estimates. To the extent possible, all major efficiency levels and technologies were captured in the selection of models for teardown analysis. The NWGF and MHGF product classes were considered separately.

Teardown units must be representative of the product class, and as such the input capacities and characteristics of the teardown units were chosen as close as possible to the representative input capacity and characteristics for both respective product classes shown in Table 5.5.1. DOE also required that teardown units be manufactured in considerable volume, be commonly available, and have the most popular features.

Table 5.5.1 Characteristics of Representative Residential Furnaces

Product Class	**Input Capacity *Btu/h***	**Blower Capacity cfm**	**Configuration**	**Heat Exchanger Type**	**Ignition**	**Draft**
Non-Weatherized Gas Furnaces	80,000	1200	Upflow	Clamshell/ Tubular	Hot Surface	Induced
Mobile Home Gas Furnaces	80,000	1200	Downflow	Clamshell/ Tubular	Hot Surface	Induced

DOE also adopted more specific criteria to guide the selection process. In order to understand incremental manufacturing costs in improving efficiency, products chosen for teardowns were taken from the same manufacturer and product series to the extent possible. This minimized the cost effects of non-efficiency-related design differences between models. The manufacturers that were chosen have large market shares of the particular product class. DOE made an exception to this criterion for the highest efficiency product (or max-tech product) in each product class; as such, the max-tech products for teardown were chosen irrespective of manufacturer. The teardown selections used for the analysis of amended AFUE standards also minimized the occurrence of non-efficiency-related premium features, which could inflate the incremental manufacturing cost of achieving higher-efficiency levels. However, for consideration in the standby and off mode analysis, DOE did analyze several furnaces with premium features because these features can impact the standby and off mode power consumption.

DOE surveyed the residential furnaces industry and identified products available to consumers and applied the aforementioned criteria and selected baseline, intermediate, and max-tech units that were as close to the representative characteristics as possible, met the energy efficiency levels being analyzed, and included the most prevalent technologies on the market. In several cases, DOE substituted a virtual teardown in the place of a physical teardown. For example, if two furnaces differed only by an extra heat exchanger tube, one was physically torn down and the additional material and manufacturing costs (*e.g.*, extra sheet metal, additional burner orifice, additional heat exchanger tube) were added to the cost of the physically torn down model to determine the MPC of the virtually torn down model.

Because the large majority of residential furnace shipments fall into the non-weatherized gas product class, DOE focused its teardown analysis heavily on non-weatherized gas-fired furnaces. As a result, DOE utilized its existing teardown data for 26 non-weatherized gas-fired furnaces and 6 mobile home gas-fired furnaces. For the non-weatherized gas product class, the furnaces selected spanned the range of efficiency levels from baseline to max-tech that were analyzed. For the mobile home gas product class, the teardowns spanned from the baseline up to 96% AFUE. DOE estimated the cost to produce a 97% AFUE MHGF by extrapolating trends in the physical changes (and associated costs) needed to increase efficiency for both NWGF and MHGF that were observed during teardowns. Figure 5.5.1 shows the efficiencies of products analyzed for the NWGF teardown analysis. DOE mostly examined products with PSC blower motors and single stage burners, but also examined some products with BPM motors as well as two stage and step-modulating burner operation. Lastly, DOE used physical teardowns of units at input capacities both above and below the representative input capacity to allow the analysis to be accurately scaled to the full range of input capacities analyzed. DOE did not identify the model number or manufacturer of the units examined during the teardown analysis because this could expose sensitive information about individual manufacturers' products.

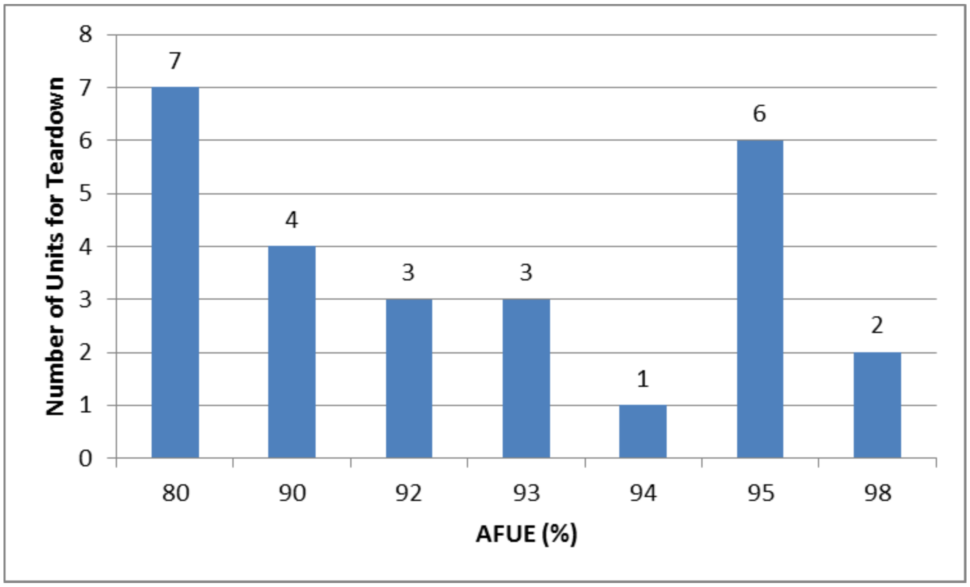


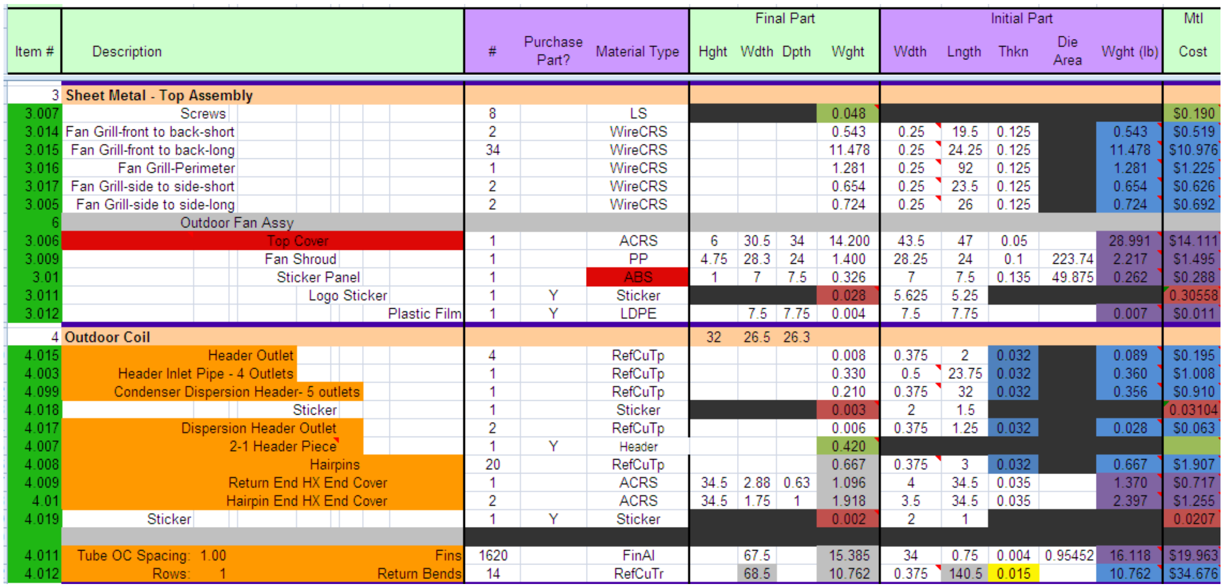
Figure 5.5.1 Efficiencies of Non-weatherized Gas Furnaces Selected for Teardown

5.5.2 Generation of Bill of Materials

The end result of each teardown is a structured BOM, describing each product component and its relationship to the other parts in the estimated order in which manufacturers assembled them. The BOMs describe each fabrication and assembly operation in detail, including the type of product needed (*e.g.*, presses, drills) and the process cycle times. The result is a thorough and explicit model of the production process. The BOMs incorporate all materials, components, and fasteners classified as either raw materials or purchased parts and assemblies. The classification into raw materials or purchased parts is based on DOE's previous industry experience, recent information in trade publications, and discussions with high- and low-volume original equipment manufacturers (OEMs). DOE also visited several manufacturing plants to reinforce its understanding of the industry's current manufacturing practices. Information was gathered to account for product designs specific to furnaces and ensure that the teardown analysis methodology and pricing were accurate. For purchased parts, the purchase price is an estimate based on high-volume price quotations and detailed discussions with suppliers and manufacturers. For fabricated parts, the price of intermediate materials (*e.g.*, tube, sheet metal) and the cost of transforming them into finished parts is an estimate based on current industry pricing. For a continued discussion of the cost details and assumptions, refer to section 5.6.2.

The BOM for a virtual teardown is identically structured and provides a description in equal detail to the BOM of a physical teardown. However, it is generated using a slightly different methodology. As stated previously, BOMs for virtual teardowns are generated by modifying the BOM of a similar unit that has been physically torn down. These modifications reflect the major physical differences between the units. Virtual teardowns were used to provide additional data for the scaling of the cost-efficiency relationship to additional input capacities for furnaces. DOE physically tore down a unit at an input capacity above and below the representative input capacity and relied on information from those two physical teardowns and the virtual teardowns to scale the analysis to other input capacities.

Figure 5.5.2 below shows an example of a section of a BOM spreadsheet. Each row of the spreadsheet represents a single part of the unit assembly and includes a description of the part, a material type, initial and final dimensions, and weight. These rows also include placeholders for the type and number or duration of fabrication processes (stamping, drilling, etc.) required to create that part. From this information, a part cost is generated, and the part costs are summed across the sheet to create a cost estimate for the entire unit. While the teardown analysis only considers technologies observed in today's units, DOE does not believe that the implementation of technologies would differ based on amended standards because manufacturers of these products generally already incorporate the most cost-effective methods for improving efficiency into their products.



					Final Part				Initial Part					Mtl
Item #	Description	#	Purchase Part?	Material Type	Hght	Wdth	Dpth	Wght	Wdth	Lngth	Thkn	Die Area	Wght (lb)	Cost
3	**Sheet Metal - Top Assembly**													
3.007	Screws	8		LS				0.048						$0.190
3.014	Fan Grill-front to back-short	2		WireCRS				0.543	0.25	19.5	0.125		0.543	$0.519
3.015	Fan Grill-front to back-long	34		WireCRS				11.478	0.25	24.25	0.125		11.478	$10.976
3.016	Fan Grill-Perimeter	1		WireCRS				1.281	0.25	92	0.125		1.281	$1.225
3.017	Fan Grill-side to side-short	2		WireCRS				0.654	0.25	23.5	0.125		0.654	$0.626
3.005	Fan Grill-side to side-long	2		WireCRS				0.724	0.25	26	0.125		0.724	$0.692
6	Outdoor Fan Assy													
3.006	Top Cover	1		ACRS	6	30.5	34	14.200	43.5	47	0.05		28.991	$14.111
3.009	Fan Shroud	1		PP	4.75	28.3	24	1.400	28.25	24	0.1	223.74	2.217	$1.495
3.01	Sticker Panel	1		ABS	1	7	7.5	0.326	7	7.5	0.135	49.875	0.262	$0.288
3.011	Logo Sticker	1	Y	Sticker				0.028	5.625	5.25				0.30558
3.012	Plastic Film	1	Y	LDPE		7.5	7.75	0.004	7.5	7.75			0.007	$0.011
4	**Outdoor Coil**				32	26.5	26.3							
4.015	Header Outlet	4		RefCuTp				0.008	0.375	2	0.032		0.089	$0.195
4.003	Header Inlet Pipe - 4 Outlets	1		RefCuTp				0.330	0.5	23.75	0.032		0.360	$1.008
4.099	Condenser Dispersion Header- 5 outlets	1		RefCuTp				0.210	0.375	32	0.032		0.356	$0.910
4.018	Sticker	1		Sticker				0.003	2	1.5				0.03104
4.017	Dispersion Header Outlet	2		RefCuTp				0.006	0.375	1.25	0.032		0.028	$0.063
4.007	2-1 Header Piece	1	Y	Header				0.420						
4.008	Hairpins	20		RefCuTp				0.667	0.375	3	0.032		0.667	$1.907
4.009	Return End HX End Cover	1		ACRS	34.5	2.88	0.63	1.096	4	34.5	0.035		1.370	$0.717
4.01	Hairpin End HX End Cover	2		ACRS	34.5	1.75	1	1.918	3.5	34.5	0.035		2.397	$1.255
4.019	Sticker	1	Y	Sticker				0.002	2	1				0.0207
4.011	Tube OC Spacing: 1.00 Fins	1620		FinAl		67.5		15.385	34	0.75	0.004	0.95452	16.118	$19.963
4.012	Rows: 1 Return Bends	14		RefCuTr		68.5		10.762	0.375	140.5	0.015		10.762	$34.676

Figure 5.5.2 Example of BOM Spreadsheet

5.6 COST MODEL

The cost model is a detailed, component-focused, activity-based tool for estimating the manufacturing cost of a product. Once teardowns were completed, DOE implemented a cost model that could translate the physical information from the BOMs into manufacturing costs. The cost model is based on production activities and divides factory costs into materials, labor, depreciation, and overhead. DOE defines the cost inputs of these broader categories in Table 5.6.1.

Table 5.6.1 Cost Model Categories and Descriptions

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

DOE input the cost data from all the BOMs—whether they were obtained through physical teardowns or virtual teardowns—into the cost model. The cost model analysis created cost estimates for each of the products analyzed in the teardown analysis. The cost model uses specific assumptions to provide cost estimates; the following sections describe these assumptions.

5.6.1 Cost Model Overview

This section provides a general overview of the process by which the cost model converts the physical information in each product's BOM into cost information. After gathering component information through physical teardowns and organizing it into BOMs, the resulting data were used as inputs for the cost model spreadsheet. To determine the costs, DOE followed one of two different paths, depending on whether a subassembly was purchased (out-sourced) or produced in-house. For purchased parts, DOE gathered price quotations from major suppliers at different production volumes. For parts produced in-house, DOE reconstructed manufacturing processes for each part using modeling software based on internal expertise. For example, for an access panel, DOE deduced the time required for setup, handling, changeover, and punching holes, as well as the number of holes and hits. By repeating this process, DOE was able to assign labor time, equipment utilization, and other important factors to each subassembly in each of the units considered for this analysis. The last step was to convert the information into dollar values. To perform this task, DOE collected information on such factors as labor rates, tooling depreciation, and costs of purchased raw materials. DOE assumed values for these parameters using internal expertise and confidential information available to its contractors. Figure 5.6.1 provides an illustration of the cost model methodology.

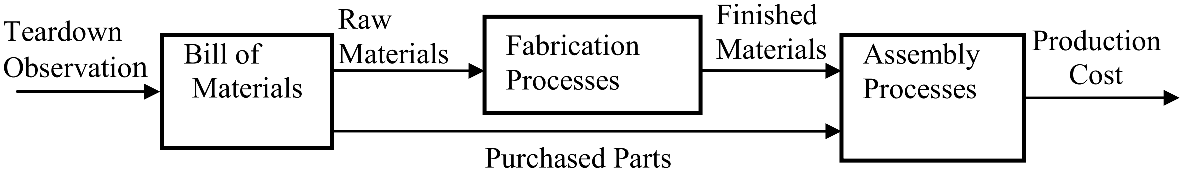


Figure 5.6.1 Cost Model Methodology

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

5.6.2 Cost Model Assumptions

Assumptions about manufacturer practices and cost structure play an important role in estimating the final cost of the products. DOE used assumptions regarding the manufacturing process parameters, (*e.g.*, equipment use, labor rates, tooling depreciation, and cost of purchased raw materials) to determine the value of each component. It then summed the values of the components into assembly costs and, finally, the total MPC for the product. The MPC includes the material, labor, depreciation, and overhead costs associated with the manufacturing facility. The material costs include both raw materials and purchased part costs. The labor costs include fabrication, assembly, and indirect and overhead (burdened) labor rates. The depreciation costs include equipment depreciation, tooling depreciation, and building depreciation. The overhead costs include indirect process costs, utilities, equipment and building maintenance, and rework. The following sections describe the cost model assumptions related to material prices, purchased parts and factory parameters.

5.6.2.1 Material Prices

DOE determined the cost of raw materials by using prices for copper, steel, and aluminum from the American Metals Market.[3] DOE noted that there have been drastic fluctuations in metal prices over the last few years. To account for these large fluctuations, DOE used prices of metals that reflect a five-year average of the Bureau of Labor Statistics Producer Price Indices (PPIs) spanning 2009 to 2013.[4] DOE used the PPIs for steel mill products and copper rolling, drawing, and extruding, and adjusted to 2013$ using the gross domestic product implicit price deflator.[5]

5.6.2.2 Fabricated Parts and Purchased Parts

DOE characterized parts based on whether manufacturers fabricated them in-house or purchased them from outside suppliers. For fabricated parts, DOE estimated the price of intermediate materials (*e.g.*, tube, sheet metal) and the cost of forming them into finished parts. For purchased parts, DOE estimated the purchase price for OEMs based on discussions with the manufacturers. Whenever possible, DOE obtained price quotes directly from suppliers of the manufacturers of the units being analyzed. DOE assumed that the components in Table 5.6.2 were purchased from outside suppliers.

Table 5.6.2 Purchased Furnace Components

Assembly	Purchased Sub-Assemblies
Burner/Exhaust	Gas Valve
	Hot Surface Igniter
	Draft Inducer Assembly
Blower	Blower Fan Blade
	Blower Fan Motor
Controls	Control Boards
	Capacitors, transformers, contactors, switches, etc.

Variability in the costs of purchased parts can account for large changes in the overall MPC values calculated. The purchased part prices utilized in this study were typical values based on estimated production volumes and other factors. In actuality, purchased part costs can vary significantly based on the quantities desired and the component suppliers chosen. The role of purchase part prices in the MPC calculation is further magnified because these parts comprise significant portions of these systems by cost. Additionally, some parts, such as molded plastic components, may be produced in-house by some manufacturers and purchased by others. The choice between these options would result in changes to the calculated overall system costs. Manufacturer feedback was solicited on these costs and used to further calibrate the numbers prior to conducting the analyses to minimize the uncertainty caused by the variability in costs.

5.6.2.3 Factory Parameters

Certain factory parameters, such as fabrication rates, labor rates, and wages, also affect the cost of each unit produced. DOE factory parameter assumptions were based on internal expertise and manufacturer feedback. Table 5.6.3 below lists the factory parameter assumptions used in the cost model. These factory parameters are independent of the efficiency level of the unit produced. Non-weatherized gas furnaces and mobile home gas furnaces are assumed to have the same production volumes because major manufacturers produce these units, which generally use the same components as non-weatherized gas furnaces. These assumptions are generalized to represent typical production and are not intended to model a specific factory.

Table 5.6.3 Factory Parameter Assumptions

Parameter	Non-weatherized Gas Furnaces Estimate*
Actual Annual Production Volume (units/year)	1,250,000
Work Days Per Year (days)	250
Assembly Shifts Per Day (shifts)	2
Fabrication Shifts Per Day (shifts)	2.5
Fabrication Labor Wages ($/h)	16
Assembly Labor Wages ($/h)	16
Length of Shift (hrs)	8
Average Equipment Installation Cost (% of purchase price)	10%
Fringe Benefits Ratio	50%
Indirect to Direct Labor Ratio	33%
Average Scrap Recovery Value	30%
Building Cost ($/ft^2)	177
Worker Downtime	10%
Building Life (in years)	30
Burdened Assembly Labor Wage ($/h)	24
Burdened Fabrication Labor Wage ($/h)	24
Supervisor Span (workers/supervisor)	25
Supervisor Wage Premium (over fabrication and assembly wage)	30%

*Includes non-weatherized mobile home furnaces.

5.7 MANUFACTURER SELLING PRICE

The output of the cost model is the MPC, which includes all direct costs including production-related labor, materials, depreciation, and overhead costs (as defined in section 5.6). To obtain the MSP, DOE multiplies the MPC by the manufacturer markup and adds the cost of shipping. The MSP includes all production and non-production costs as well as profit. The manufacturer markup is a multiplier that scales MPC to the MSP and covers non-production cost elements, including sales, general and administrative, research and development, other corporate expenses, and profit. The components of MSP are shown in Figure 5.7.1. The MPCs are obtained as an output of the cost model, and the manufacturer markup and shipping costs were derived as described in sections 5.7.1 and 5.7.2 below.

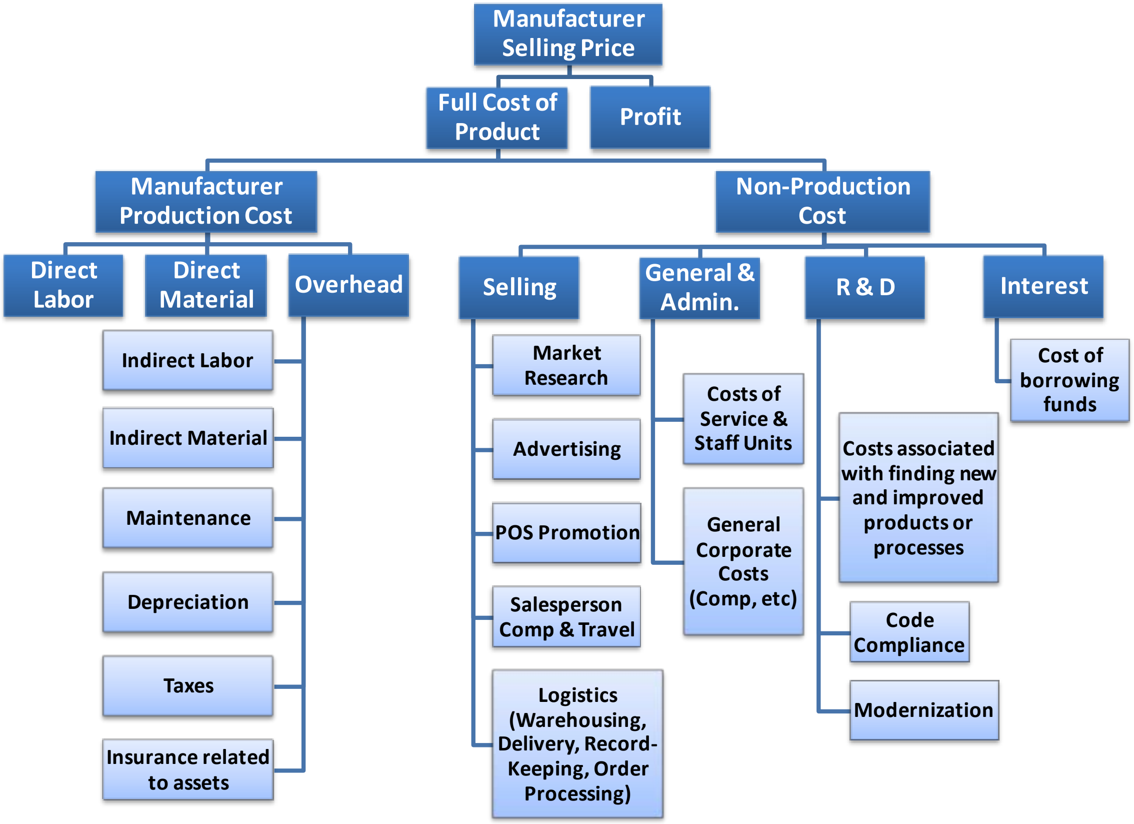


Figure 5.7.1 Components of Manufacturer Selling Price

5.7.1 Manufacturer Markup

DOE used U.S. Security and Exchange Commission (SEC) 10-K reports from publicly owned residential cooling and heating product companies to estimate manufacturer markups. The law requires publicly owned companies to disclose financial information on a regular basis by filing forms with the SEC. The SEC form 10-K, filed by companies annually, provides a comprehensive overview of the company’s business and financial conditions. The 10-K report includes the company’s revenues and direct and indirect costs. The income statement section of the 10-K often lists the figures necessary for calculating the manufacturer markup—the net sales, costs of sales, and gross profit. DOE first calculated a five year average markup for each company. After calculating the markup for each manufacturer with 10-K data, DOE then calculated a single market-share weighted manufacturer markup to represent the industry. DOE applied this manufacturer markup to the MPC to arrive at a final manufacturer selling price. This industry wide markup was further calibrated based on feedback received during manufacturer interviews. The manufacturer markup varied by product class and was 1.34 for non-weatherized gas-fired furnaces and 1.27 for mobile home gas-fired furnaces.

5.7.2 Shipping Costs

Manufacturers of HVAC products typically pay for freight to the first step in the distribution chain. Freight is not a manufacturing cost, but because it is a substantial cost incurred by the manufacturer, DOE is accounting for shipping costs separately from the non-production costs that comprise the manufacturer markup. To calculate MSP, DOE multiplied the MPC determined from the cost model by the manufacturer markup and added shipping costs. DOE calculated shipping costs based on a typical 53-foot straight frame trailer with a storage volume of 4,240 cubic feet.

DOE first calculated the cost per cubic foot of space on a trailer based on a cost of $2,600 per shipping load and the standard dimensions of a 53-foot trailer. This cost was determined based on a combination of full truck load (FTL) freight quotations and manufacturer feedback. Then, DOE examined the average sizes of products in each product class at each efficiency and capacity combination analyzed. DOE estimated the shipping costs by multiplying the product volume by the cost per cubic foot of space on the trailer. Furnace dimensions typically do not change as a result of increases in efficiency, and DOE's shipping costs show no change across efficiency levels, except for mobile home furnaces. For those products, DOE found that legacy designs, which are shipped with an evaporator coil cabinet on top of the unit, are the most common design at the baseline, while at the condensing efficiency levels the size and design of the units were more in line with non-weatherized gas furnaces at the condensing level. Due to the increased size of the baseline unit (to include the coil cabinet), the shipping cost at the baseline is higher for mobile home furnaces. In determining volumetric shipping costs, DOE also used manufacturer feedback regarding product mix on each trailer, packing efficiency, and methods and equipment used to load the trailers to revise the shipping costs. Table 5.7.1 through Table 5.7.5 show the shipping costs and shipping dimensions for the products analyzed in this rulemaking.

Table 5.7.1 Shipping Costs for Non-weatherized Gas Furnaces

	Shipping Cost ($)			
AFUE	**60 kBtu/h**	**80 kBtu/h**	**100 kBtu/h**	**120 kBtu/h**
80	10.59	10.59	12.49	14.40
90	10.59	10.59	12.49	14.40
92	10.59	10.59	12.49	14.40
95	10.59	10.59	12.49	14.40
98	10.59	10.59	12.49	14.40

Table 5.7.2 Shipping Costs for Mobile Home Gas Furnaces

AFUE	Shipping Cost ($)
80	19.67
90	10.59
92	10.59
96	10.59

Table 5.7.3 Shipping Dimensions for Non-weatherized Gas Furnaces (60 kBtu/h and 80 kBtu/h Input Capacity)

	Shipping Dimensions					
AFUE	60 kBtu/h			80 kBtu/h		
	Height (in.)	Width (in.)	Length (in.)	Height (in.)	Width (in.)	Length (in.)
80	42.0	19.5	30.5	42.0	19.5	30.5
90	42.0	19.5	30.5	42.0	19.5	30.5
92	42.0	19.5	30.5	42.0	19.5	30.5
95	42.0	19.5	30.5	42.0	19.5	30.5
98	42.0	19.5	30.5	42.0	19.5	30.5

Table 5.7.4 Shipping Dimensions for Non-weatherized Gas Furnaces (100 kBtu/h and 120 kBtu/h)

	Shipping Dimensions					
AFUE	100 kBtu/h			120 kBtu/h		
	Height (in.)	Width (in.)	Length (in.)	Height (in.)	Width (in.)	Length (in.)
80	42.0	23.0	30.5	42.0	26.5	30.5
90	42.0	23.0	30.5	42.0	26.5	30.5
92	42.0	23.0	30.5	42.0	26.5	30.5
95	42.0	23.0	30.5	42.0	26.5	30.5
98	42.0	23.0	30.5	42.0	26.5	30.5

Table 5.7.5 Shipping Dimensions for Mobile Home Furnaces (80 kBtu/h Input Capacity)

AFUE	Height (in.)	Width (in.)	Depth (in.)
80	78.0	19.5	30.5
92	42.0	19.5	30.5
95	42.0	19.5	30.5
97	42.0	19.5	30.5

5.7.3 MSP in the Downstream Analyses

The MSPs derived in the engineering analysis are important inputs to the life-cycle cost analysis (LCC) and the manufacturer impact analysis (MIA). In the LCC, the MSPs are necessary to calculate the total installed cost of each unit. In the MIA, DOE constructs a number of scenarios that analyze how different pricing schemes impact manufacturers financially. In the MIA, both MSP and the direct production cost components of MSP are important drivers of results. DOE discusses how the engineering analysis is used in the other analyses in chapters 8 and 12 of the TSD.

5.8 INDUSTRY COST-EFFICIENCY RELATIONSHIPS

DOE used the cost model to estimate the MPC of various products across the full range of efficiencies and for each manufacturer with significant market share. DOE used these results as the basis for its cost-efficiency relationship for all furnace product classes.

DOE first developed an industry cost-efficiency relationship for non-weatherized gas furnaces. DOE began its construction of the cost efficiency relationship at the baseline efficiency level for non-weatherized gas furnaces. To create an industry average cost at the baseline efficiency level, DOE calculated a market share-weighted average of the cost modeling results of each product that was torn down at the baseline efficiency level. Above the baseline, DOE examined the cost differential to reach the next highest efficiency level examined for each manufacturer. For individual manufacturers, DOE calculated the incremental cost above the baseline of achieving the next higher efficiency level (*i.e.*, the estimated cost to go from 80 percent AFUE to 90 percent AFUE, from 80 percent AFUE to 92 percent AFUE, and so on).

Following the calculation of these incremental costs for specific manufacturers, DOE estimated the incremental increase in cost to achieve each efficiency level above baseline for the entire industry by applying a curve-fit to the incremental cost data up through Efficiency Level 3 (95% AFUE). This curve fit was derived from the cumulative dataset of incremental costs at efficiency levels above baseline for each manufacturer. At the max-tech efficiency level, DOE performed two teardowns of models from manufacturers from whom DOE had also torn down units at 95% AFUE. In order to determine the incremental cost of achieving 98% AFUE, DOE compared the differences between the 95% and 98% units from these manufacturers, and calculated a market-weighted average incremental cost to achieve 98%.

Because mobile home furnace designs are typically similar to non-weatherized gas furnace designs, the cost-efficiency relationship for mobile home furnaces was developed based on 6 mobile home gas furnace teardowns in conjunction with the cost-efficiency relationship that was developed for non-weatherized gas furnaces. DOE performed teardowns of mobile home furnaces from major mobile home furnace manufacturers at each efficiency level. DOE used those teardowns to examine the differences between mobile home gas furnaces and non-weatherized gas furnaces made by each manufacturer of mobile home furnaces. DOE calculated the cost differential between each manufacturer's non-weatherized gas furnace and mobile home gas furnace at each efficiency level analyzed. DOE used these cost differentials to develop a market-representative differential cost of mobile home furnaces versus non-weatherized gas furnaces at each efficiency level. The manufacturer production costs developed using this method were validated based on the results of DOE's cost modeling for each individual mobile home furnace torn down and verified by manufacturer feedback during manufacturer interviews.

5.8.1 Furnaces with Brushless Permanent Magnet (BPM) Blower Motors

DOE's analysis focused on furnace products utilizing a standard permanent split capacitance (PSC) blower motor in the furnace fan because switching to a BPM motor does not impact AFUE. However, following the 2014 furnace fan rulemaking[a], in 2019 fan efficiency requirements will be set at a level that will likely essentially require constant-torque BPM blower motors to be used for non-weatherized gas-fired furnaces, and improved PSC blower motors to be used for mobile home gas-fired furnaces. Because the standards established furnace fan rulemaking will require compliance in 2019, higher energy conservation standards for residential furnace fans will be in place when compliance with any amended standards resulting from this rulemaking for residential furnaces are required. Therefore, DOE determined the additional cost of changing from a PSC to a constant-torque BPM blower motor for non-weatherized gas units and the cost of changing to an improved PSC blower motor for mobile home gas units in the engineering analysis.

BPM blower motors can be either a constant-torque or constant-airflow design. Constant-airflow BPM motors cost more than constant-torque BPM motors because the constant-airflow design combines a microprocessor and an electronic control directly with the motor. These electronics serve to make the motor programmable such that it can adjust its operating speed in order to maintain constant airflow to the conditioned space. DOE estimated the cost differential of both types of BPM motors and their additional wiring and controls as compared to a PSC motor based on data and manufacturer feedback obtained for the 2014 furnace fan rulemaking.

The final MPCs resulting from the engineering analysis include a constant-torque BPM blower motor as the design option for furnaces at the baseline through 95% AFUE, and a constant-airflow BPM blower motor as the design option for units at the max-tech efficiency level (as manufacturers indicated that a constant-airflow BPM motor is often used with modulating equipment, see section 5.4.3). However, DOE still calculated the additional cost to switch from a PSC motor to a constant-airflow BPM motor for the efficiency levels below max-tech. This is because constant-airflow BPM motors are sometimes used as a comfort feature on units below the max-tech efficiency level. As such, the costs of switching from a PSC to a constant-airflow BPM blower motor at each efficiency level were incorporated into the LCC analysis (see Chapter 8 of this TSD).

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[a] For more information regarding the 2014 furnace fan rulemaking, see the DOE Building Technologies Office website at: http://www1.eere.energy.gov/buildings/appliance_standards/rulemaking.aspx/ruleid/41

DOE determined that the blower motor is a purchased part; as such, the difference in price for that component is based largely on DOE's component estimates which were adjusted based on manufacturer feedback regarding DOE's estimates for purchased parts. DOE estimated the cost of switching from a PSC motor to either an improved PSC or a BPM motor separately for each input heating capacity analyzed based on the most common blower motor characteristics observed at each input capacity. Table 5.8.1 shows DOE's estimates of the costs to change from a PSC to either an improved PSC, constant-torque BPM or constant-airflow BPM blower motor for each product class and input capacity analyzed.

Table 5.8.1 Additional Cost (Including Motor, Controls, and Wiring) to Switch from PSC to Improved PSC or BPM Blower Motor

Product Class	Input Capacity (kBtu/h)	Incremental Cost Increase for Improved PSC ($)	Incremental Cost Increase for Constant-torque BPM ($)	Incremental Cost Increase for Constant-airflow BPM ($)
Non-weatherized Gas	60	-	37.29	89.60
	80	-	41.29	91.60
	100	-	45.29	93.60
	120	-	49.29	95.60
Mobile Home Gas	80	6.11	41.29	91.60

5.8.2 Two-Stage Furnaces

The market for non-weatherized gas furnaces also contains a significant number of two-stage products rated at the same efficiency as single-stage products. DOE believes consumers choose to purchase these products for the additional comfort of two-stage operation. During the teardowns, DOE examined two-stage furnace designs to analyze the production cost differential for manufacturers to switch from single-stage to two-stage (with no impact on the rated AFUE). DOE determined a market share weighted-average cost of $34.72 to change from a single stage to a two stage design. The additional cost to change to a two-stage furnace includes the added cost of a two-stage gas valve, two-speed inducer assembly, upgraded pressure switch, and additional controls and wiring.

Following the 2014 furnace fan rulemaking, in 2019 all NWGF units will be required to include multi-stage operation in addition to higher efficiency blower motors. For this reason, DOE included the $34.72 cost adder to change from a single stage to a two-stage design in the final MPCs for NWGF, except for at the max-tech efficiency level, where modulating combustion is already a standard design option.

5.9 EXPANSION OF ANALYSES TO ADDITIONAL CAPACITIES

To develop the MPCs for the analysis of capacities other than the representative input capacity (*i.e.,* at 60 kBtu/h, 100 kBtu/h, and 120 kBtu/h), DOE performed one teardown of a furnace below the representative capacity and one teardown of a furnace above the representative capacity, in addition to performing multiple virtual teardowns. DOE used the physical teardowns to estimate the changes in material and labor costs that occur at capacities higher and lower than the representative capacities based on observations made during teardowns and professional experience. Performing physical teardowns of models outside of the representative capacities allowed DOE to accurately model certain characteristics that are not identifiable in manufacturer literature. DOE modified the cost model for the representative capacity (*i.e.,*80 kBtu/h) to account for changes in the size of furnace components that would scale with input capacity (*e.g.,* heat exchanger size). DOE accurately modeled certain other characteristics (*e.g.,* gas valves) using information contained in manufacturer literature. Whenever possible, DOE maintained the same product line that was used for the teardown at the representative products to allow for a direct comparison between representative products and the products at the additional input capacities that were analyzed. To avoid the publication of sensitive material, DOE aggregated and normalized the costs for the additional input capacities in the same manner as was done for the representative input capacity.

5.10 STANDBY MODE AND OFF MODE

For the standby mode and off mode analyses, DOE adopted a design-option approach, which allowed for the calculation of incremental costs through the addition of specific design options to a baseline model. DOE decided on this approach because it did not have sufficient data to execute an efficiency-level analysis, as DOE is not aware of any manufacturers who currently rate or publish data on the standby mode and/or off mode energy consumption of their products. Because standby mode and off mode electricity consumption is not currently regulated, DOE believes manufacturers generally do not invest in reducing the off mode electrical energy consumption of their products because the production cost cannot be passed onto the consumer since consumers currently do not value this feature highly enough to pay extra for it. Therefore, DOE determined that there is no basis for comparison of efficiency levels between existing products. The design-option approach, by contrast, allowed DOE to examine potential designs for improving the off mode energy consumption.

5.10.1 Identification and Characterization of Standby Mode and Off Mode Components

Using the design-option approach, DOE identified components that contribute to standby mode and off mode energy consumption in the BOMs of the furnaces that were analyzed. DOE performed measurements of standby mode and off mode electrical energy consumption on each of these components in accordance with the DOE test procedure for residential furnaces. DOE aggregated these measurements, in conjunction with nominal power ratings and feedback from manufacturers regarding individual component's power draw, to characterize the electrical energy use of each component operating in standby mode or off mode. DOE also estimated the costs of individual components based on volume-variable price quotations and detailed discussions with manufacturers and component suppliers.

5.10.2 Baseline Model

The design-option approach was used to calculate the incremental costs to reduce energy consumption compared to a baseline level of standby or off mode energy consumption for products covered in this rulemaking. In most rulemakings, the baseline is determined by the current Federal minimum energy conservation standard. However, because there are no Federal standards that regulate the standby mode and off mode electrical energy consumption of NWGF and MHGF, DOE instead established the baseline model for the standby mode and off mode analysis based on the most energy-consumptive components of the products tested by DOE. DOE defined and identified baseline components as those that consumed the most electricity during standby mode and off mode operation. The most consumptive baseline components were then "assembled" to model the electrical system of a furnace with the maximum system off mode electrical energy consumption from DOE's representative test data.

DOE's testing of over 40 models of residential furnaces showed standby mode power consumption from 4 to 10 watts. However, because this represented only a fraction of the residential furnace market, DOE took a conservative approach and summed the most energy consumptive components in each individual furnace tested to create the baseline model. The baseline furnace model contains a 40VA control transformer, BPM blower motor (and associated controls), and linear power supply. DOE examined and tested the standby power consumption of a variety of products, including those with "premium" features that are related to consumer utility, but unrelated to product efficiency. In order to prevent a reduction in consumer utility, DOE did not consider any design options that would reduce the feature set of these units. The results of the testing for individual components are shown in Table 5.10.1 below.

Table 5.10.1 Baseline Standby Mode and Off Mode Power Consumption by Component for Furnaces

Component	**Non-weatherized Gas and Mobile Home Gas Baseline Power Consumption (W)**
Transformer	4
BPM Blower Motor (includes controls)	3
Controls/Other	4
Total	**11**

5.10.3 Cost-Power Consumption Results

The results of the engineering analysis for standby mode and off mode are reported as cost-power consumption data in the form of power (in watts) versus MPC (in dollars). For each design option that passed the screening analysis (chapter 4 of this TSD), DOE estimated the power consumption reduction of the design option based on the DOE test procedure. DOE determined that furnaces do not have a seasonal off switch and, therefore, determined that standby mode and off mode power consumption are equal. The efficiency levels listed are based on units with constant-airflow BPM motors because constant-airflow BPM motors use a higher amount of off mode power, specifically 3 watts more than units with PSC motors (including additional controls). The costs for each design option are the same regardless of motor type and therefore the results are given only for units with constant-airflow BPM motors.

The methodology for developing the cost-power consumption relationship started with determining the energy use of baseline products. Above the baseline, DOE implemented design options, which were discussed in Chapter 3, based on cost-effectiveness until all available technologies were employed (*i.e.,* at a max-tech level). The design options considered are not all mutually exclusive; therefore, systems could incorporate multiple design options simultaneously, which allowed for three different system designs and respective efficiency levels in addition to the baseline.

The first design option (utilized at Efficiency Level 1) is the change from a standard transformer to a low-loss transformer (LLTX). The second design option (utilized at Efficiency Level 2) is the change from a linear power supply to a switching mode power supply. The third design option (utilized at Efficiency Level 3) incorporates both of the first and second design options by utilizing both an LLTX and a switching mode power supply. In the third design option, a transformer is only needed to step-down the voltage for the thermostat because the switching-mode power supply is able to step-down the voltage for the other components of the furnace. As such, a smaller, lower cost LLTX is used at Efficiency Level 3. Table 5.10.2 lists the standby mode and off mode power consumption and associated MPC increases for each design option analyzed.

Table 5.10.2 Non-weatherized Gas Furnace and Mobile Home Gas Furnace Standby Mode and Off Mode Power Consumption and Cost

	Description	Standby Mode and Off Mode Power Consumption (W)	MPC ($)
Baseline	Linear Power Supply; Standard 40VA Transformer	11	0
Efficiency Level 1	Linear Power Supply with LLTX	9.5	1.00
Efficiency Level 2	Switching Mode Power Supply	9.2	9.02
Efficiency Level 3	Switching Mode Power Supply with LLTX	8.5	9.67

5.11 RESULTS

The final result of the engineering analysis is a set of cost-efficiency relationships. DOE developed relationships for both furnace product classes using the reverse-engineering and cost modeling methodology described above. The cost-efficiency results are shown in tabular form in Table 5.11.1 and Table 5.11.2 in the form of efficiency versus MPC and MSP.

Table 5.11.1 Cost-Efficiency Data for Non-weatherized Gas Furnaces with a Constant Torque BPM Blower Motor and Two-Stage Operation

AFUE	**MPC [$]**			
	60 kBtu/h	**80 kBtu/h**	**100 kBtu/h**	**120 kBtu/h**
80	349	360	382	407
90	428	443	471	507
92	436	451	485	512
95	476	505	541	584
98*	611	627	661	711
AFUE	**MSP [$]**			
	60 kBtu/h	**80 kBtu/h**	**100 kBtu/h**	**120 kBtu/h**
80	479	493	524	559
90	584	605	644	694
92	594	615	662	700
95	649	687	737	796
98*	829	850	899	968

*Furnaces at the max-tech, 98% AFUE efficiency level, utilize a constant-airflow BPM blower motor paired with modulating combustion as standard design options, rather than a constant-torque BPM blower motor paired with two-stage operation.

Table 5.11.2 Cost-Efficiency Data for Mobile Home Gas Furnaces (80 kBtu/h Input Capacity) with an Improved PSC Blower Motor

AFUE	**MPC [$]**
80	323
92	420
95	476
97	542
AFUE	**MSP [$]**

80	429
92	545
95	615
97	699

REFERENCES

[1] U.S. Department of Energy Regulations and Compliance, *Compliance Certification Management System*. (Last accessed July 17, 2014.) <http://www.regulations.doe.gov/certification-data/>

[2] AHRI. *Directory of Certified Product Performance*, Performance Data Updated June 7, 2010. (Last accessed July 23, 2014.) <http://www.ahridirectory.org/ahridirectory/pages/home.aspx>

[3] American Metals Market, (Last accessed June 16, 2014.) <http://www.amm.com/.>

[4] U.S. Department of Labor, Bureau of Labor Statistics, *Producer Price Indices*. (Last accessed June 16, 2014.) <http://www.bls.gov/ppi/>

[5] U.S. Department of Commerce, Bureau of Economic Analysis, *Gross Domestic Product Implicit Price Deflator*. (Last accessed July 10, 2014.) <http://www.bea.gov/national/nipaweb/TableView.asp?SelectedTable=13&Freq=Qtr&FirstYear=2008&LastYear=2010>

CHAPTER 6. MARKUPS ANALYSIS

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CHAPTER 6. MARKUP ANALYSIS

6.1 INTRODUCTION

To carry out its analyses, the U.S. Department of Energy (DOE) determined the cost to the consumer of baseline products and the cost of more efficient units the consumer would purchase under new energy conservation standards. DOE calculated such costs based on engineering estimates of manufacturing costs plus appropriate markups for the various distribution channels for non-weatherized gas furnaces (NWGFs) and mobile home gas furnaces (MHGFs).

For wholesalers and contractors, DOE estimated a baseline markup and an incremental markup. DOE defines a baseline markup as a multiplier that converts the manufacturer selling price (MSP) of equipment with baseline efficiency to the consumer purchase price for the equipment at the same baseline efficiency level. An incremental markup is defined as the multiplier to convert the incremental increase in manufacturer selling price of higher efficiency equipment to the 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 a product to cover their business costs and profit margin. In financial statements, gross margin is the difference between the company revenue and the company cost of sales or cost of goods sold (*CGS*). The gross margin takes account of the expenses of companies in the distribution channel, including overhead costs (sales, general, and administration); research and development (R&D) and interest expenses; depreciation; and taxes—and company profits. In order for sales of a product to contribute positively to company cash flow, the product's markup must be greater than the corporate gross margin. Products command lower or higher markups, depending on company expenses associated with the product and the degree of market competition.

6.2 DISTRIBUTION CHANNELS

The appropriate markups for determining consumer equipment prices depend on the type of distribution channels through which products move from manufacturers to purchasers. In the case of NWGFs, the majority of them are purchased for residential use, but a small fraction of NWGFs are purchased to be installed in small to mid-size commercial buildings. DOE estimated that 97 percent of total NWGFs shipments are to residential applications and 3 percent to commercial applications. Hence, DOE calculated the markups separately for both residential and commercial application of NWGFs.

Within each application, there are two primary distribution channels describing the way most products pass from the manufacturer to the consumer, one applying to NWGFs installed in replacement markets or by new owners and the other applying to NWGFs that are installed in new construction. In the replacement distribution channel, 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 consumer. The new construction distribution channel 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 then to the consumer. Figure 6.2.1 illustrates the two main distribution channels for NWGFs in the residential application.

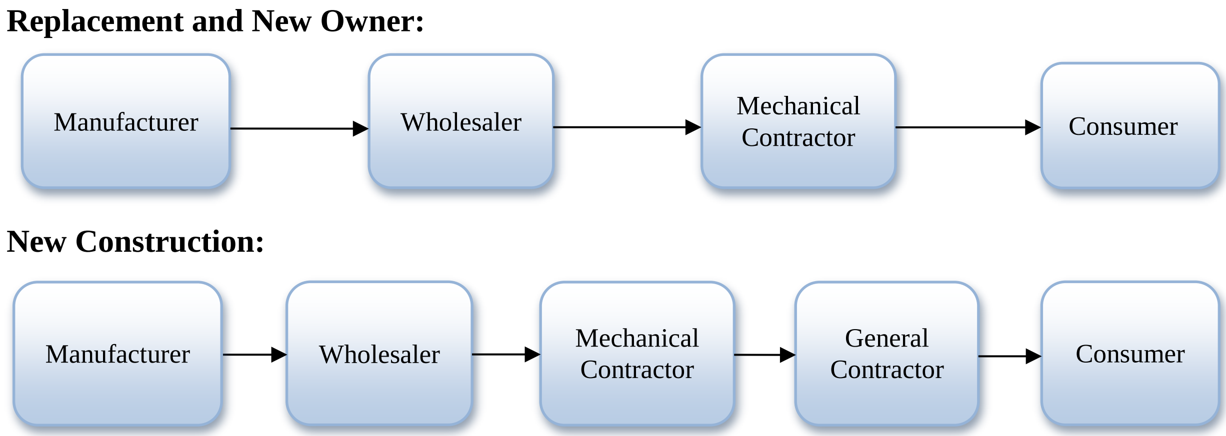

Figure 6.2.1 Distribution Channels for Non-Weatherized Gas Furnaces in Residential Applications

For NWGFs in commercial applications, DOE considers an additional distribution channel for which the manufacturer sells the product to the wholesaler and then to the consumer through a national account under both replacement and new construction markets. This national account distribution channel is applicable to small to mid-size commercial buildings where the on-site staff or internal personnel generally purchase equipment from wholesalers at much lower prices due to the large volume purchased and perform the installation themselves. Occasionally, the equipment manufacturers and wholesalers can be the same entity, so the consumer selling price could potentially be even lower than the usual national account channel. However, DOE does not have sufficient information to determine the appropriate markup for this particular distribution channel. Figure 6.2.2 shows the main distribution channels for NWGFs in the commercial applications.

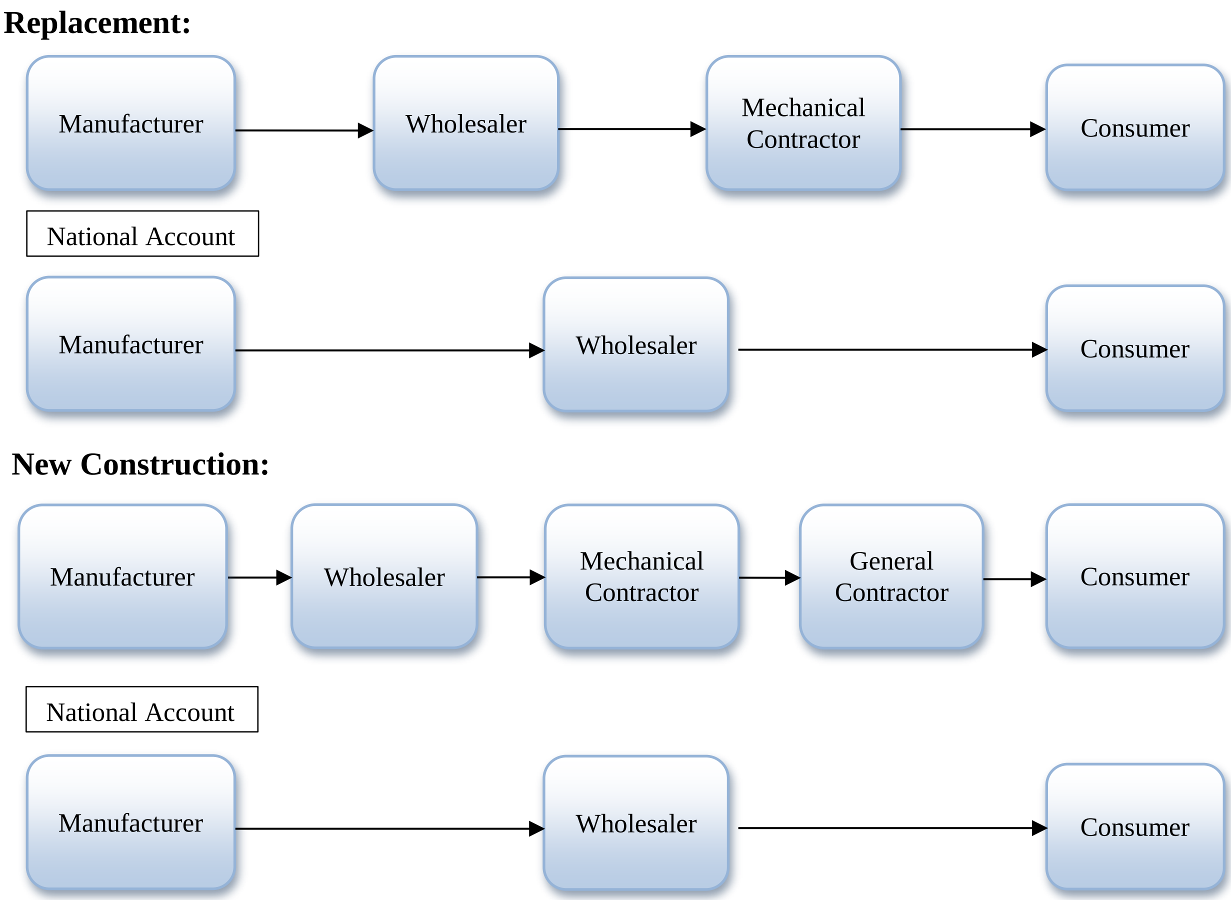

Figure 6.2.2 **Distribution Channels for Non-Weatherized Gas Furnaces in Commercial Applications**

Because MHGFs are sold as part of mobile homes, these furnaces have a specific distribution chain (Figure 6.2.3) when purchased in the new construction market, which accounts for 50 percent of the MHGF shipment. The furnace manufacturer sells MHGFs to the maker of the mobile home, who installs the equipment in the home. The mobile home manufacturer then sells the home to a mobile home dealer, who in turns sells it to a homebuyer and provides installation services. The equipment manufacturer markup for MHGFs is identical to the manufacturer markup for NWGFs. For MHGFs purchased in the replacement market, the distribution channel is assumed to be the same as the replacement distribution channel for NWGFs.

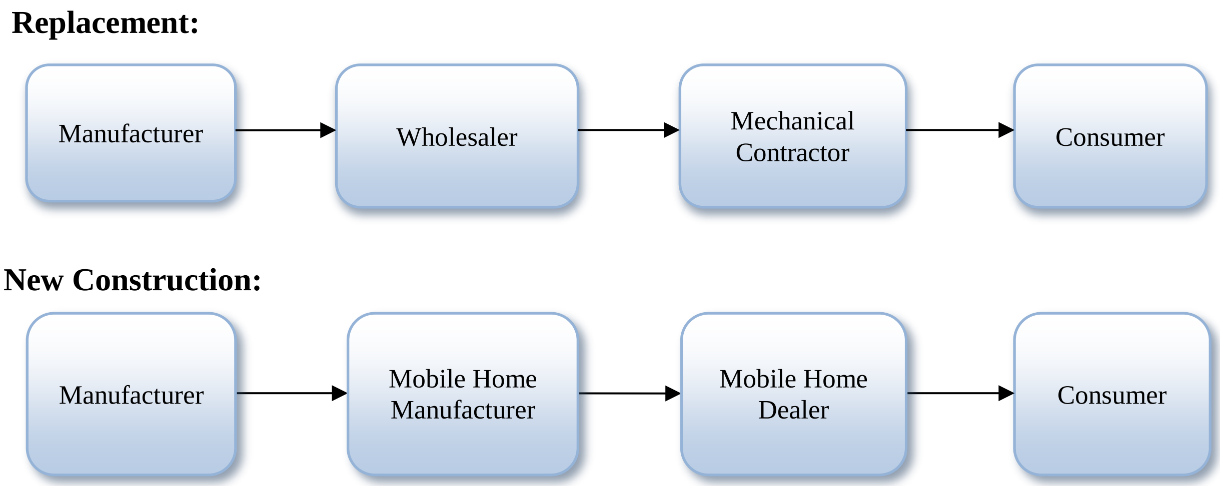

Figure 6.2.3 Distribution Channels for Mobile Home Gas Furnaces

Based on information provided from manufacturer interviews, there is another possible distribution channel that includes a retail store instead of a wholesaler. In this case, the manufacturer sells the equipment to a retailer, who in turn sells it to a mechanical contractor, who in turn sells it to the consumer. However, DOE does not have enough information at this point to make a separate markup estimation for this distribution channel. DOE assumed that the retailer markup is similar to the wholesaler markup. DOE is also aware that there may be two additional distribution channels for NWGFs and MHGFs: (1) an online distribution where manufacturers sell the products to online retailers who in turn sell them directly to consumers, and (2) a rebranding distribution channel where wholesalers or retailers negotiate good pricing from the furnace manufacturer based on high volumes and have the product customized to carry their name, and then send it through their normal distribution channel to the contractors. The former one mainly applies to the do-it-yourself (DIY) installation representing around two percent of the total HVAC shipments, which implies an even smaller fraction of the total NWGFs and MHGFs shipments. For the latter one, DOE assumes that it would have the same overall markups as the conventional distribution channels. Although manufacturers may have lower margin, wholesalers and retailers would redistribute the profit throughout the distribution channel to have the final retail price comparable with products sold through conventional distribution channels. Due to the reasons mentioned above, DOE did not consider them in this analysis.

6.3 APPROACH FOR MANUFACTURER MARKUP

DOE uses manufacturer markups to transform a manufacturer’s product cost into a manufacturer sales price. The methodology to derive manufacturer markups was described in the engineering analysis (chapter 5).

6.4 APPROACH FOR WHOLESALER AND CONTRACTOR MARKUPS

DOE examined the manner in which wholesaler and contractor markups may change in response to changes in NWGF and MHGF efficiency levels and other factors. Using the available data, DOE estimated that there are differences between *incremental* markups on incremental equipment costs of higher efficiency products and the *baseline* markup on direct business costs of products with baseline efficiency.

DOE derived the wholesaler and contractor markups from three key assumptions about the costs associated with NWGFs and MHGFs. DOE based the wholesaler and mechanical contractor markups on firm-level income statement data, and based the general contractor markups on U.S. Census Bureau data for the residential building construction industry. DOE obtained the firm income statements 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 used 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.[1] The key assumptions used to estimate markups using these financial data are:

1. The firm income statements faithfully represent the various average costs incurred by firms distributing and installing NWGFs and MHGFs.

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

3. Overall, wholesale and contractor prices for NWGFs and MHGFs vary in proportion to the wholesaler and contractor costs for NWGFs and MHGFs included in the income statements.

In support of the first assumption, the 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, including room air conditioners, furnaces, central air conditioners and heat pumps, and boilers, the data provide the most accurate available indication of the expenses associated with NWGFs and MHGFs.

Information obtained from the trade literature, selected HVAC wholesalers, contractors, and consultants tends to support the second assumption. This information indicates that wholesale and contractor markups vary according to the quantity of labor and materials used to

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[1] Wholesalers and mechanical contractors to which these reports refer handle multiple commodity lines.

distribute and install appliances. In the following discussion, 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 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 HVAC manufacturers,[3] 5,300 wholesalers of heat pumps and air-conditioning equipment,[4] more than 170,000 general residential contractors, 36,000 commercial and institutional building contractors,[5] and 91,000 HVAC contractors[6] listed in the 2007 Census. Following standard economic theory, competitive firms facing inelastic demand either set prices in line with costs or quickly go out of business.[7]

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

6.4.1 Wholesaler Markup

Using the above assumptions, DOE developed baseline and incremental markups for wholesalers using the firm income statement from the HARDI 2013 Profit Report (appendix 6A). The baseline markups cover all of the wholesaler's costs (both *invariant costs* and *variant costs*). Here, variant costs were defined as costs that likely vary in proportion to the change in MSP induced by increased efficiency standards; in contrast, invariant costs were defined as costs that are unlikely to vary in proportion to the change in MSP due to increased efficiency standards. DOE calculated 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 those products that meet 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 calculated 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 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 NWGFs and MHGFs, DOE collected financial data from the *Plumbing and HVAC Contractors* (NAICS 23822) series from the 2007 Economic Census and from ACCA 2005 Financial Analysis.

6.4.3 General Contractor Markup

To estimate general contractor markups for NWGFs and MHGFs in residential applications, DOE collected data from the Residential Building Construction series from the 2007 Economic Census, 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). To estimate general contractor markups for NWGFs in commercial applications, DOE collected data from the Commercial Building Construction series (NAICS 236220) from the 2007 Economic Census. ACCA financial data provide GM as percent of sales for the mechanical contractor industry; therefore, the baseline markup can be derived 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 calculated 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.

Analogously, DOE estimated the incremental mechanical contractor and general contractor markups by only marking up those costs that scale with a change in the MSP (variant costs, *VC*) for more energy-efficient products. As stated above, 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 categorized 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

DOE used U.S. Security and Exchange Commission (SEC) 10-K reports from publicly owned NWGF and MHGF manufacturing companies to estimate manufacturer markups. Table 6.5.1 presents manufacturer markups for the two product classes considered in this analysis.

Table 6.5.1 Manufacturer Markups by Non-Weatherized Gas Furnaces and Mobile Home Gas Furnaces Product Class

Product Class	Markup
Non-Weatherized Gas Furnace	1.34
Mobile Home Gas Furnace	1.27

6.5.2 Wholesaler Markup

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

Table 6.5.2 Wholesaler Expenses and Markups

Descriptions	**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 ($MU_{WHOLE\ BASE}$)		**1.353**
Incremental Markup ($MU_{WHOLE\ INCR}$)		**1.101**

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

In this case, direct equipment expenses (cost of goods sold) represent about $0.74 per dollar sales revenue, so for every $1 wholesalers take in as sales revenue, $0.739 is used to pay the direct equipment costs. Labor expenses represent $0.151 per dollar sales revenue, occupancy expenses represent $0.035, other operating expenses represent $0.052, and profit accounts for $0.023 per dollar sales revenue.

DOE converted the expenses per dollar sales into expenses per dollar cost of goods sold, by dividing each figure in the first data column by $0.739 (*i.e.*, cost of goods sold per dollar of sales revenue). The data in column two show that, for every $1.00 the wholesaler spends on equipment costs, the wholesaler allocates $0.204 to cover labor costs, $0.047 to cover occupancy expenses, $0.070 for other operating expenses, and $0.031 in profits. This totals to $1.353 in sales revenue earned for every $1.00 spent on equipment costs. Therefore, the wholesaler baseline markup ($MU_{WHOLE\ BASE}$) is 1.353 ($1.353 ÷ $1.00).

DOE also used the data in column two to estimate the incremental markup. The incremental markup depends on which of the costs in Table 6.5.2 are variant and which are invariant with MSP. For example, for a $1.00 increase in the MSP, if all of the other costs scale with the MSP (*i.e.*, all costs are variant), the increase in wholesale price will be $1.353, implying that the incremental markup is 1.353, 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 $0.075, which when divided by 73.9 cents in cost of goods sold yields an increase of $0.101, giving a wholesaler incremental markup ($MU_{WHOLE\ INCR}$) of 1.101. See appendix 6A 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 was able to determine the invariant (labor and occupancy expenses) and variant (other operating expenses and profits) costs for this particular sector. By using the equation mentioned above, baseline and incremental markups were estimated. The markup results representing the plumbing and HVAC contractor industry at the national aggregated level are presented in Table 6.5.3. (Appendix 6A contains the full set of data.)

Table 6.5.3 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	0.68	1.00
Labor Expenses: Salaries (indirect) and benefits	0.18	0.26
Occupancy Expense: Rent, maintenance, and utilities	0.02	0.03
Other Operating Expenses: Depreciation, advertising, and insurance.	0.08	0.12
Net Profit Before Taxes	0.04	0.06
Baseline Markup (*MUMECH BASE*): Revenue per dollar cost of goods		**1.48**
Incremental Markup (*MUMECH INCR*): Increased revenue per dollar increase in cost of goods sold		**1.18**

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

The first data column in Table 6.5.3 provides the cost of goods sold and a list of gross margin components as expenses per dollar of sales revenue. As shown in the table, the direct cost of sales represents about $0.68 per dollar sales revenue to the mechanical contractor, and the gross margin totals $0.32 per dollar sales revenue. DOE converted these expenses per dollar sales into revenue per dollar cost of goods sold by dividing each figure in the first data column by $0.68. For every $1.00 the mechanical contractor spends on equipment costs, the mechanical contractor earns $1.00 in sales revenue to cover the equipment cost and $0.48 to cover the other costs. This totals $1.48 in sales revenue earned for every $1.00 spent on equipment costs. This is equivalent to a baseline markup ($MU_{MECH\ CONT\ BASE}$) of 1.48 for mechanical contractors.

DOE was also able to use the data in column two in Table 6.5.3 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 $1.48, implying that the incremental markup is 1.48 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 $1.18, giving a general contractor incremental markup ($MU_{MECH\ CONT\ INCR}$) of 1.18.

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

DOE derived the baseline and incremental markups for both replacement and new construction markets using the 2007 Economic Census industrial cost data[8] supplemented with the most recent ACCA 2005 financial data.[2] The 2007 Economic Census provides sufficient detailed cost breakdown for the *Plumbing and HVAC Contractors* (NAICS 23822) sector so that DOE was 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 6.5.4.

Table 6.5.4 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	0.7286	1.000
Gross Margin: Labor, occupancy, operating expenses, and profit	0.2714	0.372
Revenue: Baseline revenue earned per dollar cost of goods		**1.372**
Baseline Markup ($MU_{MECH\ CONT\ BASE}$)		**1.372**

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

Table 6.5.5 summarizes the gross margin and resulting baseline markup data for all mechanical contractors that serve the replacement and new construction markets.

Table 6.5.5 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	0.7031	1.000	0.745	1.000
Gross Margin: Labor, occupancy, operating expenses, and profit	0.2969	0.422	0.255	0.342
Baseline Markup (*MUMECH CONT BASE*): Revenue per dollar cost of goods	NA	**1.422**	NA	**1.342**
% Difference from Aggregate Mechanical Contractor Baseline MU	NA	**3.63%**	NA	**-2.20%**

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

Using the baseline markup data from Table 6.5.5 and results from Table 6.5.4, 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 6.5.3. DOE assumed 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 6.5.6.

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

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

6.5.4 General Contractor Markups

DOE derived markups for general contractors from U.S. Census Bureau data for the residential building construction and commercial building construction sector to reflect the residential and commercial application of NWGFs.[9] The residential construction sector includes establishments primarily engaged in construction work, including new construction work, additions, alterations, and repairs of residential buildings, whereas the commercial construction sector includes establishments primarily responsible for the construction of commercial and institutional 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 assumed that the total dollar values that the U.S. Census Bureau reported, once converted to a percentage basis, represent revenues and expenses for an average or typical contracting business. Similar to the data for wholesalers, Table 6.5.7 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 contains the full set of data.)

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 (*MUGEN CONT BASE*): Revenue per dollar cost of goods		**1.47**
Incremental Markup (*MUGEN CONT INCR*): Increased revenue per dollar increase in cost of goods sold		**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 converted these expenses per dollar sales into revenue per dollar cost of goods sold, by dividing each figure in the first data column by $0.68. 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, \$0.12 to cover labor costs, \$0.01 to cover occupancy expenses, \$0.09 for other operating expenses, and \$0.25 in profits. This totals to \$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 was also able to use the data in column two 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 1.48, 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.

Table 6.5.8 summarizes the expenses for general contractors in commercial building construction at the national aggregated level as expenses per dollar sales revenue in the first data column. (Appendix 6A contains the full set of data.)

Table 6.5.8 Commercial Building General Contractor Expenses and Markups

Description	**Wholesale Firm Expenses or Revenue**	
	Per Dollar Sales Revenue *\$*	**Per Dollar Cost of Goods *\$***
Direct Cost of Equipment Sales: Cost of goods sold	0.76	1.00
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 (*MUGEN CONT BASE*): Revenue per dollar cost of goods		**1.31**
Incremental Markup (*MUGEN CONT INCR*): Increased revenue per dollar increase cost of goods sold		**1.19**

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 converted these expenses per dollar sales into revenue per dollar cost of goods sold, by dividing each figure in the first data column by \$0.76. The data in column two show that, for every $1.00 the general contractor spends on equipment costs, the general contractor earns $1.00 in sales revenue to cover the equipment cost, $0.10 to cover labor costs, $0.01 to cover occupancy expenses, $0.04 for other operating expenses, and $0.15 in profits. This totals to $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 was also able to use the data in column two of Table 6.5.8 to estimate the incremental markups, after classifying the costs as either invariant or variant. At one extreme, if all of the other costs scale with the equipment price (i.e., all costs are variant), the increase in general contractor price will be $1.48, implying that the incremental markup is 1.48, 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.

6.6 DERIVATION OF CENSUS REGIONS MARKUPS

To make the analysis more accurate, regional markups were calculated for each residential furnace product class in residential applications as well as commercial applications when applicable. Wholesalers and mechanical and general contractors in the furnace industry were divided into the 30 regions[2] provided by the latest RECS for the residential application of NWGFs and MHGFs and also were divided into the nine regions provided by the latest CBECS for the commercial application of NWGFs. Regional baseline and incremental markups were derived using the region/state level data from the 2013 HARDI Profit Report and the 2007 Economic Census.

6.6.1 Estimation of Regional Wholesaler Markups

Based on the regional income statement from the 2013 HARDI Profit Report, DOE estimated baseline and incremental markups for the seven HARDI regions (Northeastern, Mid-Atlantic, Southwestern, Great Lakes, Central, Southwestern, and Western) using the methodology shown in Table 6.5.2. Next, each state in each region was assigned the HARDI regional baseline and incremental markups for the region to which it belongs. Then, DOE assigned all states to one of the 30 RECS regions used in the analysis and then calculated shipment-weighted baseline and incremental markup averages for each region in residential application. The results are summarized in Table 6.6.1.

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[2] RECS 2009 provides 27 regions (also called reportable domains). The 27th region includes Oregon, Washington, Alaska, and Hawaii. DOE subdivided Alaska and Hawaii into separate regions (28 and 29, respectively) based on cooling and heating degree days. In addition, West Virginia, which is in RECS 2009 region 14was disaggregated into region 30 based on cooling and heating degree days.

Table 6.6.1 Wholesaler Markups for Non-Weatherized Gas Furnaces in Residential Applications and Mobile Home Gas Furnaces in Replacement Market

RECS Regions	State(s)	Baseline MU	Incremental MU
1	Connecticut, Maine, New Hampshire, Rhode Island, Vermont	1.366	1.072
2	Massachusetts	1.366	1.072
3	New York	1.366	1.072
4	New Jersey	1.355	1.092
5	Pennsylvania	1.354	1.095
6	Illinois	1.364	1.115
7	Indiana, Ohio	1.353	1.097
8	Michigan	1.353	1.097
9	Wisconsin	1.364	1.115
10	Iowa, Minnesota, North Dakota, South Dakota	1.364	1.115
11	Kansas, Nebraska	1.364	1.115
12	Missouri	1.364	1.115
13	Virginia	1.355	1.092
14	Delaware, District of Columbia, Maryland	1.355	1.092
15	Georgia	1.330	1.097
16	North Carolina, South Carolina	1.330	1.097
17	Florida	1.330	1.097
18	Alabama, Kentucky, Mississippi	1.339	1.097
19	Tennessee	1.330	1.097
20	Arkansas, Louisiana, Oklahoma	1.348	1.112
21	Texas	1.348	1.112
22	Colorado	1.364	1.115
23	Idaho, Montana, Utah, Wyoming	1.403	1.110
24	Arizona	1.404	1.110
25	Nevada, New Mexico	1.387	1.110
26	California	1.404	1.110
27	Oregon, Washington	1.404	1.110
28	Alaska	1.404	1.110
29	Hawaii	1.404	1.110
30	West Virginia	1.353	1.097

In commercial application of NWGFs, DOE assigned all states to one of the nine CBECS regions used in the analysis and then calculated shipment-weighted baseline and incremental markup averages for each region. The results are summarized in Table 6.6.2.

Table 6.6.2 Regional Wholesaler Markups for Non-Weatherized Gas Furnaces in Commercial Applications

CBECS Regions	Census Divisions	Baseline MU	Incremental MU
1	New England	1.366	1.072
2	Middle Atlantic	1.359	1.086
3	East North Central	1.358	1.104
4	West North Central	1.364	1.115
5	South Atlantic	1.339	1.095
6	East South Central	1.336	1.097
7	West South Central	1.348	1.112
8	Mountain	1.389	1.111
9	Pacific	1.404	1.110

6.6.2 Estimation of Regional 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 equation mentioned in Section 6.4.2. DOE was able to estimate baseline markups for each state. Because the Census does not provide more disaggregated cost data, DOE was not able to differentiate between invariant and variant cost.

Alternatively, DOE calculated the national baseline and incremental markups (Table 6.6.3) and found that the incremental markup is around 20 percent lower than the baseline markups. DOE further derived the state-level incremental markups by applying this ratio to the baseline markup in each state, assuming that this deviation applies equally to all states. (Appendix 6A contains the full set of data.)

In order to estimate the baseline and incremental markups for both replacement and new construction markets for each state, DOE applied the markup deviations (*i.e.*, 3.6 percent higher and 2.2 percent lower for the replacement and new construction markets, respectively) derived in Section 6.5.3.2 to the statewide baseline and incremental markups. DOE assumed that this deviation of replacement and new construction markets applies equally to the baseline and incremental markups.

Lastly, DOE divided all states among the 30 RECS regions and then calculated shipment-weighted average baseline and incremental markups for mechanical contractors for each region in residential application, as shown in Table 6.6.3.

Table 6.6.3 Shipment-Weighted Mechanical Contractor Markups for Non-Weatherized Gas Furnaces in Residential Applications and Mobile Home Gas Furnaces in Replacement Market

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	1.557	1.246	1.449	1.159
2	Massachusetts	1.538	1.231	1.431	1.145
3	New York	1.600	1.280	1.488	1.191
4	New Jersey	1.583	1.267	1.473	1.178
5	Pennsylvania	1.479	1.183	1.375	1.100
6	Illinois	1.577	1.262	1.467	1.173
7	Indiana, Ohio	1.563	1.251	1.454	1.163
8	Michigan	1.530	1.224	1.423	1.138
9	Wisconsin	1.510	1.208	1.404	1.123
10	Iowa, Minnesota, North Dakota, South Dakota	1.530	1.224	1.423	1.139
11	Kansas, Nebraska	1.443	1.154	1.342	1.073
12	Missouri	1.479	1.183	1.376	1.101
13	Virginia	1.557	1.246	1.448	1.158
14	Delaware, District of Columbia, Maryland	1.489	1.191	1.384	1.108
15	Georgia	1.474	1.179	1.371	1.096
16	North Carolina, South Carolina	1.494	1.196	1.390	1.112
17	Florida	1.512	1.210	1.407	1.125
18	Alabama, Kentucky, Mississippi	1.527	1.222	1.421	1.136
19	Tennessee	1.477	1.182	1.374	1.099
20	Arkansas, Louisiana, Oklahoma	1.527	1.221	1.420	1.136
21	Texas	1.498	1.198	1.393	1.115
22	Colorado	1.531	1.225	1.424	1.139
23	Idaho, Montana, Utah, Wyoming	1.486	1.189	1.382	1.106
24	Arizona	1.580	1.264	1.470	1.176
25	Nevada, New Mexico	1.532	1.225	1.424	1.140
26	California	1.607	1.286	1.495	1.196
27	Oregon, Washington	1.586	1.269	1.475	1.180
28	Alaska	1.766	1.413	1.642	1.314
29	Hawaii	1.835	1.468	1.707	1.366
30	West Virginia	1.528	1.222	1.421	1.137

In commercial application of NWGFs, DOE divided all states among the nine CBECS regions and then calculated shipment-weighted average baseline and incremental markups for mechanical contractors for each region, as shown in Table 6.6.4.

Table 6.6.4 Shipment-Weighted Mechanical Contractor Markups for Non-Weatherized Gas Furnaces in Commercial Application

CBECS Regions	Census Divisions	Replacement Baseline MU	Replacement Incremental MU	New Construction Baseline MU	New Construction Incremental MU
1	New England	1.548	1.238	1.440	1.152
2	Middle Atlantic	1.546	1.237	1.438	1.151
3	East North Central	1.553	1.242	1.444	1.155
4	West North Central	1.492	1.194	1.388	1.110
5	South Atlantic	1.497	1.197	1.392	1.114
6	East South Central	1.509	1.207	1.404	1.123
7	West South Central	1.508	1.207	1.403	1.122
8	Mountain	1.524	1.219	1.417	1.134
9	Pacific	1.603	1.282	1.491	1.193

6.6.3 Estimation of Regional General Contractor Markups

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

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 estimated the statewide incremental markups by applying the ratio of national baseline and incremental markups (*i.e.*, the national incremental markup is around 8.84 and 9.16 percent lower than the national baseline markup in residential and commercial application, respectively) to the baseline markups for each state. Lastly, DOE divided all states among the 30 RECS regions and nine CBECS regions; then calculated shipment-weighted average baseline and incremental markups for general contractors for each region in both residential and commercial application. The final results are summarized in Table 6.6.5 for residential application Table 6.6.6 for commercial application (Appendix 6A contains the full set of data.)

Table 6.6.5 Shipment-Weighted General Contractor Markups for Non-Weatherized Gas Furnaces in Residential Application

RECS Regions	State(s)	Baseline MU	Incremental MU
1	Connecticut, Maine, New Hampshire, Rhode Island, Vermont	1.389	1.264
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	1.372	1.248
11	Kansas, Nebraska	1.353	1.231
12	Missouri	1.325	1.206
13	Virginia	1.450	1.320
14	Delaware, District of Columbia, Maryland	1.422	1.294
15	Georgia	1.428	1.300
16	North Carolina, South Carolina	1.393	1.267
17	Florida	1.528	1.391
18	Alabama, Kentucky, Mississippi	1.357	1.235
19	Tennessee	1.353	1.231
20	Arkansas, Louisiana, Oklahoma	1.342	1.221
21	Texas	1.499	1.364
22	Colorado	1.499	1.364
23	Idaho, Montana, Utah, Wyoming	1.325	1.206
24	Arizona	1.707	1.553
25	Nevada, New Mexico	1.645	1.497
26	California	1.717	1.562
27	Oregon, Washington	1.431	1.302
28	Alaska	1.854	1.687
29	Hawaii	1.417	1.289
30	West Virginia	1.545	1.406

Table 6.6.6 Shipment-Weighted General Contractor Markups for Non-Weatherized Gas Furnaces in Commercial Application

CBECS Regions	Census Division	Baseline MU	Incremental MU
1	New England	1.332	1.210
2	Middle Atlantic	1.419	1.289
3	East North Central	1.313	1.192
4	West North Central	1.287	1.170
5	South Atlantic	1.355	1.231
6	East South Central	1.320	1.199
7	West South Central	1.304	1.184
8	Mountain	1.253	1.138
9	Pacific	1.319	1.198

6.7 MARKUP FOR MOBILE HOME GAS FURNACES

DOE used *Manufactured Home (Mobile Home) Manufacturing* (NAICS 321991) sector[11] and *All Other Specialty Trade Contractors* (NAICS 238990) sector[11] from the 2007 Economic Census to calculate markups for mobile home gas furnace manufacturers and dealers in the new construction market, respectively.

6.7.1 Markups for Mobile Home Manufacturers

The *Manufactured Home (Mobile Home) Manufacturing* (NAICS 321991) industrial series includes revenue and expenses associated with making mobile homes, and the second series accounts for the expenses and revenue associated with performing manufactured (mobile) home setup and tie-down work for new construction. The detailed cost breakdown for mobile home manufacturers and the final estimates for both baseline and incremental markups are listed in Table 6.7.1. Detailed industrial series data can be found in appendix 6A.

Table 6.7.1 Mobile Home Manufacturer Expenses and Markups for New Construction

Description	Mobile Home Manufacturer Expenses or Revenue Per Dollar Sales Revenue *$*	 Per Dollar Cost of Goods *$*
Direct Cost of Equipment Sales: Cost of goods sold	0.71	1.00
Labor Expenses: Salaries (indirect) and benefits	0.08	0.11
Occupancy Expense: Rent, maintenance, and utilities	0.01	0.02
Other Operating Expenses: Depreciation, advertising, and insurance.	0.09	0.13
Net Profit Before Taxes	0.11	0.15
Baseline Markup (*MUMOBILE HOME BASE*): Revenue per dollar cost of goods		**1.41**
Incremental Markup (*MUMOBILE HOME INCR*): Increased revenue per dollar increase cost of goods sold		**1.28**

Source: U.S. Census Bureau. 2007. Manufactured Home (Mobile Home) Manufacturing. Sector 31: 321991. Manufacturing: Industry Series: Detailed Statistics for Establishments: 2007

As shown in the first column, the direct cost of sales represents about $0.71 per dollar sales revenue to the mobile home contractor. Labor expenses represent $0.08 per dollar sales revenue, occupancy expenses represent $0.01 per dollar sales revenue, other operating expenses represent $0.09, and profit makes up $0.11 per dollar sales revenue. DOE then converted these expenses per dollar sales into revenue per dollar cost of goods sold, by dividing each figure in the first data column by $0.71. The data in column two show that, for every $1.00 the mobile home gas furnace manufacturer spends on equipment costs, the mobile home gas furnace manufacturer earns $1.00 in sales revenue to cover the equipment cost, $0.11 to cover labor costs, $0.02 to cover occupancy expenses, $0.13 for other operating expenses, and $0.15 in profits. Thus, the manufacturer baseline markup for mobile home gas furnaces ($MU_{MOBILE\ HOME\ MFG\ BASE}$) is 1.41. DOE believes the labor and occupancy costs to be invariant and the other operating costs and profit to scale with the equipment price (*i.e.,* be variant). In this case, for a $1.00 increase in the equipment price, the manufacturer price for mobile home gas furnaces will increase by $1.28, giving a mobile home gas furnace manufacturer incremental markup ($MU_{MOBILE\ HOME\ MFG\ INCR}$) of 1.28.

6.7.2 Markups for Mobile Home Dealers

DOE derived the baseline and incremental markups for mobile home dealers using the 2007 Economic Census industrial cost data, supplemented with numerous references from credible organizations and business experts in related industries. The 2007 Economic Census provides sufficient detailed cost breakdown for the *All Other Specialty Trade Contractors* (NAICS 238990) sector, which includes businesses associated with set-up and tie-down work of mobile homes; however, this aggregated industrial series also consists of many other contracting businesses, whose work is not related to the installation of mobile homes. Therefore, DOE carefully reviewed references from major mobile home dealers' websites and other sources[12, 13,]

[14, 15] and estimated that proposed markups for mobile home dealers generally range from 1.25 to 1.35. From this information, DOE constructed a triangular distribution for dealer markups, with 1.30 as the likeliest baseline markup estimate for mobile home dealers and 1.25 and 1.35 as the minimum and maximum values of the distribution. The Manufactured Housing Institute (MHI) also suggested that the markup of the retailer and shipping costs are traditionally 1/3 of the free on board (FOB) price, which is in line with DOE's baseline markup estimate of 1.30.[16] Note that in the case of the mobile home market, the terms "*retailer*" and "*dealer*" are used interchangeably, and shipping costs are borne by mobile home dealers and also marked up by them in our analysis as well.

In order to calculate the incremental markup for mobile home dealers, DOE scaled the baseline markup estimate (1.30) with the baseline/incremental markup ratio calculated using the *All Other Specialty Trade Contractors* (NAICS 238990) industrial series. The detailed cost breakdown for the *All Other Specialty Trade Contractors* (NAICS 238990) sector from the 2007 Economics Census and the final estimates for both baseline and incremental markups are listed in Table 6.7.2. Detailed industrial series data can be found in appendix 6A

Table 6.7.2 Contractor Expenses and Markups for All Other Specialty Trade Contractors (NAICS 238990)

	Mobile Home Contractor Expenses or Revenue	
Description	**Per Dollar Sales Revenue *$***	**Per Dollar Cost of Goods *$***
Direct Cost of Equipment Sales: Cost of goods sold	0.60	1.00
Labor Expenses: Salaries (indirect) and benefits	0.14	0.24
Occupancy Expense: Rent, maintenance, and utilities	0.03	0.06
Other Operating Expenses: Depreciation, advertising, and insurance.	0.11	0.18
Net Profit Before Taxes	0.11	0.19
Baseline Markup (*MUMOBILE HOME BASE*): Revenue per dollar cost of goods		**1.66**
Incremental Markup (*MUMOBILE HOME INCR*): Increased revenue per dollar increase cost of goods sold		**1.37**

Source: U.S. Census Bureau. 2007. All Other Specialty Trade Contractors. Sector 23: 238990. Construction: Summary Series: General Summary: Detailed Statistics for Establishments: 2007.

Based on the baseline and incremental markup estimates shown in Table 6.7.2, DOE concluded that the ratio of baseline to incremental markups is 1.78 (=(1.66-1)/(1.37-1)). DOE then applied this ratio to the baseline markup for mobile home dealers (1.30) to derive its incremental markup, which is equal to 1.17. Thus, in the final overall markup calculation for furnaces installed in mobile homes, DOE used 1.30 as the baseline markup ($MU_{MOBILE\ HOME\ CONT\ BASE}$) and 1.17 as the incremental markup ($MU_{MOBILE\ HOME\ CONT\ INCR}$). Based on the distribution channel for mobile home furnaces in the new construction market that DOE described in Figure 6.2.1, in order to derive the final retail price for MHGFs, the total markup applied to the manufacturing cost of heating equipment equals the product of the manufacturer markup for gas furnaces and manufacturer markup and dealer markup for MHGFs. In this case, the baseline overall markup DOE estimated for mobile home gas furnaces reconciles with the comment submitted from the MHI suggesting that the markup of the home manufacturer's material costs to the retailer's sale price to the owner has traditionally been a factor of 2.22.[16] As for those units purchased for replacement, DOE used the same baseline and incremental markups estimated for NWGFs to apply to the manufacturing price of gas furnaces.

6.8 SALES TAX

The sales tax represents state and local sales taxes that are applied to the consumer price of the equipment. The sales tax is a multiplicative factor that increases the consumer equipment price. DOE only applied the sales tax to the consumer price of the equipment in the replacement market, not the new construction market. The common practice for selling larger residential appliances like NWGFs and MHGFs 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 consumers. Therefore, no additional sales tax is necessary to calculate the consumer equipment price for the new construction market.

DOE derived state and local taxes from data provided by the Sales Tax Clearinghouse.[17] These data represent weighted averages that include county and city rates. DOE then derived shipment-weighted average tax values for each RECS and CBECS region to match the regional markups for wholesalers and mechanical and general contractors, as shown in Table 6.8.1 and Table 6.8.2. Detailed sales tax data by each state can be found in appendix 6A.

Table 6.8.1 Average Sales Tax Rates by RECS Region

RECS Regions	State(s)	Fraction of Total Shipments (1992-2003) %	Tax Rate (2014) %
1	Connecticut, Maine, New Hampshire, Rhode Island, Vermont	0.69	3.79
2	Massachusetts	0.69	6.25
3	New York	2.96	8.40
4	New Jersey	1.87	6.95
5	Pennsylvania	3.38	6.40
6	Illinois	6.24	8.05
7	Indiana, Ohio	9.36	7.06
8	Michigan	5.06	6.00
9	Wisconsin	3.17	5.45
10	Iowa, Minnesota, North Dakota, South Dakota	4.57	6.89
11	Kansas, Nebraska	2.63	6.85
12	Missouri	3.44	7.45
13	Virginia	1.85	5.60
14	Delaware, District of Columbia, Maryland	2.91	5.63
15	Georgia	4.49	7.05
16	North Carolina, South Carolina	3.28	6.98
17	Florida	0.74	6.65
18	Alabama, Kentucky, Mississippi	3.45	7.25
19	Tennessee	1.92	9.45
20	Arkansas, Louisiana, Oklahoma	5.57	8.70
21	Texas	9.88	7.90
22	Colorado	2.19	6.05
23	Idaho, Montana, Utah, Wyoming	2.48	5.86
24	Arizona	1.18	7.15
25	Nevada, New Mexico	1.53	7.47
26	California	10.52	8.45
27	Oregon, Washington	3.50	3.58
28	Alaska	0.07	1.30
29	Hawaii	0.03	4.40
30	West Virginia	0.37	6.10
Shipment-Weighted National Average			**7.13**

Table 6.8.2 Average Sales Tax Rates by CBECS Region

CBECS Regions	Census Divisions	Fraction of Total Shipments (1992-2003) %	Tax Rate (2014) %
1	New England	1.37	5.02
2	Middle Atlantic	8.21	7.25
3	East North Central	23.81	6.88
4	West North Central	10.64	7.06
5	South Atlantic	13.64	6.48
6	East South Central	5.36	8.04
7	West South Central	15.45	8.19
8	Mountain	7.39	6.46
9	Pacific	14.12	7.20
Shipment-Weighted National Average			**7.13**

6.9 OVERALL MARKUPS

DOE used the overall baseline markup to estimate the consumer product price of baseline models, given the manufacturer cost of the baseline models. As stated previously, DOE considers baseline models to be products sold under existing market conditions (*i.e.,* without new energy conservation standards). The following equation shows how DOE used the overall baseline markup to determine the product 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} = consumer product 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 used the overall incremental markup to estimate changes in the consumer product price, given changes in the manufacturer cost from the baseline model cost resulting from an energy conservation standard to raise product energy efficiency. The total consumer product price for more energy-efficient models is composed of two components: the consumer product price of the baseline model and the change in consumer product price associated with the increase in manufacturer cost to meet the new energy conservation standard. The following equation shows how DOE used the overall incremental markup to determine the consumer product 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} = consumer product price for models meeting new energy conservation standards,
CPP_{BASE} = consumer product 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 (product 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 6.9.1 to Table 6.9.3 for NWGFs and MHGFs. These values represent the weighted-average markups based on the state-level markup values and shipment data by state as weight. Based on NWGF and MHGF shipment forecasts for the year 2021 (see chapter 9), DOE estimated that 25 percent of NWGFs and 50 percent of MHGFs go to new construction. On the other hand, 75 percent of NWGFs and 50 percent of MHGFs go to the replacement market. By weighting the markups by the market shares for each type of NWGF and MHGF and market, overall markups are listed in Table 6.9.4.

Table 6.9.1 Summary of Overall Markups for Non-Weatherized Gas Furnaces in Residential Applications

	Replacement		**New Construction**	
	Baseline Markup	**Incremental Markup**	**Baseline Markup**	**Incremental Markup**
Manufacturer	1.34		1.34	
Wholesaler	1.36	1.10	1.36	1.10
Mechanical Contractor	1.53	1.23	1.43	1.14
General Contractor	-		1.46	1.33
Sales Tax	1.07		-	
Total Markup	3.00	1.95	3.80	2.24

Note: Components may not multiply to the Total Markup due to rounding.

Table 6.9.2 Summary of Overall Markups for Non-Weatherized Gas Furnaces in Commercial Applications

	Replacement			New Construction		
	Baseline Markup	**Incremental Markup**	**National Account: Baseline/ Incr. MU**	**Baseline Markup**	**Incremental Markup**	**National Account: Baseline/ Incr. MU**
Manufacturer	1.34			1.34		
Wholesaler	1.36	1.10	1.36/1.10	1.36	1.10	1.36/1.10
Mechanical Contractor	1.53	1.23	-	1.43	1.14	-
General Contractor	-			1.46	1.33	-
Sales Tax	1.07			-		
Total Markup	3.00	1.95	1.96/1.59	3.80	2.24	1.83/1.48

Note: Components may not multiply to the Total Markup due to rounding.

Table 6.9.3 Summary of Overall Markups on Mobile Home Gas Furnaces in Residential Applications

	Replacement		New Construction	
	Baseline Markup	**Incremental Markup**	**Baseline Markup**	**Incremental Markup**
Manufacturer	1.27		1.27	
Wholesaler (replacement only)	1.36	1.10	-	-
Mechanical Contractor (replacement only)	1.53	1.23	-	-
Mobile Home Manufacturer (new construction only)	-	-	1.41	1.28
Mobile Home Dealer (new construction only)	-	-	1.30	1.17
Sales Tax (replacement only)	1.07	1.07	-	-
Total Markup	2.84	1.84	2.32	1.90

Note: Components may not multiply to the Total Markup due to rounding.

Table 6.9.4 Summary of Overall Markup by Non-Weatherized Gas Furnaces and Mobile Home Gas Furnaces Product Class

Product Class	Baseline Markup	Incremental Markup
Non-Weatherized Gas Furnace	3.20	2.02
Mobile Home Gas Furnace	2.57	1.87

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APPENDIX 6A. DETAILED DATA FOR PRODUCT 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) 2013 Profit Report, Table 6.5.2 of chapter 6 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) assumed to scale with only the baseline markup and which with both the baseline and incremental markups. As described in chapter 6, section 6.4.1, only those expenses that scale with both baseline and incremental costs are marked up when there is an incremental change in product costs.

Table 6A.1.1 Disaggregated Costs and Expenses for Wholesalers

Item	Percent of Revenue %	Scaling
Cost of Goods Sold	**73.9**	
Gross Margin	**26.1**	
Payroll Expenses	**15.1**	Baseline
Executive Salaries & Bonuses	1.6	
Branch Manager Salaries and Commissions	1.3	
Sales Executive Salaries & Commissions	0.5	
Outside Sales Salaries & Commissions	2.3	
Inside/Counter Sales/Wages	2.6	
Purchasing Salaries/Wages	0.5	
Credit Salaries/Wages	0.2	
IT Salaries/Wages	0.2	
Warehouse Salaries/Wages	1.4	
Accounting	0.5	
Delivery Salaries/Wages	0.8	
All Other Salaries/Wages & Bonuses	0.8	
Payroll Taxes	1.0	
Group Insurance	1.0	
Benefit Plans	0.4	
Occupancy Expenses	**3.5**	Baseline
Utilities: Heat, Light, Power, Water	0.4	
Telephone	0.3	
Building Repairs & Maintenance	0.3	
Rent or Ownership in Real Estate	2.5	

Item	Percent of Revenue %	Scaling
Other Operating Expenses	**5.2**	Baseline & Incremental
Sales Expenses (incl. advertising & promotion)	0.9	
Insurance (business liability & casualty)	0.2	
Depreciation	0.4	
Vehicle Expenses	1.2	
Personal Property Taxes/Licenses	0.1	
Collection Expenses	0.3	
Bad Debt Losses	0.2	
Data Processing	0.3	
All Other Operating Expenses	1.6	
Total Operating Expenses	**23.8**	
Operating Profit	**2.3**	Baseline & Incremental
Other Income	0.4	
Interest Expense	0.4	
Other Non-operating Expenses	0.0	
Profit Before Taxes	**2.3**	

Source: Heating, Air-conditioning & Refrigeration Distributors International. 2013. 2013 Profit Report (2012 Data).
Note: The wholesaler costs and expenses are percentage values as opposed to the per-dollar of sales revenue values shown in Table 6.4.1.

6A.2 DETAILED MECHANICAL CONTRACTOR DATA

Tables 6.5.4 and Table 6.5.5 of 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 did not provide a more disaggregated tabulation of these costs and expenses. As in section 6A.1, the gross margin category was assumed to scale only with the baseline markup.

A further disaggregated breakdown of costs used to scale the incremental markup are shown in Table 6A.2.1 by both dollar value and percentage terms from the 2007 Census of Business. As the ACCA data were 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 product 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.

Note: Mechanical contractor costs and expenses are first presented as *total dollar* values and then converted to *percentage* values. This is in contrast to the *cost per dollar of sales revenue* values shown in Table 6.5.2.

6A.3 DETAILED GENERAL CONTRACTOR COST DATA

Based on U.S. Department of Census data, Table 6.5.7 and Table 6.5.8 of chapter 6 show both residential building and commercial building general contractor revenues and costs in aggregated form. Table 6A.3.1 shows the complete breakdown of costs and expenses of residential building contractor provided by the U.S. Department of Census. The column labeled "Scaling" indicates which expenses DOE assumed to scale with only the baseline markup and which are scaled with both the baseline and incremental markups. Only those expenses that scale with baseline and incremental costs are marked up when there is an incremental change in product costs. Table 6A.3.2 shows the similar analysis for commercial building contractors.

Table 6A.3.1 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.

Note: General contractor costs and expenses are first presented as *total dollar* values and then converted to *percentage* values. This is in contrast to the *cost per dollar of sales revenue* values shown in Table 6.5.6.

Table 6A.3.2 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**	
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	Baseline
Occupancy Expenses	**3,301,046**	**1.00**	
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	Baseline
Other Operating Expenses	**10,770,620**	**3.28**	
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	Baseline & Incremental
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.

Note: General contractor costs and expenses are first presented as *total dollar* values and then converted to *percentage* values. This is in contrast to the *cost per dollar of sales revenue* values shown in Table 6.5.6.

6A.4 ESTIMATION OF CONTRACTOR MARKUP BY STATE

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	1.498	1.198	1.393	1.114
Alaska	583,171	344,729	1.692	1.353	1.766	1.413	1.642	1.314
Arizona	3,522,116	2,326,475	1.514	1.211	1.580	1.264	1.470	1.176
Arkansas	1,065,754	743,395	1.434	1.147	1.496	1.197	1.392	1.113
California	16,726,969	10,865,201	1.539	1.232	1.607	1.286	1.495	1.196
Colorado	3,056,988	2,084,454	1.467	1.173	1.531	1.225	1.424	1.139
Connecticut	1,704,668	1,135,871	1.501	1.201	1.566	1.253	1.457	1.166
Delaware	481,900	D	1.421	1.137	1.483	1.186	1.379	1.104
District of Colum.	34,600	D	1.458	1.167	1.522	1.218	1.416	1.133
Florida	9,061,426	6,254,391	1.449	1.159	1.512	1.210	1.407	1.125
Georgia	4,700,799	3,329,842	1.412	1.129	1.474	1.179	1.371	1.096
Hawaii	800,221	455,122	1.758	1.407	1.835	1.468	1.707	1.366
Idaho	900,698	617,165	1.459	1.168	1.523	1.219	1.417	1.133
Illinois	7,641,642	5,058,047	1.511	1.209	1.577	1.262	1.467	1.173
Indiana	4,002,323	2,605,238	1.536	1.229	1.604	1.283	1.491	1.193
Iowa	1,868,483	1,305,883	1.431	1.145	1.493	1.195	1.389	1.111
Kansas	1,395,359	966,707	1.443	1.155	1.507	1.205	1.401	1.121
Kentucky	1,747,925	1,157,360	1.510	1.208	1.576	1.261	1.466	1.173
Louisiana	1,997,044	1,317,429	1.516	1.213	1.582	1.266	1.472	1.177
Maine	580,816	394,847	1.471	1.177	1.535	1.228	1.428	1.142
Maryland	5,329,135	3,739,560	1.425	1.140	1.487	1.190	1.383	1.107
Massachusetts	4,099,301	2,781,377	1.474	1.179	1.538	1.231	1.431	1.145
Michigan	4,420,638	3,015,948	1.466	1.173	1.530	1.224	1.423	1.138
Minnesota	3,402,921	2,315,330	1.470	1.176	1.534	1.227	1.427	1.141
Mississippi	1,025,452	715,571	1.433	1.146	1.496	1.197	1.391	1.113
Missouri	3,335,124	2,353,598	1.417	1.134	1.479	1.183	1.376	1.101
Montana	483,578	345,458	1.400	1.120	1.461	1.169	1.359	1.087
Nebraska	1,004,296	755,338	1.330	1.064	1.388	1.110	1.291	1.033
Nevada	2,327,842	1,600,555	1.454	1.164	1.518	1.214	1.412	1.130
New Hampshire	620,761	D	1.472	1.178	1.537	1.230	1.429	1.144
New Jersey	5,062,336	3,337,013	1.517	1.214	1.583	1.267	1.473	1.178
New Mexico	891,914	595,659	1.497	1.198	1.563	1.250	1.454	1.163
New York	10,364,779	6,760,337	1.533	1.227	1.600	1.280	1.488	1.191
North Carolina	5,111,396	3,631,802	1.407	1.126	1.469	1.175	1.366	1.093
North Dakota	360,683	255,057	1.414	1.131	1.476	1.181	1.373	1.098
Ohio	5,618,591	3,809,806	1.475	1.180	1.539	1.231	1.432	1.145
Oklahoma	1,352,943	924,264	1.464	1.171	1.528	1.222	1.421	1.137
Oregon	1,893,678	1,237,956	1.530	1.224	1.597	1.277	1.485	1.188
Pennsylvania	6,487,476	4,579,367	1.417	1.133	1.479	1.183	1.375	1.100
Rhode Island	631,202	410,653	1.537	1.230	1.604	1.284	1.492	1.194
South Carolina	1,991,303	1,326,690	1.501	1.201	1.567	1.253	1.457	1.166
South Dakota	386,186	239,017	1.616	1.293	1.686	1.349	1.569	1.255
Tennessee	2,595,613	1,834,242	1.415	1.132	1.477	1.182	1.374	1.099

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
Texas	10,810,308	7,532,064	1.435	1.148	1.498	1.198	1.393	1.115
Utah	1,746,398	1,235,004	1.414	1.131	1.476	1.181	1.373	1.098
Vermont	294,806	D	1.472	1.178	1.537	1.230	1.429	1.144
Virginia	4,623,151	3,099,329	1.492	1.193	1.557	1.246	1.448	1.158
Washington	4,111,543	2,734,093	1.504	1.203	1.570	1.256	1.460	1.168
West Virginia	655,100	D	1.464	1.171	1.528	1.222	1.421	1.137
Wisconsin	2,926,545	2,023,634	1.446	1.157	1.510	1.208	1.404	1.123
Wyoming	289,391	198,105	1.461	1.169	1.525	1.220	1.418	1.135

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
http://factfinder.census.gov/bkmk/table/1.0/en/ECN/2007_US/23I1 and
Geographic Area Series: Detailed Statistics for Establishments: 2007.
Notes: The Census Bureau withheld data for some states.
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)

Table 6A.4.2 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	1.234
Alaska	598,572	322,897	1.854	1.678
Arizona	14,743,264	8,636,727	1.707	1.546
Arkansas	821,493	638,546	1.287	1.165
California	49,325,592	28,727,843	1.717	1.555
Colorado	9,711,667	6,478,218	1.499	1.357
Connecticut	2,835,015	1,914,706	1.481	1.341
Delaware	912,121	714,609	1.276	1.156
District of Columbia	177,004	115,545	1.532	1.387
Florida	33,290,091	21,780,175	1.528	1.384
Georgia	12,492,752	8,745,668	1.428	1.293
Hawaii	2,739,122	1,933,143	1.417	1.283
Idaho	2,565,176	2,014,522	1.273	1.153
Illinois	13,035,923	8,206,105	1.589	1.438
Indiana	4,637,976	3,418,576	1.357	1.228
Iowa	1,846,602	1,449,114	1.274	1.154
Kansas	1,940,745	1,443,265	1.345	1.217
Kentucky	3,074,656	2,244,283	1.370	1.240
Louisiana	2,429,529	1,650,884	1.472	1.332
Maine	821,980	630,393	1.304	1.181
Maryland	6,616,960	4,635,717	1.427	1.292
Massachusetts	7,693,991	5,728,767	1.343	1.216
Michigan	5,383,752	3,501,797	1.537	1.392
Minnesota	5,558,816	3,847,679	1.445	1.308
Mississippi	1,241,083	939,692	1.321	1.196
Missouri	4,754,552	3,588,694	1.325	1.200
Montana	1,148,453	919,206	1.249	1.131

State	Value of Residential Construction *$1,000*	Cost of Goods Sold *$1,000*	Baseline Markup	Incremental Markup
Nebraska	577,746	424,822	1.360	1.231
Nevada	6,697,489	4,026,111	1.664	1.506
New Hampshire	292,227	228,854	1.277	1.156
New Jersey	8,492,015	5,649,618	1.503	1.361
New Mexico	2,236,262	1,395,073	1.603	1.451
New York	16,958,113	12,176,837	1.393	1.261
North Carolina	16,254,736	11,579,895	1.404	1.271
North Dakota	D	D	1.331	1.205
Ohio	6,788,825	4,883,462	1.390	1.259
Oklahoma	1,419,859	1,075,586	1.320	1.195
Oregon	5,519,819	4,019,693	1.373	1.243
Pennsylvania	9,971,624	7,323,399	1.362	1.233
Rhode Island	309,403	205,383	1.506	1.364
South Carolina	5,921,453	4,350,205	1.361	1.232
South Dakota	297,424	228,839	1.300	1.177
Tennessee	5,243,037	3,874,974	1.353	1.225
Texas	32,123,700	21,429,103	1.499	1.357
Utah	4,201,276	3,095,214	1.357	1.229
Vermont	527,837	387,905	1.361	1.232
Virginia	12,761,751	8,799,880	1.450	1.313
Washington	11,158,559	7,361,497	1.516	1.372
West Virginia	348,291	225,500	1.545	1.398
Wisconsin	3,820,533	2,850,921	1.340	1.213
Wyoming	524,809	418,215	1.255	1.136

Sources: U.S. Bureau of the Census, American Factfinder. 2007 Economic Census. Sector 23: Subsectors 236115 (residential single-family), 236116 (residential multifamily), 236117 (operative builders), and 236118 (residential remodelers). Sector 23: EC0723A1: Construction: Geographic Area Series: Detailed Statistics for Establishments: 2007.
Notes: The Census Bureau withheld data for some states.
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).

Table 6A.4.3 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	1.266
Alaska	1,687,503	1,265,663	1.333	1.333
Arizona	12,151,583	9,218,504	1.318	1.318
Arkansas	3,187,913	2,524,259	1.263	1.263
California	43,866,759	32,549,870	1.348	1.348
Colorado	9,218,679	7,554,813	1.220	1.220
Connecticut	2,398,913	1,704,640	1.407	1.407
Delaware	727,553	508,123	1.432	1.432
District of Columbia	918,723	792,275	1.160	1.160
Florida	19,686,238	14,553,102	1.353	1.353
Georgia	10,541,824	7,189,660	1.466	1.466
Hawaii	2,341,014	1,802,494	1.299	1.299
Idaho	1,555,058	1,291,347	1.204	1.204
Illinois	13,909,785	10,206,749	1.363	1.363
Indiana	5,967,203	4,636,748	1.287	1.287

State	Value of Construction *$1,000*	Cost of Goods Sold *$1,000*	Baseline Markup	Incremental Markup
Iowa	3,405,782	2,585,432	1.317	1.317
Kansas	2,721,025	2,252,824	1.208	1.208
Kentucky	3,028,131	2,289,475	1.323	1.323
Louisiana	4,476,198	3,078,813	1.454	1.454
Maine	738,455	585,867	1.260	1.260
Maryland	8,299,684	6,472,850	1.282	1.282
Massachusetts	7,035,875	5,272,385	1.334	1.334
Michigan	5,363,993	3,824,364	1.403	1.403
Minnesota	8,203,910	5,908,604	1.388	1.388
Mississippi	3,593,463	2,094,843	1.715	1.715
Missouri	9,293,483	7,970,536	1.166	1.166
Montana	924,342	734,797	1.258	1.258
Nebraska	1,589,168	1,080,612	1.471	1.471
Nevada	6,285,128	4,704,160	1.336	1.336
New Hampshire	1,040,005	816,281	1.274	1.274
New Jersey	7,331,413	4,421,279	1.658	1.658
New Mexico	1,537,718	1,210,550	1.270	1.270
New York	19,752,366	14,491,190	1.363	1.363
North Carolina	8,605,888	6,566,496	1.311	1.311
North Dakota	659,818	542,850	1.215	1.215
Ohio	8,889,511	7,158,247	1.242	1.242
Oklahoma	3,307,370	2,875,301	1.150	1.150
Oregon	3,273,641	2,606,128	1.256	1.256
Pennsylvania	11,676,721	8,744,986	1.335	1.335
Rhode Island	847,621	627,945	1.350	1.350
South Carolina	3,532,858	2,885,636	1.224	1.224
South Dakota	912,508	757,264	1.205	1.205
Tennessee	7,004,112	5,784,562	1.211	1.211
Texas	26,821,716	20,332,044	1.319	1.319
Utah	3,141,938	2,604,471	1.206	1.206
Vermont	445,373	367,539	1.212	1.212
Virginia	8,926,148	6,759,203	1.321	1.321
Washington	9,936,986	8,276,568	1.201	1.201
West Virginia	563,473	424,942	1.326	1.326
Wisconsin	7,248,667	5,891,541	1.230	1.230
Wyoming	432,812	349,769	1.237	1.237

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.
Notes: The Census Bureau withheld data for some states.

6A.5 DETAILED MOBILE HOME MANUFACTURING COST DATA

Based on U.S. Department of Census data, Table 6.7.1 of chapter 6, section 6.7.1, *Markups for Mobile Home Manufacturers* shows mobile home manufacturer revenues and costs in aggregated form. Table 6A.6.1 in this appendix shows the complete breakdown of costs and expenses provided by the U.S. Department of Census. The column labeled "Scaling" in Table 6A.6.1 indicates which expenses DOE assumed to scale with only the baseline markup and which scaled with both the baseline and incremental markups. As described in chapter 6, section 6.5, only those expenses that scale with baseline and incremental costs are marked up when there is an incremental change in product costs.

Table 6A.5.1 Mobile Home Manufacturer Expenses and Markups

Item	**Dollar Value** ***\$1,000***	**Percentage** ***%***	**Scaling**
Total Cost of Equipment Sales	**4,307,968**	71.17	
Total payroll, construction workers wages	853,156	14.10	
Cost of materials, components, and supplies	3,355,251	55.43	
Cost of construction work subcontracted out to others	45,533	0.75	
Total cost of selected power, fuels, and lubricants	54,028	0.89	
Gross Margin	**1,744,723**	28.83	
Payroll Expenses	**466,896**	7.71	Baseline
Total payroll, other employees wages	53,309	0.88	
Total fringe benefits	391,239	6.46	
Temporary staff and leased employee expenses	22,348	0.37	
Occupancy Expenses	**78,216**	1.29	Baseline
Rental costs of machinery and equipment	10,612	0.18	
Rental costs of buildings	29,535	0.49	
Communication services	9,882	0.16	
Cost of repair to machinery and equipment	28,187	0.47	
Other Operating Expenses	**561,308**	9.27	Baseline & Incremental
Purchased professional and technical services	24,940	0.41	
Data processing and other purchased computer services	1,943	0.03	
Expensed computer hardware and other equipment	2,451	0.04	
Expensed purchases of software	672	0.01	
Advertising and promotion services	19,941	0.33	
All other expenses	358,478	5.92	
Refuse removal (including hazardous waste) services	47,861	0.79	
Taxes and license fees	25,498	0.42	
Total depreciation (\$1,000)	79,524	1.31	
Net Profit Before Income Taxes	**638,303**	10.55	Baseline & Incremental

Source: U.S. Census Bureau. 2007. Manufactured Home (Mobile Home) Manufacturing. Sector 31: 321991. Manufacturing: Industry Series: Preliminary Detailed Statistics for Establishments: 2007.

6A.6 DETAILED MOBILE HOME DEALER COST DATA

Based on U.S. Department of Census data, Table 6.7.2 in chapter 6.7.2 shows mobile home contractor revenues and costs in the new construction market in aggregated form. Table 6A.6.1 in this appendix shows the complete breakdown of costs and expenses provided by the U.S. Department of Census. The column labeled “Scaling” in Table 6A.6.1 indicates which expenses DOE assumed to scale with only the baseline markup and which scaled with both the baseline and incremental markups. As described in chapter 6, section 6.5, only those expenses that scale with baseline and incremental costs are marked up when there is an incremental change in product costs.

Table 6A.6.1 Mobile Home Contractor Expenses and Markups

Item	Dollar Value *$1,000*	Percentage *%*	Scaling
Total Cost of Equipment Sales	**23,435,485**	60.09	
Total payroll, construction workers wages	5,955,136	15.27	
Cost of materials, components, and supplies	12,877,819	33.02	
Cost of construction work subcontracted out to others	3,328,722	8.53	
Total cost of selected power, fuels, and lubricants	1,273,808	3.27	
Gross Margin	**15,567,895**	39.91	
Payroll Expenses	**5,626,453**	14.43	Baseline
Total payroll, other employees wages	3,247,619	8.33	
Total fringe benefits	2,253,444	5.78	
Temporary staff and leased employee expenses	125,390	0.32	
Occupancy Expenses	**1,319,033**	3.38	Baseline
Rental costs of machinery and equipment	469,659	1.20	
Rental costs of buildings	303,861	0.78	
Communication services	160,085	0.41	
Cost of repair to machinery and equipment	385,428	0.99	
Other Operating Expenses	**4,262,987**	10.93	Baseline & Incremental
Purchased professional and technical services	212,923	0.55	
Data processing and other purchased computer services	19,927	0.05	
Expensed computer hardware and other equipment	66,392	0.17	
Expensed purchases of software	15,905	0.04	
Advertising and promotion services	328,278	0.84	
All other expenses	1,765,345	4.53	
Refuse removal (including hazardous waste) services	50,145	0.13	
Taxes and license fees	334,769	0.86	
Total depreciation ($1,000)	1,469,303	3.77	
Net Profit Before Income Taxes	**4,359,422**	11.18	Baseline & Incremental

Source: U.S. Census Bureau. 2007. All Other Specialty Trade Contractor. Sector 23: 238990. Construction, Industry Series, General Summary: Detailed Statistics for Establishments: 2007.

Note: Mobile home contractor costs and expenses are first presented as *total dollar* values and then converted to *percentage* values. This is in contrast to the *cost per dollar of sales revenue* values shown in Table 6.7.1.

6A.7 STATE SALES TAX RATES

Table 6A.7.1 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	8.55	Kentucky	6.00	North Dakota	5.90
Alaska	1.30	Louisiana	8.75	Ohio	7.10
Arizona	7.15	Maine	5.50	Oklahoma	8.35
Arkansas	8.90	Maryland	6.00	Oregon	--
California	8.45	Massachusetts	6.25	Pennsylvania	6.40
Colorado	6.05	Michigan	6.00	Rhode Island	7.00
Connecticut	6.35	Minnesota	7.20	South Carolina	7.20
Delaware	--	Mississippi	7.00	South Dakota	5.40
Dist. of Columbia	5.75	Missouri	7.45	Tennessee	9.45
Florida	6.65	Montana	--	Texas	7.90
Georgia	7.05	Nebraska	6.00	Utah	6.70
Hawaii	4.40	Nevada	7.85	Vermont	6.05
Idaho	6.05	New Hampshire	--	Virginia	5.60
Illinois	8.05	New Jersey	6.95	Washington	8.90
Indiana	7.00	New Mexico	6.60	West Virginia	6.10
Iowa	6.85	New York	8.40	Wisconsin	5.45
Kansas	7.85	North Carolina	6.90	Wyoming	5.50

Source: The Sales Tax Clearinghouse at https://thestc.com/STRates.stm (Accessed on January 22, 2014).

CHAPTER 7. ENERGY USE ANALYSIS

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CHAPTER 7. ENERGY USE ANALYSIS

7.1 INTRODUCTION

The purposes of the energy use analysis are to determine the annual energy consumption of residential non-weatherized gas furnaces (NWGFs) and mobile home gas furnaces (MHGFs) in use in the United States and to assess the energy savings potential of increases in annual fuel utilization efficiency (AFUE) and standby mode and off mode standards. In contrast to the U.S. Department of Energy (DOE) test procedure, which uses typical operating conditions in a laboratory setting, the energy use analysis seeks to estimate the range of energy consumption of the products in the field. DOE estimated the annual energy consumption of NWGFs and MHGFs at specified energy efficiency levels across a range of climate zones, building characteristics, and heating applications. The energy use analysis provides estimates of the distribution of annual energy consumption for NWGFs and MHGFs at the efficiency levels considered.

The NWGFs and MHGFs analyzed utilize gas for heating air and electric energy to power a blower, a draft inducer, an ignitor, and other auxiliary equipment. Standby energy use is also calculated for each product class.

For NWGFs, DOE considered the energy use associated with providing space heating in either residential or commercial buildings. MHGFs are only installed in residential homes. DOE developed a building sample for each of the two product classes based on the Energy Information Administration's (EIA) 2009 Residential Energy Consumption Survey (RECS 2009) and 2003 Commercial Building Energy Consumption Survey (CBECS 2003).[1, 2] These are the latest available surveys for residential and commercial buildings.[a] This sample is further described in section 7.2.

DOE used RECS 2009- or CBECS 2003-reported heating energy consumption (based on the existing heating system) to calculate the heating load of each household or building. The heating load represents the amount of heating required to keep a housing unit or building comfortable throughout an average year. DOE assigned the energy efficiency of existing systems based on the design of the distribution systems, a historical distribution of energy efficiencies for NWGFs and MHGFs, and data about the age of the existing furnace. The estimation of heating loads also required calculating the electricity consumption of the blower, because heat from the operation of the blower contributes to space heating. In addition, DOE made adjustments based on historical weather data, projections of building shell efficiency and building square footage, and for homes that had secondary heating equipment that used the same fuel as the furnace. To complete the analysis, DOE calculated the energy consumption of alternative (more energy-efficient) products if they replaced existing systems in each housing unit or commercial building.

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[a] EIA is currently working on the 2012 version of CBECS, which are not expected to be fully available until end of 2015. EIA is currently working on the 2015 version of RECS, which are not expected to be available until 2017. Additionally, EIA determined that the 2007 CBECS did not yield valid statistical estimates of building counts, energy characteristics, consumption and expenditures and therefore did not release the majority of the data tables and public use files.

7.2 BUILDING SAMPLES

DOE's calculation of the annual energy use of NWGFs and MHGFs relied on data from RECS 2009 and CBECS 2003. RECS 2009 includes energy-related data from 12,083 housing units that represent almost 113.6 million households. CBECS 2003 includes energy-related data from 5,215 buildings representing 4.9 million commercial buildings.

The subset RECS 2009 or CBECS 2003 records used in the analysis met all of the following criteria:

- used a furnace as the main or secondary source of heat,
- used a heating fuel that is natural gas or liquefied petroleum gas (LPG),
- had an energy consumption greater than zero, and
- heated square footage is less than or equal to 10,000 square feet.

DOE divided the furnace subset into replacement and new construction subsets designed to include consumers that use one of the furnace product classes. See criteria used to divide the furnace subset in Table 7.2.1 and Table 7.2.2 for residential applications and Table 7.2.3 and Table 7.2.4 for commercial applications. The new construction sample includes only buildings built after 2000 for NWGFs in residential applications, after 1990 for NWGFs in commercial applications, and after 1995 for MHGFs; DOE believes such buildings would have more similar building characteristics to the new construction buildings in 2021 (*e.g.*, building insulation, regional distribution of the buildings).

The RECS 2009 and CBECS 2003 weighting indicates how commonly each household or commercial building configuration occurred in the general population in 2009 and 2003, respectively. DOE adjusted EIA's weightings for each RECS 2009 household or CBECS 2003 building to create furnace population weights in 2021 by differentiating between non-weatherized and weatherized gas furnaces, accounting for buildings with multiple furnaces, adjusting RECS regional weights so that they matched historical furnace shipments, and adjusting the final weights to match the projected furnace shipments in 2021.

The RECS 2009 sample does not distinguish between weatherized and non-weatherized gas furnaces. To determine the number of households with NWGFs, DOE assumed that a fraction of households with gas furnaces use weatherized furnaces. DOE also adjusted the weightings to account for households or buildings with multiple furnaces and furnaces that are shared between one or more households. The weightings were then adjusted so that the regional weights matched the historical shipments by region. Finally, the weights were adjusted to match the projected furnace shipments modeled in the shipments analysis described in chapter 9.

To sample between the residential and commercial samples for NWGFs, DOE used the shipments model described in chapter 9 to estimate that 3 percent of NWGF shipments will be installed in commercial buildings. To sample between the new construction and replacement markets,[b] DOE used the shipments model to estimate that the new construction market accounts for 25 percent of NWGFs and 50 percent of MHGFs.

Appendix 7A presents the RECS and CBECS variables used in this analysis and their definitions, as well as further information about the derivation of the household and building samples, the adjustments to the furnace population weights, and sampling fractions for each of the four samples (residential new construction and replacement and commercial new construction and replacement).

Table 7.2.1 Selection of RECS 2009 Records for Furnaces (Replacements)

Product Class	Algorithm	Region	No. of Records	RECS 2009	DOE 2021
				Number of Houses million	**Furnaces Shipped** *million*
Non-Weatherized Gas Furnace	Primary or Secondary Heating Equipment = Central Warm-Air Furnace Heating Fuel = Gas or LPG Home type = Single- or Multi-Family Heated Square Footage ≤10,000 sq ft	National	4955	46.602	2.475
		North	2932	27.425	1.30
		Rest of Country	2023	19.177	1.18
Mobile Home Gas Furnace	Primary or Secondary Heating Equipment = Central Warm-Air Furnace Heating Fuel = Gas or LPG Home type = Mobile Home Heated Square Footage ≤10,000 sq ft	National	157	2.019	0.05
		North	100	1.236	0.03
		Rest of Country	57	0.782	0.02

Table 7.2.2 Selection of RECS 2009 Records for Furnaces (New Construction)

Product Class	Algorithm	Region	No. of Records	RECS 2009	DOE 2021
				Number of Houses ***million***	**Furnaces Shipped** ***million***
Non-Weatherized Gas Furnace	Primary or Secondary Heating Equipment = Central Warm-Air Furnace Heating Fuel = Gas or LPG Home type = Single- or Multi-Family House Built = after 2000 Heated Square Footage ≤10,000 sq ft	National	745	7.136	0.825
		North	369	3.384	0.44
		Rest of Country	376	3.752	0.39
Mobile Home Gas Furnace	Primary or Secondary Heating Equipment = Central Warm-Air Furnace Heating Fuel = Gas or LPG Home type = mobile home House Built = after 1995 Heated Square Footage ≤10,000 sq ft	National	38	0.494	0.05
		North	23	0.301	0.03
		Rest of Country	15	0.193	0.02

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[b] Replacements includes both replacements of existing furnaces and new owners, which are existing homes that do not have an existing NWGF or MHGF. New owners are estimated to account for 10 percent of replacement sample for NWGFs. See chapter 9 for more details about these market segments.

Table 7.2.3 Selection of CBECS 2003 Records for Non-Weatherized Gas Furnaces (Replacements)

Product Class	Algorithm	Region	No. of Records	CBECS 2003	DOE 2021
				Number of Buildings *million*	**Furnaces Shipped** *million*
Non-Weatherized Gas Furnace	Primary or Secondary Heating Equipment = Central Warm-Air Furnace Heating Fuel = Gas or LPG Heated Square Footage ≤10,000 sq ft	National	576	0.983	0.08
		North	384	0.661	0.05
		Rest of Country	192	0.322	0.03

Table 7.2.4 Selection of CBECS 2003 Records for Non-Weatherized Gas Furnaces (New Construction)

Product Class	Algorithm	Region	No. of Records	CBECS 2003	DOE 2021
				Number of Buildings *million*	**Furnaces Shipped** *million*
Non-Weatherized Gas Furnace	Primary or Secondary Heating Equipment = Central Warm-Air Furnace Heating Fuel = Gas or LPG Building Built = after 1990 Heated Square Footage ≤10,000 sq ft	National	109	0.179	0.03
		North	70	0.123	0.02
		Rest of Country	39	0.055	0.01

7.3 NON-WEATHERIZED GAS FURNACE AND MOBILE HOME GAS FURNACE ENERGY CONSUMPTION

To calculate the energy use of NWGFs and MHGFs, DOE determined the energy consumption associated with space heating and any auxiliary electrical use. DOE estimated the input capacity and burner operating hours (BOH) of the existing furnace using the building heating load and furnace characteristics.

The electrical consumption was determined using the operating hours associated with heating and individual electrical power of all electrical components. Standby mode and off mode electrical consumption were also considered. The sum of the heating energy and electricity consumption represents the estimated annual energy use of a sampled furnace.

The calculation used for determining total energy use is:

$$Energy\ Use_{Total} = FuelUse + ElecUse$$

Eq. 7.1

Where:

$FuelUse$ = total fuel consumption as a result of space heating loads (MMBtu/yr), and
$ElecUse$ = electrical consumption of all electrical components, including standby mode and off mode consumption (kWh/yr).

The details for calculating energy consumption appear in appendix 7B.

7.3.1 Fuel Consumption

The Department calculated the fuel consumption (*FuelUse*) for each single-stage furnace using the following formula from the current American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) test procedure SPC 103-2007 section C:[c]

$$FuelUse = BOH \times Q_{IN}$$

Eq. 7.2

Where:

BOH = heating burner operating hours (hr), and
Q_{IN} = input capacity of the existing furnace (kBtu/hr).

DOE derived the BOH from the building heating load served by a single furnace. The building heating load was determined from annual fuel consumption for heating reported in RECS and CBECS and on the AFUE of the existing furnace.

7.3.1.1 Determination of Burner Operating Hours

The Department calculated BOH, the number of hours the existing furnace burner is on during a year, for the existing furnace as:

$$BOH = \frac{BHL_{Furnace}}{Q_{Useful}}$$

Eq. 7.3

Where:

$BHL_{Furnace}$ = building heating load served by a single furnace (kBtu/yr), and,
Q_{Useful} = total useful energy output of the furnace, including useful heat from auxiliary electrical components (kBtu/hr).

The total useful energy output (Q_{Useful}) includes the output heating capacity of the furnace as well as useful heat from auxiliary electrical components (such as the electronic ignition, fan, and power to the burner) during the periods of space heating. See appendix 7B for more details.

7.3.1.2 Overview of Heating Load Estimates

The annual building heating load ($BHL_{Furnace}$) is the total amount of heat output from the furnace that the house or building needs during the heating season.[d] This includes heat from the

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[c] For two-stage and modulating products, this formula includes parameters for the operation at full, modulating, and reduced load. See appendix 7B for more details on the calculations for two-stage and modulating products.

burner as well as other electrical components. DOE determined projected $BHL_{Furnace}$ in 2021 for each sampled housing unit or building, based on the efficiency of the assigned existing furnace, using the following calculation:

$$BHL_{Furnace} = \frac{(Q_{YR} \times AFUE_{ex} + BlowerHeat) \times Adj_{Factor}}{FurnaceCount} \times NumberofUnitsServed$$

Eq. 7.4

Where:

Q_{YR} = annual fuel consumption for heating based on RECS 2009 or CBECS 2003 (kBtu/yr),
$AFUE_{ex}$ = AFUE of the existing furnace (see appendix 7B),
BlowerHeat = useful heat from furnace fan blower,
Adj_{Factor} = adjustment factor (discussed below),
FurnaceCount = number of furnaces used to fulfill the building heating load, and
NumberofUnitsServed = number of housing units served by a single furnace.

Both RECS 2009 and CBECS 2003 report fuel consumption for heating (Q_{YR}) for each of the sampled buildings. Table 7.3.1 shows the original RECS 2009 and CBECS 2003 heating energy use for the sampled buildings.

Table 7.3.1 Range of Reported Heating Energy Use for Each Furnace Product Class by Region in RECS 2009 and CBECS 2003, MMBtu/year

Region	Min	Max	Average	Percentiles				
				5%	25%	50%	75%	95%
Non-Weatherized Gas Furnaces								
National	0.5	611.5	50.5	11.7	27.9	43.7	63.0	107.5
North	0.5	611.5	64.3	23.8	41.8	56.4	75.6	125.5
Rest of Country	0.6	355.1	35.0	8.9	19.6	30.4	44.7	73.3
Mobile Home Gas Furnaces								
National	2.2	146.5	39.7	11.3	26.9	36.2	48.3	75.7
North	4.5	146.5	47.8	24.0	36.2	44.2	58.5	88.1
Rest of Country	2.2	67.9	26.6	7.6	14.6	27.5	35.9	48.3

The AFUE of the existing furnace ($AFUE_{ex}$) is determined by matching historical AFUE data to the reported age of the furnace in RECS 2009 when the furnace is used in a residential application, or to the assigned age of the furnace for commercial applications.[e] Details on the derivation of the AFUE of existing equipment are in appendix 7B.

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[d] $BHL_{Furnace}$ is the load served by a single furnace. DOE assumed that some houses and buildings would be served by multiple residentially-sized furnaces based on RECS data. DOE also assumed that some furnaces serve multiple houses or buildings.

[e] CBECS 2003 does not report the age of the equipment, so DOE created a uniform distribution (from 0 to 30 years, the upper limit being the age of the building) to estimate the age of the product.

DOE adjusted $BHL_{Furnace}$ to reflect the expectation that buildings in 2021 will have a somewhat different $BHL_{Furnace}$ than the buildings in the RECS 2009 and CBECS 2003 furnace sample. The adjustment involves multiplying the calculated $BHL_{Furnace}$ for each RECS 2009 or CBECS 2003 unit by a building shell efficiency index[f] derived from the National Energy Modeling System (NEMS) simulation performed for EIA's *AEO 2014*.[3] For the year 2021, the factor applied for homes is 0.91 for replacements and 0.92 for new construction, while for commercial buildings it ranged from 0.73 to 0.97 for replacements (depending on building type), and was 0.89 for new construction. This means that the average home or commercial building in 2021 will have a lower heating load than one in 2009 for residential buildings and 2003 for commercial buildings.

DOE also adjusted the calculated $BHL_{Furnace}$ to reflect historical average climate conditions by using heating degree days (HDD) reported in RECS 2009 and CBECS 2003 for each building and National Oceanic and Atmospheric Administration (NOAA) historic HDD data by region:[4]

$$Adj_{Factor,avg\ climate} = \frac{HDD_{10yr\ avg}}{HDD_{bldg,2009\ or\ 2003}}$$

Eq. 7.5

Where:

$HDD_{bldg,\ 2009\ or\ 2003}$ = HDD in 2009 for RECS 2009 or 2003 for CEBCS 2003 for the specific region where the unit is located, and,
$HDD_{10yr\ avg}$ = 10-year average HDD (2004–2013) based on NOAA data for the specific region where the unit is located.

The historical average climate conditions adjustment factors for residential buildings range from 0.94 to 1.05 and average 0.96 for the furnace building sample (*i.e.*, 2009 was in general colder than the 10-year average). This adjustment factor for commercial buildings range from 0.94 to 0.99 and average 0.96 for the furnace building sample (*i.e.*, 2003 was in general colder than the 10-year average).

DOE also accounted for future climate trends based on *AEO 2014* HDD projections by Census division, which show a decline in HDD, leading to lower projected $BHL_{Furnace}$ in 2021 relative to the non-climate-trend-adjusted $BHL_{Furnace}$ values.

DOE determined that some of the sampled buildings used multiple heating products with the same fuel as the furnace(s), such as a boiler, wall furnace, room heater, stove, or fireplace. Therefore, DOE adjusted the calculated $BHL_{Furnace}$ when necessary to reflect the use of secondary heating equipment using the same fuel as the furnace(s). The adjustment factors are

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[f] The building shell efficiency index sets the heating load value at 1.00 for an average home in 2009 for residential buildings and 2003 for commercial buildings (by type) in each census division. The values listed in Table 7.3.2 represent the change in heating load based on the difference in physical size and shell attributes for homes in the future (which takes into account physical size difference and efficiency gains from better insulation and windows).

calculated using reported survey information from both RECS 2009 and CBECS 2003 regarding the fraction of heating that was met by different heating equipment. In the case when a household or building was determined to have multiple furnaces, the house heating load was divided by the number of furnaces. Details are presented in appendix 7B.

DOE calculated the national average annual heating load to be 35.3 MMBtu/yr for NWGFs and 27.4 MMBtu/yr for MHGFs in 2021. The variations between product classes primarily reflect differences in the geographical distribution of furnaces and the differences in housing characteristics. These results are smaller than those reported in RECS 2009 or CBECS 2003, primarily due to projected improvements in building shell efficiency and projected lower heating loads due to decreased heating degree days. Table 7.3.2 shows the range in adjusted heating load among sample households.

Table 7.3.2 Range of Adjusted Heating Load for Each Furnace Product Class by Region, MMBtu/year

Region	Min	Max	Average	Percentiles				
				5%	25%	50%	75%	95%
Non-Weatherized Gas Furnaces								
National	0.3	454.9	35.2	8.4	19.4	30.8	44.3	74.6
North	0.3	454.9	44.5	16.0	28.7	38.9	51.7	87.2
Rest of Country	0.4	248.4	24.6	6.8	14.1	21.2	31.7	52.5
Mobile Home Gas Furnaces								
National	1.2	113.6	27.4	7.9	18.7	25.7	33.6	51.8
North	2.6	113.6	32.7	16.0	24.5	29.6	40.9	58.7
Rest of Country	1.2	53.4	18.8	5.9	11.0	20.2	23.9	33.7

Once the heating load of each sample housing unit or building is known, it is possible to estimate what the burner operating hours and energy consumption of the baseline product (80-percent AFUE) as well as more-efficient products used in the analysis. Table 7.3.3 shows the results for the baseline heating furnace (80-percent AFUE) burner operating hours among sample households and buildings in 2021.

Table 7.3.3 Range of Baseline Furnace Heating Annual Burner Operating Hours for Each Furnace Product Class, hours

Region	Min	Max	Average	Percentiles				
				5%	25%	50%	75%	95%
Non-Weatherized Gas Furnaces								
National	5.7	8760.0	726.4	199.7	424.5	630.2	880.1	1498.0
North	5.7	8760.0	876.7	291.9	557.0	750.2	1019.5	1799.3
Rest of Country	11.7	4398.7	557.0	162.8	328.5	495.9	693.4	1136.9
Mobile Home Gas Furnaces								
National	18.3	1731.1	416.1	120.2	284.8	391.3	512.1	782.9
North	39.2	1731.1	497.2	243.9	369.7	450.5	623.4	885.5
Rest of Country	18.3	805.4	285.6	89.5	166.9	307.4	365.0	513.9

7.3.2 Electricity Consumption

The Department calculated furnace electricity consumption when the furnace is in operation (active mode) and when the furnace is in standby or off mode as:

$$ElecUse = ElecUse_{ActiveMode} + ElecUse_{Stby}$$

Eq. 7.6

Where:

$ElecUse_{ActiveMode}$ = electricity use of electrical components during furnace operation, (kWh/yr) (Eq. 7.7), and
$ElecUse_{Stby}$ = electricity use of electrical components during standby or off mode (Eq. 7.8), (kWh/yr).

7.3.2.1 Active Mode Electricity Consumption

The Department calculated furnace electricity consumption when the furnace is in operation (active mode) as follows:[g]

$$ElecUse_{ActiveMode} = ElecPower_{ElecComp} \times OH_{ElecComp} + ElecUse_{Aux} + DiffElecUse_{fan}$$

Eq. 7.7

Where:

$ElecPower_{ElecComp}$ = power of multiple electrical components required during furnace operation, (kW) (refer to the test procedure variables that relate to electricity consuming components as detailed in appendix 7B),
$OH_{ElecComp}$ = operating hours of the electrical components, (h),

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

$ElecUse_{Aux}$ = electricity use of the auxiliary equipment, such as condensate pumps and heat tape, (kWh), and
$DiffElecUse_{Fan}$ = differential of electricity use of the furnace fan during cooling and continuous fan circulation, (kWh).

The active mode electricity consumption takes into account the electricity consumption of the electrical components of the furnace (such as blower, the draft inducer, and the ignitor). The blower (also referred to as the furnace fan) electricity use accounts for the minimum efficiency requirements set by the 2014 furnace fan final rule that will take effect on July 3, 2019. (10 CFR 430.32(y)) DOE also included the electricity use of auxiliary equipment, such as condensate pumps and heat tape, which are sometimes installed with higher-efficiency products. The electricity consumption of the auxiliary equipment ($ElecUse_{Aux}$) is added to the total electricity consumption. If a household required a condensate pump, DOE assumed that it consumes 60 watts and operates at the same time as the burner. If a household required heat tape to prevent the condensate withdrawal pipe from freezing, DOE assumed that it consumes 3 watts per square foot (on average 45 watts total) and operates only when the average monthly outside temperature drops below 45 °F. Details of how DOE determined whether a household required a condensate pump or heat tape can be found in chapter 8.

The blower, in addition to moving heated air through the house, can operate during the cooling season (summer) if the house is air conditioned and could also operate for a fraction of homes in continuous furnace fan mode. Therefore, the Department also considered the difference in electricity consumption of higher-efficiency products during the cooling season and continuous furnace fan operation ($DiffElecUse_{Fan}$).[h]

Details for calculating electricity consumption are presented in appendix 7B.

7.3.2.2 Standby Mode Electricity Consumption

For this analysis, DOE assumed that furnaces are not usually equipped with an off mode, so only the standby electricity consumption was considered. The Department calculated the standby electricity consumption as:

$$ElecUse_{Stby} = StbyE \times (8760 - BOH - COH - CFOH) \qquad \textbf{Eq. 7.8}$$

Where:

$StbyE$ = power consumption during standby (kW),
8760 = hours in a year,
BOH = burner operating hours,

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[h] Condensing furnaces tend to have a more restricted airflow path than non-condensing furnaces because of the secondary heat exchanger. In general, the furnace fan requires more energy to produce the equivalent airflow output for a condensing furnace compared to a similar non-condensing furnace. The analysis accounts for this additional energy consumption and resulting additional heat released by the furnace fan motor that needs to be compensated by the central air conditioner.

COH = cooling operating hours, and
CFOH = continuous fan operating hours.

DOE calculated the standby electricity consumption for each standby mode efficiency level described in chapter 5 using the base case burner operating hours (BOH). DOE assumed that the standby power was directly related to different furnace fan designs and took into account the furnace fan designs available after the furnace fan energy efficiency standard takes effect on July 3, 2019. The standby power consumption *StbyE* was determined in the engineering analysis described in chapter 5. Cooling operating hours (COH) and continuous fan operating hours (CFOH) were determined for households that use the furnace fan for cooling and continuous fan operations. See appendix 7B for more details on the calculation of the COH and CFOH.

Table 7.3.4 presents the range of standby hours for each product class by region. Note that a larger fraction of households and buildings use their furnace fan for continuous circulation year-round in the North than in the Rest of Country.

Table 7.3.4 Range of Standby Hours for Each Furnace Product Class, Hours

Region	Min	Max	Average	Percentiles				
				5%	25%	50%	75%	95%
Non-Weatherized Gas Furnaces								
National	0.0	8710.6	7376.2	5064.7	7426.0	7784.6	8034.7	8365.7
North	0.0	8710.6	7072.4	0.0	7258.6	7726.7	7990.7	8316.2
Rest of Country	0.0	8684.0	7718.6	6993.0	7568.4	7835.1	8079.4	8411.9
Mobile Home Gas Furnaces								
National	0.0	8715.3	7705.1	6720.6	7936.1	8128.1	8307.8	8502.7
North	0.0	8715.3	7438.8	0.0	7821.4	8043.0	8198.9	8402.3
Rest of Country	0.0	8709.1	8133.5	7755.1	8048.3	8283.3	8390.3	8561.3

The details for calculating standby and off mode electricity consumption are presented in appendix 7B.

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 furnace product class. For NWGFs, the results reflect energy use in both the residential and commercial samples. The LCC and PBP analysis uses the results calculated for each sample building. Negative results indicate that energy use increases.

Table 7.4.1 lists the average annual energy use for NWGFs and the average energy savings for each considered energy efficiency level compared to the baseline for the Nation and the North and Rest of Country regions.

Table 7.4.1 Annual AFUE Standards Energy Consumption for Non-Weatherized Gas Furnaces

EL	AFUE	Annual Fuel Use		Annual Electricity Consumption of Auxiliary Components	
		Total *MMBtu/yr*	Savings *MMBtu/yr*	Total *kWh/yr*	Savings *kWh/yr*
National					
0	80%	42.7	-	333.2	-
1	90%	38.1	4.6	325.9	7.3
2	92%	37.3	5.4	321.1	12.0
3	95%	36.1	6.6	305.6	27.5
4	98%	34.8	7.9	332.3	0.8
North					
0	80%	54.1	-	378.3	-
1	90%	48.2	5.9	368.6	9.7
2	92%	47.2	6.9	363.0	15.3
3	95%	45.8	8.3	345.8	17.2
4	98%	44.0	10.1	377.2	(31.4)
Rest of Country					
0	80%	29.8	-	282.3	-
1	90%	26.6	3.2	277.8	4.5
2	92%	26.0	3.8	274.0	8.3
3	95%	25.2	4.6	260.4	21.9
4	98%	24.4	5.5	281.7	0.6

Note: Parentheses indicate negative values.

Table 7.4.2 lists average annual energy use for MHGFs and average energy savings for each energy efficiency level evaluated in the LCC analysis, compared to the baseline furnace.

Table 7.4.2 Annual AFUE Standards Energy Consumption for Mobile Home Gas Furnaces

EL	AFUE	Annual Fuel Use		Annual Electricity Consumption of Auxiliary Components	
		Total *MMBtu/yr*	**Savings** *MMBtu/yr*	**Total** *kWh/yr*	**Savings** *kWh/yr*
National					
0	80%	33.3	-	252.0	-
1	92%	29.0	4.3	250.9	1.1
2	95%	28.2	5.1	241.0	11.0
3	97%	27.6	5.7	262.1	(10.1)
North					
0	80%	39.8	-	292.3	-
1	92%	34.7	5.1	296.6	(4.3)
2	95%	33.7	6.1	279.5	12.8
3	97%	33.0	6.8	299.0	(6.6)
South					
0	80%	22.8	-	187.0	-
1	92%	19.9	2.9	177.3	9.8
2	95%	19.3	3.5	179.0	8.0
3	97%	19.0	3.9	202.8	(15.7)

Note: Parentheses indicate negative values.

Table 7.4.3 shows the average annual standby and off mode energy use for NWGFs and MHGFs and the average energy savings for each energy efficiency level described in chapter 5, compared to the baseline.

Table 7.4.3 Annual Standby Energy Consumption for Non-Weatherized Gas Furnaces and Mobile Home Gas Furnaces

EL	Watts	Design Option	Annual Electricity Consumption for Standby	
			Total	Savings
			kWh/yr	*kWh/yr*
Non-Weatherized Gas Furnaces				
0	11	Baseline	84.9	-
1	9.5	Linear PS, Toroidal Xfmr	73.4	11.6
2	9.2	Switch Mode PS	71.0	13.9
3	8.5	SMPS, Toroidal Xfmr	65.6	19.3
Mobile Home Gas Furnaces				
0	11	Baseline	89.5	-
1	9.5	Linear PS, Toroidal Xfmr	77.3	12.2
2	9.2	Switch Mode PS	74.8	14.6
3	8.5	SMPS, Toroidal Xfmr	69.1	20.3

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APPENDIX 7A. BUILDING VARIABLES

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APPENDIX 7A. BUILDING VARIABLES

7A.1 INTRODUCTION

DOE created a database containing a subset of the records and variables from DOE's Energy Information Administration (EIA)'s RECS 2009 using Microsoft ACCESS.[1] DOE used this RECS subset in the life-cycle cost (LCC) analysis of the Residential Furnace Rulemaking for non-weatherized gas furnaces (NWGFs) and mobile home gas furnaces (MHGFs). This appendix explains the variable name abbreviations and provides definitions of the variable values.

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

7A.2 RECS 2009 SAMPLE DETERMINATION

RECS 2009 consists of three parts:

- Personal interviews with households for information about energy used, how it is used, energy-using appliances, structural features, energy efficiency measures, and demographic characteristics of the household.
- Telephone interviews with rental agents for households that have any of their energy use included in their rent. This information augments information collected from those households that may not be knowledgeable about the fuels used for space heating or water heating.
- Mail questionnaires sent to energy suppliers (after obtaining permission from households) to collect the actual billing data on energy consumption and expenditures.

The subset of RECS 2009 records used to study NWGFs and MHGFs met all of the following criteria:

- used a central warm-air furnace as the main or secondary source of heat;
- used a heating fuel that is natural gas or liquefied petroleum gas (LPG), and;
- had an energy consumption greater than zero.

The RECS 2009 weighting indicates how commonly each household configuration occurs in the general population. Table 7A.2.1 shows the RECS 2009 sample weights and criteria for replacements[a] and Table 7A.2.2 shows the RECS sample weights and criteria for new construction. DOE made some adjustments to EIA's weightings for each RECS 2009 household in order to create NWGF and MHGF sample weights in 2021. The NWGF and MHGF sample weights are adjusted to account for:

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[a] Replacements includes both replacements of existing furnaces and new owners, which are existing homes that do not have an existing NWGF or MHGF. See chapter 9 for more details about these market segments.

1. Households sharing a furnace: RECS 2009-reported weight is decreased by the number of units sharing the furnace as follows a) single-family unit is assumed to share a furnace with one other unit; b) multi-family unit (2-4 units) is assumed to share a furnace with three other units; b) multi-family unit (5 or more units) is assumed to share a furnace with the number of reported units in the building;
2. Buildings with multiple furnaces: RECS 2009-reported weight is increased by the number of furnaces in a building (residential buildings with over 5,000 square feet are assumed to have two NWGFs) for households listed in RECS 2009 with a primary and secondary furnace;
3. Projected growth of the number of furnaces by 2021 based on shipments analysis, see chapter 9;
4. For NWGFs, DOE used 1992 and 1994-2003 Air-Conditioning, Heating, and Refrigeration Institute (AHRI)[b] gas furnace shipments by state[2] to match NWGF sample weights to furnace shipments (see Table 7A.2.3 and Table 7A.2.4) and;
5. RECS 2009 does not distinguish between weatherized and non-weatherized gas furnaces. For NWGFs, DOE used shipments data to reweight the sample to account for weatherized gas furnaces. Based on AHRI shipment data[3] for weatherized and non-weatherized gas furnaces, which shows that about 10 percent of total furnace shipments are weatherized furnaces, DOE multiplied the RECS 2009 weight for households with both a gas furnace and central air conditioning (CAC) by 0.97 for the North region,[c] 0.79 for the hot-dry Rest of Country region,[d] and 0.82 for hot-humid Rest of Country region.[e]

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[b] Previously Gas Appliance Manufacturers Association (GAMA).

[c] The North region is comprised of the following states: Alaska, Colorado, Connecticut, Idaho, Illinois, Indiana, Iowa, Kansas, Maine, Massachusetts, Michigan, Minnesota, Missouri, Montana, Nebraska, New Hampshire, New Jersey, New York, North Dakota, Ohio, Oregon, Pennsylvania, Rhode Island, South Dakota, Utah, Vermont, Washington, West Virginia, Wisconsin, and Wyoming.

[d] The hot-dry South Region includes: Alabama, Arkansas, Delaware, Florida, Georgia, Hawaii, Kentucky, Louisiana, Maryland, Mississippi, North Carolina, Oklahoma, South Carolina, Tennessee, Texas, and Virginia.

[e] The hot-humid South Region includes: Arizona, California, New Mexico, Nevada.

Table 7A.2.1 Selection of RECS 2009 Records for Furnaces (Replacements)

Product Class	**Algorithm**	**Region**	**No. of Records**	**RECS 2009**	**DOE 2021**
				Number of Houses ***million***	**Number of Furnaces Shipped** ***million***
Non-Weatherized Gas Furnace	Primary or Secondary Heating Equipment = Central Warm-Air Furnace Heating Fuel = Gas or LPG Home type = Single- or Multi-Family Heated Square Footage ≤10,000 sq ft	National	4955	46.602	2.475
		North	2932	27.425	1.30
		Rest of Country	2023	19.177	1.18
Mobile Home Gas Furnace	Primary or Secondary Heating Equipment = Central Warm-Air Furnace Heating Fuel = Gas or LPG Home type = Mobile Home Heated Square Footage ≤10,000 sq ft	National	157	2.019	0.05
		North	100	1.236	0.03
		Rest of Country	57	0.782	0.02

Table 7A.2.2 Selection of RECS 2009 Records for Furnaces (New Construction)

Product Class	**Algorithm**	**Region**	**No. of Records**	**RECS 2009**	**DOE 2021**
				Number of Houses ***million***	**Number of Furnaces Shipped** ***million***
Non-Weatherized Gas Furnace	Primary or Secondary Heating Equipment = Central Warm-Air Furnace Heating Fuel = Gas or LPG Home type = Single- or Multi-Family House Built = after 2000 Heated Square Footage ≤10,000 sq ft	National	745	7.136	0.825
		North	369	3.384	0.44
		Rest of Country	376	3.752	0.39
Mobile Home Gas Furnace	Primary or Secondary Heating Equipment = Central Warm-Air Furnace Heating Fuel = Gas or LPG Home type = mobile home House Built = after 1995 Heated Square Footage ≤10,000 sq ft	National	38	0.494	0.05
		North	23	0.301	0.03
		Rest of Country	15	0.193	0.02

Table 7A.2.3 shows the average furnace shipments by state from 1992 and 1994-2003 based on AHRI shipment data.[2]

Table 7A.2.3 Average Gas Furnace Shipments by State from 1992, 1994-2003 (AHRI Data)

Region ID	State	Average Furnace Shipments	Weighting
18	Alabama	39,310	1.41%
28	Alaska	1,963	0.07%
24	Arizona	32,910	1.18%
20	Arkansas	71,275	2.56%
26	California	292,719	10.52%
22	Colorado	60,947	2.19%
1	Connecticut	6,822	0.25%
14	Delaware	4,928	0.18%
14	District of Columbia	3,097	0.11%
17	Florida	20,544	0.74%
15	Georgia	124,877	4.49%
29	Hawaii	837	0.03%
23	Idaho	14,675	0.53%
6	Illinois	173,519	6.24%
7	Indiana	97,226	3.49%
10	Iowa	40,142	1.44%
11	Kansas	33,749	1.21%
18	Kentucky	36,697	1.32%
20	Louisiana	38,085	1.37%
1	Maine	678	0.02%
14	Maryland	72,981	2.62%
2	Massachusetts	19,109	0.69%
8	Michigan	140,696	5.06%
10	Minnesota	71,070	2.55%
18	Mississippi	19,865	0.71%
12	Missouri	95,801	3.44%
23	Montana	6,790	0.24%
11	Nebraska	39,338	1.41%
25	Nevada	29,814	1.07%
1	New Hampshire	7,858	0.28%
4	New Jersey	51,997	1.87%
25	New Mexico	12,854	0.46%
3	New York	82,412	2.96%
16	North Carolina	67,470	2.43%
10	North Dakota	6,077	0.22%
7	Ohio	163,051	5.86%
20	Oklahoma	45,517	1.64%
27	Oregon	58,228	2.09%
5	Pennsylvania	94,017	3.38%
1	Rhode Island	2,845	0.10%
16	South Carolina	23,782	0.85%

Region ID	State	Average Furnace Shipments	Weighting
10	South Dakota	9,805	0.35%
19	Tennessee	53,388	1.92%
21	Texas	275,005	9.88%
23	Utah	45,139	1.62%
1	Vermont	925	0.03%
13	Virginia	51,413	1.85%
27	Washington	39,146	1.41%
30	West Virginia	10,402	0.37%
9	Wisconsin	88,072	3.17%
23	Wyoming	2,343	0.08%
	United States	2,782,212	100.00%

Table 7A.2.4 shows the derivation of the shipment weighted adjustment factors. It is derived as the ratio of the un-shipment weighted NWGF sample total (where 75 percent is replacements and 25 percent is new construction) to the average AHRI shipments by state. This factor is then multiplied to each household in the NWGF sample.

Table 7A.2.4 Shipment-Weighted Adjustment Factors for NWGF and MHGF Residential Sample based on AHRI Shipments by State

ID	States	1992, 1994-2003 Average Shipments	NWGF and MHGF Sample (Unweighted)			Shipment-Weighted Adjustment Factor
			Replacement	New Construction	Total	
1	CT, ME, NH, RI, VT	0.7%	0.8%	0.4%	0.7%	0.974
2	Massachusetts	0.7%	1.2%	0.9%	1.2%	0.498
3	New York	3.0%	4.2%	2.2%	3.7%	0.777
4	New Jersey	1.9%	3.7%	3.5%	3.7%	0.358
5	Pennsylvania	3.4%	4.3%	6.7%	4.9%	0.522
6	Illinois	6.2%	7.4%	7.0%	7.3%	0.807
7	Indiana, Ohio	9.4%	10.3%	7.5%	9.6%	0.965
8	Michigan	5.1%	5.4%	1.8%	4.5%	1.140
9	Wisconsin	3.2%	3.5%	2.7%	3.3%	0.961
10	IA, MN, ND, SD	4.6%	5.6%	5.4%	5.5%	0.767
11	Kansas, Nebraska	2.6%	2.6%	2.0%	2.5%	1.082
12	Missouri	3.4%	2.9%	2.5%	2.8%	1.282
13	Virginia	1.8%	1.8%	2.5%	2.0%	0.918
14	DE, DC, MD	2.9%	1.4%	1.6%	1.4%	2.475
15	Georgia	4.5%	3.4%	4.9%	3.7%	1.293
16	NC, SC	3.3%	3.0%	6.9%	4.0%	0.684
17	Florida	0.7%	0.7%	1.3%	0.9%	0.735
18	AL, KY, MS	3.4%	2.8%	3.5%	3.0%	1.212
19	Tennessee	1.9%	1.5%	2.4%	1.7%	1.147
20	AR, LA, OK	5.6%	2.6%	1.5%	2.3%	2.651
21	Texas	9.9%	6.8%	8.8%	7.3%	1.518
22	Colorado	2.2%	2.8%	3.2%	2.9%	0.673
23	ID, MT, UT, WY	2.5%	3.0%	2.6%	2.9%	0.810
24	Arizona	1.2%	1.4%	2.4%	1.6%	0.562
25	NV, NM	1.5%	2.1%	3.0%	2.3%	0.496
26	California	10.5%	11.2%	8.1%	10.4%	1.015
27	OR, WA	3.5%	3.1%	4.5%	3.4%	1.025
28	Alaska	0.1%	0.1%	0.1%	0.1%	0.421
29	Hawaii	0.0%	0.0%	0.0%	0.0%	1.000
30	West Virginia	0.4%	0.3%	0.2%	0.3%	1.277

Table 7A.2.5 shows the final sample weight. The total for NWGF sample assumes 75 percent is the replacement sample and 25 percent is the new construction sample, while the total for MHGF assumes 50 percent replacement and 50 percent new construction.

Table 7A.2.5 NWGF and MHGF Final Residential Sample Weights by RECS 2009 Regions

ID	States	NWGF Sample			MHGF Sample		
		Replacement	New Construction	Total	Replacement	New Construction	Total
1	CT, ME, NH, RI, VT	0.8%	0.4%	0.7%	0.0%	0.0%	0.0%
2	Massachusetts	0.6%	0.9%	0.7%	1.0%	0.0%	0.5%
3	New York	3.2%	2.2%	3.0%	0.3%	0.0%	0.2%
4	New Jersey	1.3%	3.5%	1.9%	2.9%	0.0%	1.5%
5	Pennsylvania	2.3%	6.7%	3.4%	4.7%	15.6%	10.2%
6	Illinois	6.0%	7.0%	6.2%	0.0%	0.0%	0.0%
7	Indiana, Ohio	10.0%	7.5%	9.4%	8.4%	6.4%	7.4%
8	Michigan	6.1%	1.8%	5.1%	11.9%	3.3%	7.6%
9	Wisconsin	3.3%	2.7%	3.2%	2.5%	0.0%	1.2%
10	IA, MN, ND, SD	4.3%	5.4%	4.6%	9.3%	10.8%	10.0%
11	Kansas, Nebraska	2.9%	2.0%	2.6%	5.2%	9.6%	7.4%
12	Missouri	3.7%	2.5%	3.4%	4.5%	2.0%	3.3%
13	Virginia	1.6%	2.5%	1.8%	1.4%	2.8%	2.1%
14	DE, DC, MD	3.4%	1.6%	2.9%	0.0%	0.0%	0.0%
15	Georgia	4.3%	4.9%	4.5%	0.6%	2.5%	1.6%
16	NC, SC	2.1%	6.9%	3.3%	3.7%	0.0%	1.8%
17	Florida	0.5%	1.3%	0.7%	2.4%	2.8%	2.6%
18	AL, KY, MS	3.4%	3.5%	3.4%	7.1%	3.6%	5.4%
19	Tennessee	1.8%	2.4%	1.9%	0.0%	0.0%	0.0%
20	AR, LA, OK	6.9%	1.5%	5.6%	3.5%	5.5%	4.5%
21	Texas	10.3%	8.8%	9.9%	4.0%	2.1%	3.1%
22	Colorado	1.9%	3.2%	2.2%	4.8%	8.1%	6.5%
23	ID, MT, UT, WY	2.5%	2.6%	2.5%	3.7%	4.8%	4.3%
24	Arizona	0.8%	2.4%	1.2%	5.6%	8.3%	7.0%
25	NV, NM	1.0%	3.0%	1.5%	3.5%	7.0%	5.3%
26	California	11.3%	8.1%	10.5%	6.9%	4.5%	5.7%
27	OR, WA	3.2%	4.5%	3.5%	0.9%	0.0%	0.5%
28	Alaska	0.1%	0.1%	0.1%	1.0%	0.0%	0.5%
29	Hawaii	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
30	West Virginia	0.4%	0.2%	0.4%	0.0%	0.0%	0.0%

7A.2.1 RECS 2009 Variables and Values

Table 7A.2.6 lists the RECS 2009 variables use in the analysis.

Table 7A.2.6 List of RECS 2009 Variables Used for Non-Weatherized Gas Furnaces and Mobile Home Gas Furnaces

Variable	Description
Location Variables	
REGIONC	Census Region
DIVISION	Census Division
REPORTABLE_DOMAIN	Reportable states and groups of states

Variable	Description
HDD65	Heating degree days in 2009, base temperature 65F
CDD65	Heating degree days in 2009, base temperature 65F
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
BTUELCOL	Electricity usage for air-conditioning, central and window/wall (room), 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
WARMAIR	Central warm-air furnace used for secondary space heating
FURNFUEL	Fuel used by warm-air furnace 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
USECENAC	Frequency central air conditioner used in summer 2009
AGECENAC	Age of central air conditioner
ACOTHERS	Central air conditioner cools other homes, business, or farm
USEWWAC	Frequency most-used window/wall air conditioning unit used in summer 2009
MAINTAC	Routine service or maintenance performed on central air conditioner
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

Variable	Description
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 7C)
MONEYPY	2009 gross household income
STORIES	Number of stories in a single-family home
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.2.2 RECS 2009 Database Variable Response Codes

Table 7A.2.7 provides the response codes for all RECS 2009 variables used in the NWGF and MHGF samples.

Table 7A.2.7 Definitions of RECS 2009 Variables Used in Life-Cycle Cost Analysis

Variable	Response Codes
ACOTHERS	0 No 1 Yes -2 Not Applicable
AGECENAC	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
BTUELCOL	Thousand BTU
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 65F	
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
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
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
FURNFUEL	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 65F
HEATOTH	0 No 1 Yes -2 Not Applicable
HIGHCEIL	0 No 1 Yes -2 Not Applicable
MAINTAC	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	
Seniors*	0	No
	1	Yes
POVERTY100	0	No
	1	Yes
StationID*	Three character identifier for weather station	
REGIONC	1	Northeast Census Region
	2	Midwest Census Region
	3	South Census Region
	4	West Census Region
REPORTABLE_DOMAIN	1	Connecticut, Maine, New Hampshire, Rhode Island, Vermont
	2	Massachusetts
	3	New York
	4	New Jersey
	5	Pennsylvania
	6	Illinois
	7	Indiana, Ohio
	8	Michigan
	9	Wisconsin
	10	Iowa, Minnesota, North Dakota, South Dakota
	11	Kansas, Nebraska
	12	Missouri
	13	Virginia
	14	Delaware, District of Columbia, Maryland, West Virginia
	15	Georgia
	16	North Carolina, South Carolina
	17	Florida
	18	Alabama, Kentucky, Mississippi
	19	Tennessee
	20	Arkansas, Louisiana, Oklahoma
	21	Texas
	22	Colorado
	23	Idaho, Montana, Utah, Wyoming
	24	Arizona
	25	Nevada, New Mexico
	26	California
	27	Alaska, Hawaii, Oregon, Washington
Seniors	0	No
	1	Yes
StationID	Three character identifier for weather station	
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
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
USECENAC	1 Turned on only a few days or nights when really needed 2 Turned on quite a bit 3 Turned on just about all summer -2 Not Applicable
USEWWAC	1 Turned on only a few days or nights when really needed 2 Turned on quite a bit 3 Turned on just about all summer -2 Not Applicable
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
WARMAIR	0 No 1 Yes -2 Not Applicable
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.

7A.3 CBECS 2003 SAMPLE DETERMINATION

The U.S. Department of Energy (DOE) created a database containing a subset of the records and variables from DOE's Energy Information Administration (EIA)'s CBECS 2003.[4] DOE used this CBECS subset in the life-cycle cost (LCC) analysis of NWGFs. This appendix explains the variable name abbreviations and provides definitions of the variable values. For the entire CBECS 2003 dataset, refer to www.eia.gov/consumption/commercial/data/2003/.

7A.3.1 CBECS 2003 Variables and Values

The subset of CBECS records used for NWGFs met all of the following criteria:

- a central warm-air furnace served as a main or secondary source of heating;
- used a heating fuel that is natural gas or liquefied petroleum gas (LPG);
- building is not vacant, and;
- a furnace is used as the heating product at least a portion of the building.[f]

Buildings were assigned to the sub-samples based on the amount of heating area per NWGF, with similar reasoning as for the residential NWGF sample. CBECS 2003 provides the total heating square footage and the fraction of heating by the NWGF for each building record, but does not provide the number of NWGFs used by the building, so the entire heating square footage is used to determine the subsamples.

The CBECS 2003 weighting indicates how commonly each building configuration occurs in the general population. Table 7A.3.1 shows the CBECS 2003 sample weights and criteria for replacements and Table 7A.3.2 shows the CBECS 2003 sample weights and criteria for new construction. DOE adjusted EIA's weightings for each CBECS 2003 household to create NWGF sample weights in 2021. The NWGF sample weights are adjusted to account for buildings with multiple furnaces: the CBECS 2003-reported weight is increased by the number of furnaces in a building, assuming that commercial buildings with over 4,000 square feet have two NWGFs, and over 8,000 square feet will have three NWGFs. CBECS 2003 does not distinguish between weatherized and non-weatherized gas furnaces, so sample weights are also adjusted to take into account the fraction of WGFs. Also, DOE took into account AHRI 1992, and 1994-2003 historical furnace shipments by state.

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[f] Sum of the fraction of all other heating products is less than 100 percent.

Table 7A.3.1 Selection of CBECS 2003 Records for Non-Weathered Gas Furnaces (Replacements)

Product Class	Algorithm	Region	No. of Records	CBECS 2003	DOE 2021
				Number of Buildings *million*	Number of Furnaces Shipped *million*
Non-Weatherized Gas Furnace	Primary or Secondary Heating Equipment = Central Warm-Air Furnace Heating Fuel = Gas or LPG Heated Square Footage ≤10,000 sq ft	National	576	0.983	0.08
		North	384	0.661	0.05
		Rest of Country	192	0.322	0.03

Table 7A.3.2 Selection of CBECS 2003 Records for Non-Weatherized Gas Furnaces (New Construction)

Product Class	Algorithm	Region	No. of Records	CBECS 2003	DOE 2021
				Number of Buildings *million*	Number of Furnaces Shipped *million*
Non-Weatherized Gas Furnace	Primary or Secondary Heating Equipment = Central Warm-Air Furnace Heating Fuel = Gas or LPG Building Built = after 1990 Heated Square Footage ≤10,000 sq ft	National	109	0.179	0.03
		North	70	0.123	0.02
		Rest of Country	39	0.055	0.01

Table 7A.3.3 shows the final commercial sample weights by Census division. DOE assumed that 75 percent of the total NWGF sample is the replacement sample and 25 percent is the new construction sample.

Table 7A.3.3 NWGF Final Commercial Sample Weights by Census Division

ID	Region	NWGF Sample		
		Replacement	New Construction	Total
1	New England	1.9%	0.0%	1.4%
2	Middle Atlantic	12.5%	8.4%	11.5%
3	East North Central	28.2%	24.4%	27.3%
4	West North Central	13.5%	18.9%	14.8%
5	South Atlantic	9.7%	14.7%	11.0%
6	East South Central	4.8%	5.2%	4.9%
7	West South Central	10.3%	14.6%	11.4%
8	Mountain	9.3%	5.6%	8.4%
9	Pacific	9.8%	8.1%	9.4%

Table 7A.3.4 lists the CBECS 2003 variables use in the analysis.

Table 7A.3.4 CBECS 2003 Variables Used for Non-Weatherized Gas Furnaces

Variable	Description
Location Variables	
CENDIV8	Census division
HDD658	Heating degree days (base 65)
CDD658	Cooling degree days (base 65)
REGION8	Census region
Household 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
FURNP8	Percent heated by furnaces
FURNAC8	Furnaces inside the building
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)

7A.3.2 CBECS 2003 Database Variable Response Codes

Table 7A.3.5 provides the response codes for all CBECS 2003 variables used in the commercial NWGF sample.

Table 7A.3.5 CBECS 2003 Variable Response Codes

Variable	Response Codes
PUBID8	Unique identifier for each respondent

ADJWT8	Final sample weight	
REGION8	01	Northeast
	02	Midwest
	03	South
	04	West
CENDIV8	01	New England
	02	Middle Atlantic
	03	East North Central
	04	West North Central
	05	South Atlantic
	06	East South Central
	07	West South Central
	08	Mountain
	09	Pacific
YRCON8	1	Before 1920
	2	1920 to 1945
	3	1946 to 1959
	4	1960 to 1969
	5	1970 to 1979
	6	1980 to 1989
	7	1990 to 1999
	8	2000 to 2003
	9	2004
SQFT8	0-9999999996	0,000,000,009
	9999999997	Not ascertained
	9999999998	Refused
	9999999999	Don't know
HDD658	Heating degree days in 2003, base temperature 65F	
CDD658	Cooling degree days in 2003, base temperature 65F	
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
FURNP8	0-996	009
	997	Not ascertained
	998	Refused
	999	Don't know
FURNAC8	1	Yes
	2	No
	7	Not Ascertained
	8	Refused
	9	Don't Know
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
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
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

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APPENDIX 7B. DETERMINATION OF RESIDENTIAL FURNACE ENERGY USE IN THE LCC ANALYSIS

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APPENDIX 7B. DETERMINATION OF RESIDENTIAL FURNACE ENERGY USE IN THE LCC ANALYSIS

7B.1 INTRODUCTION

For calculating the energy consumed by non-weatherized gas furnaces (NWGFs) and mobile home gas furnaces (MHGFs), DOE considered the energy use associated with providing space heating and the operation of the furnace fan for cooling or continuous air circulation, if applicable. The furnace space heating energy consumption methodology is based on the American Society for Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) 103-2007 "Method of Testing for Annual Fuel Utilization Efficiency of Residential Central Furnaces and Boilers" with some modifications to more accurately reflect field operation.[1] The calculation used for the determination of the total energy use per unit is as follows:

$$Energy\ Use_{Total} = FuelUse + ElecUse_{Total}$$

Eq. 7B.1

Where:

FuelUse = total fuel consumption as a result of space heating loads (MMBtu/yr), and
$ElecUse_{Total}$ = electrical consumption of all electrical components, including standby mode and off mode consumption (kWh/yr).

This appendix provides the detailed energy use calculation methodology for NWGFs and MHGFs.

7B.2 DETERMINATION OF ANNUAL FUEL ENERGY CONSUMPTION

The average annual fuel consumption (*FuelUse*) is calculated based on Appendix C section 2 of the ASHRAE 103/2007 test procedure (assuming that the product does not have continuous pilot ignition):[a]

$$FuelUse_{SH} = BOH_{SS} \times Q_{IN}, \text{ for single-stage furnaces,}$$
$$FuelUse_{SH} = (BOH_H \times Q_{IN}) + (BOH_R \times Q_{IN,R}), \text{ for two-stage furnaces, or}$$
$$FuelUse_{SH} = (BOH_M \times Q_{IN,M}) + (BOH_R \times Q_{IN,R}), \text{ for continuous modulating}^{b} \text{ furnaces}$$

Eq. 7B.2

Where:

BOH_{SS} = number of burner operating hours for each household (see derivation in section 7B.2.1),

---

[a] Continuous pilot ignitions were effectively eliminated from furnaces by the National Appliance Energy Conservation Act of 1987 (NAECA).

[b] In this analysis, "continuous modulating" term is used instead of "step-modulating." Both terms are interchangeably used in the literature.

BOH_H = number of burner operating hours at the maximum operating mode for two-stage furnaces for each household (see derivation in section 7B.2.1),
BOH_R = number of burner operating hours at the reduced operating mode for two-stage or continuous modulating furnaces or each household (see derivation in section 7B.2.1),
BOH_M = number of burner operating hours at the modulating operating mode for continuous modulating furnaces for each household (see derivation in section 7B.2.1),
Q_{IN} = steady-state nameplate input rate in Btu/h for single-stage furnaces or steady-state nameplate maximum input rate in Btu/h for two-stage and continuous modulating furnaces,
$Q_{IN,R}$ = steady-state reduced fuel input rate, and
$Q_{IN,M}$ = average modulating fuel input rate.

For the *FuelUse* calculation in chapter 7, DOE used $FuelUse_i$ as the basis for determining energy use for each operating mode (*e.g.*, single-stage, two-stage, or modulating) as follows:

$$FuelUse_i = BOH_i \times Q_{IN,i}$$

Eq. 7B.3

Where:

BOH_i = BOH_{SS}, BOH_H, BOH_R, or BOH_M, space heating burner operating hours for each household (hr/yr), and
$Q_{IN,i}$ = Q_{IN}, $Q_{IN,H}$, $Q_{IN,R}$, or $Q_{IN,M}$, input capacity of existing furnace (kBtu/hr).

Q_{IN} is based on the rated input capacity for each product. DOE assumed $Q_{IN,R}$ to be 70 percent of Q_{IN} for two-stage products and $Q_{IN,M}$ to be 40 percent of Q_{IN} for modulating products, as derived using manufacturer product literature. These percentages represent the average ratio of $Q_{IN}/Q_{IN,i}$. $Q_{IN,M}$ is calculated by dividing $Q_{OUT,M}$ by $Effy_{SS,M}$ (as defined in section 11.4.8.9 and 11.5.8.8 in the ASHRAE 103-2007 test procedure, respectively).

7B.2.1 Determination of Burner Operating Hours (BOH_{SS})

From the ASHRAE 103-2007 test procedure, the national average number of burner operating hours for furnaces is calculated in Appendix C section 1 (assuming that the product has no continuous pilot ignition):[c]

$$BOH_{SS} = 2080 \times 0.77 \times A \times \left(\frac{Q_{OUT}}{1+a}\right), \text{ for single-stage furnaces,}$$

$$BOH_H = X_H \times 2080 \times 0.77 \times A_H \times \left(\frac{Q_{OUT}}{1+a}\right), \text{ for two-stage furnaces at the maximum operating mode,}$$

---

[c] For factor *B*, in the expanded equation, if $Q_P = 0$ (pilot flame fuel input rate in Btu/h), then $B = 0$, which is true for all furnace product classes in this analysis.

$BOH_R = X_R \times 2080 \times 0.77 \times A_R \times \left(\frac{Q_{OUT}}{1+a}\right)$, for two-stage and continuous modulating furnaces operating at the reduced operating mode, and

$BOH_M = X_H \times 2080 \times 0.77 \times A_M \times \left(\frac{Q_{OUT}}{1+a}\right)$, for continuous modulating furnaces operating at the modulating operating mode,

Eq. 7B.4

Where:

2080 = national average heating load hours,
0.77 = adjustment factor to adjust the calculated design heating requirements and heating load hours to the actual heating load experienced by the heating system,
A = 100,000/ [341300(y_P * PE + y_{IG} *PE_{IG} + y * BE) + Q_{IN} * $Effy_{HS}$],[d,3]
A_H = 100,000/ [341300($y_{P,H}$ * PE_H + $y_{IG,H}$ *$PE_{IG,H}$ + y * BE_H) + Q_{IN} * $Effy_{U,H}$],
A_R = 100,000/ [341300($y_{P,R}$ * PE_R + $y_{IG,R}$ *$PE_{IG,R}$ + y_R * BE_R) + $Q_{IN,R}$ * $Effy_{U,R}$],
A_M = 100,000/ [341300($y_{P,H}$ * PE_H + $y_{IG,H}$ *$PE_{IG,H}$ + y * BE_H) + $Q_{IN,M}$ * $Effy_{U,M}$],
Q_{OUT} = maximum fuel input rate heating capacity (see Eq. 7B.7),
α = oversize factor set to the national average value of 0.7,
X_H = fraction of heating load at maximum fuel input rate operating mode as defined in section 11.4.8.5 of ASHRAE 103-2007,
X_R = fraction of heating load at reduced fuel input rate operating mode, which equals 1-X_H,
Q_{IN} = as defined in Eq. 7B.2,
$Q_{IN,R}$ = as defined in Eq. 7B.2,
$Q_{IN,M}$ = as defined in Eq. 7B.2,
y_P = ratio of induced or forced draft blower on-time to average burner on-time,
$y_{P,R}$ = ratio of induced or forced draft blower on-time to average burner on-time, measured at the reduced fuel input rate,
PE = burner electrical power input at full-load steady-state operation in kW,
PE_H = burner electrical power input at full-load steady-state operation in kW, measured at the maximum fuel input rate,
PE_R = burner electrical power input at full-load steady-state operation in kW**,** measured at the reduced fuel input rate,
y_{IG} = ratio of burner interrupted-ignition device on-time to average burner on-time,
$y_{IG,H}$ = ratio of burner interrupted-ignition device on-time to average burner on-time, measured at the maximum fuel input rate,
$y_{IG,R}$ = ratio of burner interrupted-ignition device on-time to average burner on-time, measured at the reduced fuel input rate,
PE_{IG} = electrical input rate to the interrupted ignition device on the burner in kW,
$PE_{IG,H}$ = electrical input rate to the interrupted ignition device on the burner, measured at the maximum fuel input rate in kW,
$PE_{IG,R}$ = electrical input rate to the interrupted ignition device on the burner, measured at the reduced fuel input rate in kW,

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[d] The ASHRAE test procedure does not include ignitor energy consumption. The ratio of ignitor on-time to burner on-time and the ignitor power consumption variables come from the DOE test procedure.[2]

y = blower on-time to burner on-time,
y_R = blower on-time to burner on-time, measured at the reduced fuel input rate,
BE = circulating air fan electrical energy input rate at full-load steady-state operation in kW,
BE_R = circulating air fan electrical energy input rate at full-load steady-state operation in kW, measured at the reduced fuel input rate,
BE_H = circulating air fan electrical energy input rate at full-load steady-state operation in kW**,** measured at the maximum fuel input rate.
$Effy_{HS}$ = heating seasonal efficiency,
$Effy_{U,H}$ = average part load efficiency at the maximum fuel input rate, which is equal to $Effy_{HS}$,
$Effy_{U,R}$ = average part load efficiency at the reduced fuel input rate, and
$Effy_{U,M}$ = average part load efficiency at the modulating fuel input rate.

In Eq. 7B.4, the national average parameters of 2,080 hours, 0.77 adjustment factor, and α, along with Q_{OUT}, are used to calculate the building heating load used in the ASHRAE 103-2007 test procedure , which can be expressed as:

$$BHL_{NationalAverage} = 2080 \times 0.77 \times \left(\frac{Q_{OUT}}{1+a}\right)$$

Eq. 7B.5

For each sampled building, DOE calculated the building heating load experienced by each individual furnace using the energy use data from RECS 2009 and CBECS 2003 rather than the national average parameters used in Eq. 7B.4. Therefore, in the LCC spreadsheet, $BHL_{NationalAverage}$ is substituted by the building heating load served by a single furnace ($BHL_{Furnace}$).

Thus, Eq. 7B.4 was modified in the LCC spreadsheet as follows (note that the $BOH_{SH,i}$ is the same as BOH_{SS}, BOH_H, BOH_R, or BOH_M depending on operating mode):[e]

$$BOH_{SH,i} = X_i \times BHL_{Furnace} \times A_i = X_i \frac{BHL_{Furnace}}{Q_{Useful,i}}$$

Eq. 7B.6

Where:

X_i = the fraction of heating load fulfilled at different fuel input rate operating modes, which is set to 1 for single stage products or X_H, X_R, or X_M (as defined in Eq. 7B.4) for two-stage and modulating products,
$BHL_{Furnace}$ = building heating load served by a single furnace (kBtu/yr), as described in section 7B.2.2,
A_i = A, A_H, A_R, or A_M, as defined in Eq. 7B.4, and

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[e] Maximum value for BOH is set to 8760, the number of hours in a year.

$Q_{Useful,i}$ = the total useful energy output of the furnace product, including useful heat from auxiliary electrical components for each operating mode (kBtu/hr), which is set to1/A, 1/A_H, 1/A_R, or 1/A_M.

DOE calculated X_H as defined in section 11.4.8.5 of ASHRAE 103-2007 by using T_C (balance-point temperature as defined in section 11.4.8.4 of ASHRAE 103-2007 test procedure), α (the oversize factor, as determined in Eq. 7B.4), Q_{OUT} (heating capacity), and $Q_{OUT,R}$ (reduced fuel input rate heating capacity). $Q_{OUT,R}$ is assumed to be equal to 70 percent of Q_{OUT} for two-stage products, and $Q_{OUT,M}$ is assumed to be equal to 40 percent of Q_{OUT} for modulating products. X_R is equal to 1-X_H. Q_{OUT} for all product classes is calculated using the following regression analysis equation based on AHRI Directory data for non-condensing and condensing furnaces:[3]

$$Q_{OUT} = Q_{IN}(a \times AFUE + b)$$

Eq. 7B.7

Where:

Q_{IN} = as defined in Eq. 7B.2,
$AFUE$ = AFUE of the furnace, and
a, b = linear regression fit parameters. For non-condensing furnaces, a = 0.7247 and b = 0.22346. For condensing furnaces, a = 0.8127 and b = 0.17557.

In the LCC spreadsheet, to calculate factors A, A_H, A_R, A_M, DOE calculated y_P, $y_{P,R}$, PE, PE_R, PE_H, y_{IG}, $y_{IG,R}$, PE_{IG}, $PE_{IG,R}$, $PE_{IG,H}$, y, y_R, BE, BE_R, BE_H, PE_{IG}, y, BE, Q_{IN}, and, as described in Eq. 7B.4 and section 7B.3 of this appendix. DOE calculated $Effy_{HS}$, the heating seasonal efficiency, as defined in sections 11.2.11, 11.3.11.3, 11.4.11.3, and 11.5.11.3 of the ASHRAE 103-2007 test procedure. $Effy_{HS}$ is equal to the annual fuel utilization efficiency ($AFUE$) for the furnaces in this analysis because no furnaces in this analysis have a continuous pilot. DOE assumed that $Effy_{U,H}$ is equal to $Effy_{U,R}$ and therefore, using the equation in section 11.5.11.3 of ASHRAE 103-2007 test procedure, is equal to $Effy_{SS}$.[f] $Effy_{U,M}$ is calculated using the equation in section 11.4.9.2.3 of ASHRAE 103-2007 test procedure. $Effy_{U,M}$ is calculated using $Effy_{SS}$, C_J (jacket loss factor, where 1.7 is the default value for furnaces in isolated combustion systems), and L_J (jacket loss value, where 1 percent is the default value for furnaces located outdoors or in isolated combustion systems). DOE calculated the steady-state efficiency $Effy_{SS}$ of each furnace using Q_{OUT} (as defined in Eq. 7B.7), K (factor that adjusts the jacket losses), and L_J (jacket loss value, where 1 percent is the default value), by revising the equation described in section 11.2.8.1 of ASHRAE 103-2007 as follows

$$Effy_{SS} = \frac{Q_{OUT}}{Q_{IN}} + K \times L_J$$

Eq. 7B.8

Where:

---

[f] $Effy_{U,H}$ is usually different from $Effy_{U,R}$, but for two-stage furnaces these values are similar and they operate mostly at reduced mode.

Q_{OUT} = as defined in Eq. 7B.7,
Q_{IN} = as defined in Eq. 7B.2,K = factor that adjusts jacket loss measured in the laboratory to those that would be measured under outdoor design conditions, which is assumed to be 1.7 for furnaces intended to be installed as isolated combustion systems according to ASHRAE 103-2007, and
L_J = jacket loss value, which is assumed to be 1 percent according to ASHRAE 103-2007.

7B.2.2 Determination of Building Heating Load Estimates for Furnace

The annual building heating load ($BHL_{Furnace}$) is the total amount of heat output from the furnace that the house or building needs during the heating season.[g] This includes heat from the burner as well as other electrical components. DOE determined projected $BHL_{Furnace}$ in 2021 for each sampled housing unit or building, based on the efficiency of the assigned existing furnace, using the following calculation:

$$BHL_{Furnace} = \frac{(Q_{YR} \times AFUE_{ex} + BlowerHeat) \times Adj_{Factor}}{FurnaceCount} \times NumberofUnitsServed$$

Eq. 7B.9

Where:

Q_{YR} = annual fuel consumption for heating based on RECS 2009 or CBECS 2003 (kBtu/yr),
$AFUE_{ex}$ = AFUE of the existing furnace (see section 7B.2.3.3),
$BlowerHeat$ = useful heat from furnace fan blower,
Adj_{Factor} = adjustment factor (see section 7B.2.2.1),
$FurnaceCount$ = number of furnaces used to fulfill the building heating load, and
$NumberofUnitsServed$ = number of housing units served by a single furnace.

Both RECS 2009 and CBECS 2003 report fuel consumption for heating (Q_{YR}) for each of the sampled buildings. Table 7B.2.1 shows the original RECS 2009 and CBECS 2003 heating energy use for the sampled buildings.

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[g] $BHL_{Furnace}$ is the load served by a single furnace. DOE assumed that some houses and buildings would be served by multiple residentially-sized furnaces based on RECS data. DOE also assumed that some furnaces serve multiple houses or buildings.

Table 7B.2.1 Range of Reported Heating Energy Use for Each Furnace Product Class by Region in RECS 2009 and CBECS 2003, MMBtu/year

Region	Min	Max	Average	Percentiles				
				5%	25%	50%	75%	95%
Non-Weatherized Gas Furnaces								
National	0.5	611.5	50.5	11.7	27.9	43.7	63.0	107.5
North	0.5	611.5	64.3	23.8	41.8	56.4	75.6	125.5
Rest of Country	0.6	355.1	35.0	8.9	19.6	30.4	44.7	73.3
Mobile Home Gas Furnaces								
National	2.2	146.5	39.7	11.3	26.9	36.2	48.3	75.7
North	4.5	146.5	47.8	24.0	36.2	44.2	58.5	88.1
Rest of Country	2.2	67.9	26.6	7.6	14.6	27.5	35.9	48.3

The AFUE of the existing furnace ($AFUE_{ex}$) is determined by matching historical AFUE data to the reported age of the existing furnace determined using RECS 2009 and CBECS 2003 variables. See section 7B.2.3.3 for more details.

To calculate useful heat from the furnace fan blower (*BlowerHeat*), DOE assumes that the existing furnace has a PSC furnace fan and operating hours are approximated by dividing the RECS 2009 or CBECS 2003 heating energy by the furnace input capacity. Based on the 2014 furnace fan final rule,[4] DOE determined the average power for a PSC non-condensing furnace in heating mode for the three major furnace fan sizes: 276 watts (2-ton unit), 467 watts (3-ton unit), and 934 watts (5-ton unit). See section 7B.2.3.2 for the furnace fan sizing methodology. For condensing units, DOE assumed that the power would be 5 percent higher due to the increased internal static pressure of the secondary heat exchanger.

DOE applied adjustment factors to account for changes in building shell efficiency, average climate conditions, climate change, and secondary heating products. See section 7B.2.2.1 for more details.

In the case when a household or building was determined to have multiple furnaces, the house heating load was divided by the number of furnaces. For NWGFs, the *FurnaceCount* is one furnace per building for 88.8 percent of shipments, two furnaces per building for 10.5 percent of shipments, and three furnaces per building for 0.7 percent of shipments. For MHGFs, DOE assumed one furnace per building.

Some furnaces are shared by multiple residential housing units, as indicated by the RECS 2009 variable HEATOTH (see appendix 7A). For NWGFs, the *NumberofUnitsServed* is one furnace per building for 99.2 percent of shipments, two housing units share a furnace for 0.4 percent of shipments, and three or more housing units share a furnace for 0.4 percent of shipments. For MHGFs, the *NumberofUnitsServed* is one furnace per building for 99.8 percent of shipments and two housing units share a furnace for 0.2 percent of shipments.

DOE calculated the national average annual heating load to be 35.3 MMBtu/yr for NWGFs and 27.4 MMBtu/yr for MHGFs in 2021. The variations between product classes primarily reflect differences in the geographical distribution of furnaces and the differences in housing characteristics. These results are smaller than those reported in RECS 2009 or CBECS 2003, primarily due to projected improvements in building shell efficiency and projected lower heating loads due to decreased heating degree days. Table 7B.2.2 shows the range of adjusted heating load among sample households.

Table 7B.2.2 Range of Adjusted Heating Load for Each Furnace Product Class by Region, MMBtu/year

Region	Min	Max	Average	Percentiles				
				5%	25%	50%	75%	95%
Non-Weatherized Gas Furnaces								
National	0.3	454.9	35.2	8.4	19.4	30.8	44.3	74.6
North	0.3	454.9	44.5	16.0	28.7	38.9	51.7	87.2
Rest of Country	0.4	248.4	24.6	6.8	14.1	21.2	31.7	52.5
Mobile Home Gas Furnaces								
National	1.2	113.6	27.4	7.9	18.7	25.7	33.6	51.8
North	2.6	113.6	32.7	16.0	24.5	29.6	40.9	58.7
Rest of Country	1.2	53.4	18.8	5.9	11.0	20.2	23.9	33.7

Once the heating load of each sample housing unit or building is known, it is possible to estimate what the burner operating hours and energy consumption of the baseline product (80-percent AFUE) as well as more-efficient products used in the analysis. Table 7B.2.3 shows the results for the baseline heating furnace (80-percent AFUE) burner operating hours among sample households and buildings in 2021.

Table 7B.2.3 Range of Baseline Furnace Heating Annual Burner Operating Hours for Each Furnace Product Class, hours

Region	Min	Max	Average	Percentiles				
				5%	25%	50%	75%	95%
Non-Weatherized Gas Furnaces								
National	5.7	8760.0	726.4	199.7	424.5	630.2	880.1	1498.0
North	5.7	8760.0	876.7	291.9	557.0	750.2	1019.5	1799.3
Rest of Country	11.7	4398.7	557.0	162.8	328.5	495.9	693.4	1136.9
Mobile Home Gas Furnaces								
National	18.3	1731.1	416.1	120.2	284.8	391.3	512.1	782.9
North	39.2	1731.1	497.2	243.9	369.7	450.5	623.4	885.5
Rest of Country	18.3	805.4	285.6	89.5	166.9	307.4	365.0	513.9

7B.2.2.1 Adjustment Factors for the Building Heating Load

Building Shell Efficiency Index. DOE adjusted $BHL_{Furnace}$ to reflect the expectation that buildings in 2021 will have a somewhat different $BHL_{Furnace}$ than the buildings in the RECS 2009 and CBECS 2003 furnace sample. The adjustment involves multiplying the calculated $BHL_{Furnace}$ for each RECS 2009 or CBECS 2003 unit by a building shell efficiency index[h] derived from the National Energy Modeling System (NEMS) simulation performed for EIA's *AEO 2014*.[5] For the year 2021, the factor applied for homes is 0.91 for replacements and 0.92 for new construction (as shown in Table 7B.2.4). Table 7B.2.5 shows for the year 2021 the factor applied for commercial building replacements depending on building type and census division (ranging from 0.73 to 0.97). Table 7B.2.6 shows the mapping of NEMS commercial building types to the commercial building types reported in CBECS 2003. For new construction commercial buildings, the factor used was 0.89 (as shown in Table 7B.2.7). This means that the average home or commercial building in 2021 will have a lower heating load than one in 2009 for residential buildings and 2003 for commercial buildings.

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[h] The building shell efficiency index sets the heating load value at 1.00 for an average home in 2009 for residential buildings and 2003 for commercial buildings (by type) in each census division. The values listed in Table 7B.2.2 represent the change in heating load based on the difference in physical size and shell attributes for homes in the future (which takes into account physical size difference and efficiency gains from better insulation and windows).

Table 7B.2.4 Residential Building Shell Index (based on AEO 2014 Reference Case)

Year	Pre-2009 Homes	New Construction
2011	0.97	1.02
2012	0.97	1.03
2013	0.96	1.01
2014	0.96	0.99
2015	0.95	0.95
2016	0.95	0.92
2017	0.94	0.91
2018	0.93	0.91
2019	0.93	0.92
2020	0.92	0.92
2021	**0.91**	**0.92**
2022	0.91	0.92
2023	0.90	0.92
2024	0.90	0.92
2025	0.89	0.92
2026	0.88	0.93
2027	0.88	0.93
2028	0.87	0.93
2029	0.86	0.93
2030	0.86	0.93
2031	0.85	0.93
2032	0.85	0.94
2033	0.84	0.94
2034	0.83	0.93
2035	0.83	0.93
2036	0.82	0.93
2037	0.81	0.93
2038	0.81	0.93
2039	0.80	0.93
2040	0.79	0.93

Table 7B.2.5 2021 Commercial Building Shell Index for Replacements Based on Building Type and Census Division (based on AEO 2014 Reference Case)

NEMS Building ID	NEMS Building Type	Commercial Building Shell Index								
		Census Division								
		1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
1	Assembly	0.96	0.93	0.96	0.94	0.92	0.87	0.87	0.94	0.73
2	Education	0.94	0.91	0.94	0.91	0.92	0.86	0.88	0.93	0.81
3	Food Sales	0.96	0.95	0.97	0.96	0.96	0.94	0.96	0.97	0.96
4	Food Service	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96
5	Health Care	0.95	0.93	0.95	0.93	0.94	0.93	0.94	0.97	0.86
6	Lodging	0.95	0.93	0.94	0.95	0.94	0.93	0.94	0.97	0.93
7	Large Office	0.96	0.94	0.96	0.96	0.92	0.91	0.89	0.95	0.78
8	Small Office	0.93	0.91	0.93	0.91	0.92	0.87	0.90	0.93	0.84
9	Merc Service	0.95	0.93	0.94	0.94	0.95	0.91	0.92	0.96	0.79
10	Warehouse	0.89	0.92	0.89	0.92	0.90	0.91	0.88	0.85	0.82
11	Other	0.94	0.93	0.95	0.92	0.92	0.82	0.83	0.92	0.74

Table 7B.2.6 Mapping of Commercial NEMS Index IDs to CBECS 2003 PBA ID

CBECS 2003 (PBA_ID)	CBECS 2003 (PBA_Value)	NEMS_ID	NEMS Value
1	Vacant	11	Other
2	Office	8	Small Office
4	Laboratory	11	Other
5	Nonrefrigerated warehouse	10	Warehouse
6	Food sales	3	Food Sales
7	Public order and safety	1	Assembly
8	Outpatient health care	5	Health Care
11	Refrigerated warehouse	10	Warehouse
12	Religious worship	1	Assembly
13	Public assembly	1	Assembly
14	Education	2	Education
15	Food service	4	Food Service
16	Inpatient health care	5	Health Care
17	Nursing	5	Health Care
18	Lodging	6	Lodging
23	Strip shopping mall	9	Merc Service
24	Enclosed mall	9	Merc Service
25	Retail other than mall	9	Merc Service
26	Service	9	Merc Service
91	Other	11	Other

Table 7B.2.7 Commercial Building Shell Index for New Construction (based on AEO 2014 Reference Case)

Year	Adj. Factor Heating
2003	1.00
2004	1.00
2005	0.99
2006	0.99
2007	0.99
2008	0.99
2009	0.98
2010	0.97
2011	0.96
2012	0.95
2013	0.94
2014	0.93
2015	0.92
2016	0.92
2017	0.91
2018	0.90
2019	0.89
2020	0.89
2021	**0.89**
2022	0.89
2023	0.88
2024	0.88
2025	0.88
2026	0.88
2027	0.87
2028	0.87
2029	0.87
2030	0.87
2031	0.86
2032	0.86
2033	0.86
2034	0.86
2035	0.85
2036	0.85
2037	0.85
2038	0.85
2039	0.84
2040	0.84

Average Climate Conditions. DOE also adjusted the calculated $BHL_{Furnace}$ to reflect historical average climate conditions by using heating degree days (HDD) reported in RECS 2009 and CBECS 2003 for each building and National Oceanic and Atmospheric Administration (NOAA) historic HDD data by region:[6]

$$Adj_{Factor,avg\ climate} = \frac{HDD_{10yr\ avg}}{HDD_{bldg,2009\ or\ 2003}}$$

Eq. 7B.10

Where:

$HDD_{bldg,\ 2009\ or\ 2003}$ = HDD in 2009 for RECS 2009 or 2003 for CEBCS 2003 for the specific region where the unit is located, and,

$HDD_{10yr\ avg}$ = 10-year average HDD (2004–2013) based on NOAA data for the specific region where the unit is located.

As shown in Table 7B.2.8, the historical average climate conditions adjustment factors for residential buildings range from 0.94 to 1.05 and have an average of 0.96 for the furnace building sample (*i.e.*, 2009 was in general colder than the 10-year average). As shown in Table 7B.2.9, this adjustment factor for commercial buildings range from 0.94 to 0.99 and average 0.96 for the furnace building sample (*i.e.*, 2003 was in general colder than the 10-year average).

Table 7B.2.8 HDD Adjustment Factors by RECS 2009 Regions (based on NOAA data)

Region	States	2009 HDD	10-Year Avg. (2004-2013)	HDD Adjustment Factor
1	CT, ME, NH, RI, VT	6936	6563	0.95
2	Massachusetts	6383	6043	0.95
3	New York	6235	5909	0.95
4	New Jersey	5294	5045	0.95
5	Pennsylvania	5880	5623	0.96
6	Illinois	6385	6017	0.94
7	Indiana, Ohio	5878	5624	0.96
8	Michigan	7036	6634	0.94
9	Wisconsin	7890	7429	0.94
10	IA, MN, ND, SD	8359	7863	0.94
11	Kansas, Nebraska	5958	5585	0.94
12	Missouri	5176	4923	0.95
13	Virginia	4431	4216	0.95
14	DE, DC, MD	4727	4489	0.95
15	Georgia	2981	2822	0.95
16	NC, SC	3332	3171	0.95
17	Florida	705	690	0.98
18	AL, KY, MS	3398	3274	0.96
19	Tennessee	3903	3742	0.96
20	AR, LA, OK	3113	2958	0.95
21	Texas	1849	1793	0.97
22	Colorado	7354	7102	0.97
23	ID, MT, UT, WY	7513	7292	0.97
24	Arizona	1894	1982	1.05
25	NV, NM	3879	3854	0.99
26	California	2879	2899	1.01
27	OR, WA	5724	5572	0.97
28	Alaska	10097	10335	1.02
29	Hawaii	0	0	1.00
30	West Virginia	5233	5046	0.96

Table 7B.2.9 HDD Adjustment Factors by CBECS 2003 Census Divisions (based on NOAA data)

ID	Division Name	2003 HDD	10-Year Avg. (2004-2013)	HDD Adjustment Factor
1	New England	6660	6303	0.95
2	Middle Atlantic	5875	5595	0.95
3	East North Central	6524	6181	0.95
4	West North Central	6736	6349	0.94
5	South Atlantic	3573	3396	0.95
6	East South Central	3579	3442	0.96
7	West South Central	2305	2213	0.96
8	Mountain	5811	5671	0.98
9	Pacific	3564	3541	0.99

Climate Change. DOE also accounted for future climate trends based on *AEO 2014* HDD projections by Census division (as shown in Table 7B.2.10), which show a decline in HDD, leading to lower projected $BHL_{Furnace}$ in 2021 relative to the non-climate-trend-adjusted $BHL_{Furnace}$ values. DOE used 2014 as the base year of the projected and calculated HDD adjustment factors as shown in for each census division.

Table 7B.2.10 Projected HDD by Census Divisions from AEO 2014

Year	New England	Middle Atlantic	East North Central	West North Central	South Atlantic	East South Central	West South Central	Mountain	Pacific	United States
2011	6082	5405	6163	6635	2568	3358	2145	5223	3532	4258
2012	5541	4886	5350	5537	2297	2896	1683	4445	3150	3712
2013	6287	5667	6416	6890	2754	3584	2156	5064	3102	4314
2014	6377	5680	6216	6406	2713	3448	2085	4758	3116	4207
2015	6115	5384	5999	6278	2624	3298	1979	4722	3218	4086
2016	6101	5369	5986	6268	2617	3290	1968	4711	3223	4072
2017	6087	5353	5972	6258	2610	3282	1957	4699	3229	4058
2018	6073	5338	5959	6247	2603	3274	1946	4687	3234	4044
2019	6059	5322	5946	6237	2596	3266	1935	4674	3239	4030
2020	6045	5307	5933	6226	2588	3258	1924	4660	3244	4015
2021	6031	5291	5920	6215	2581	3250	1914	4646	3249	4002
2022	6017	5276	5907	6204	2573	3242	1903	4632	3254	3988
2023	6003	5260	5894	6193	2566	3234	1892	4616	3258	3973
2024	5989	5245	5880	6181	2559	3226	1881	4601	3263	3960
2025	5975	5229	5867	6170	2551	3218	1870	4586	3267	3945
2026	5961	5214	5854	6158	2544	3209	1859	4570	3272	3932
2027	5947	5198	5841	6147	2537	3201	1848	4555	3277	3918
2028	5933	5183	5828	6135	2530	3193	1837	4540	3281	3904
2029	5919	5167	5815	6123	2523	3185	1826	4524	3286	3891
2030	5905	5152	5801	6112	2516	3177	1815	4508	3290	3877
2031	5891	5137	5788	6100	2509	3168	1805	4492	3295	3864
2032	5877	5121	5775	6088	2502	3160	1794	4477	3300	3850
2033	5863	5106	5762	6076	2495	3152	1783	4461	3305	3837
2034	5849	5091	5749	6064	2488	3143	1772	4444	3309	3824
2035	5835	5076	5735	6053	2481	3135	1761	4428	3314	3810
2036	5820	5060	5722	6041	2474	3126	1750	4412	3319	3797
2037	5806	5045	5709	6029	2468	3118	1739	4396	3324	3784
2038	5792	5030	5696	6016	2461	3109	1729	4379	3329	3771
2039	5777	5015	5682	6004	2455	3101	1718	4363	3334	3758
2040	5763	5000	5669	5992	2448	3093	1707	4347	3339	3745

Table 7B.2.11 Climate Change HDD Adjustment Factors by Census Division*

Year	New England	Middle Atlantic	East North Central	West North Central	South Atlantic	East South Central	West South Central	Mountain	Pacific	United States
2011	0.95	0.95	0.99	1.04	0.95	0.97	1.03	1.10	1.13	1.01
2012	0.87	0.86	0.86	0.86	0.85	0.84	0.81	0.93	1.01	0.88
2013	0.99	1.00	1.03	1.08	1.02	1.04	1.03	1.06	1.00	1.03
2014	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2015	0.96	0.95	0.97	0.98	0.97	0.96	0.95	0.99	1.03	0.97
2016	0.96	0.95	0.96	0.98	0.96	0.95	0.94	0.99	1.03	0.97
2017	0.95	0.94	0.96	0.98	0.96	0.95	0.94	0.99	1.04	0.96
2018	0.95	0.94	0.96	0.98	0.96	0.95	0.93	0.99	1.04	0.96
2019	0.95	0.94	0.96	0.97	0.96	0.95	0.93	0.98	1.04	0.96
2020	0.95	0.93	0.95	0.97	0.95	0.94	0.92	0.98	1.04	0.95
2021	**0.95**	**0.93**	**0.95**	**0.97**	**0.95**	**0.94**	**0.92**	**0.98**	**1.04**	**0.95**
2022	0.94	0.93	0.95	0.97	0.95	0.94	0.91	0.97	1.04	0.95
2023	0.94	0.93	0.95	0.97	0.95	0.94	0.91	0.97	1.05	0.94
2024	0.94	0.92	0.95	0.96	0.94	0.94	0.90	0.97	1.05	0.94
2025	0.94	0.92	0.94	0.96	0.94	0.93	0.90	0.96	1.05	0.94
2026	0.93	0.92	0.94	0.96	0.94	0.93	0.89	0.96	1.05	0.93
2027	0.93	0.92	0.94	0.96	0.94	0.93	0.89	0.96	1.05	0.93
2028	0.93	0.91	0.94	0.96	0.93	0.93	0.88	0.95	1.05	0.93
2029	0.93	0.91	0.94	0.96	0.93	0.92	0.88	0.95	1.05	0.92
2030	0.93	0.91	0.93	0.95	0.93	0.92	0.87	0.95	1.06	0.92
2031	0.92	0.90	0.93	0.95	0.92	0.92	0.87	0.94	1.06	0.92
2032	0.92	0.90	0.93	0.95	0.92	0.92	0.86	0.94	1.06	0.92
2033	0.92	0.90	0.93	0.95	0.92	0.91	0.86	0.94	1.06	0.91
2034	0.92	0.90	0.92	0.95	0.92	0.91	0.85	0.93	1.06	0.91
2035	0.92	0.89	0.92	0.94	0.91	0.91	0.84	0.93	1.06	0.91
2036	0.91	0.89	0.92	0.94	0.91	0.91	0.84	0.93	1.07	0.90
2037	0.91	0.89	0.92	0.94	0.91	0.90	0.83	0.92	1.07	0.90
2038	0.91	0.89	0.92	0.94	0.91	0.90	0.83	0.92	1.07	0.90
2039	0.91	0.88	0.91	0.94	0.90	0.90	0.82	0.92	1.07	0.89
2040	0.90	0.88	0.91	0.94	0.90	0.90	0.82	0.91	1.07	0.89

* Base year = 2014

Secondary Heating. DOE determined that some of the sampled buildings used multiple heating products with the same fuel as the furnace(s), such as a boiler, wall furnace, room heater, stove, or fireplace. Therefore, DOE adjusted the calculated $BHL_{Furnace}$ when necessary to reflect the use of secondary heating products using the same fuel as the furnace(s). The adjustment factors are calculated using reported survey information from both RECS 2009 and CBECS 2003 regarding the fraction of heating that was met by different heating products. RECS 2009 reports the amount of heating that is provided by the main heating product (using the variable EQMAMT, see appendix 7A) as shown in Table 7B.2.12. For each of the reported bins, DOE created a triangular distribution representing the fraction of secondary heating product energy use. Table 7B.2.12 also shows the fraction of NWGF impacted by this adjustment (14.1 percent of the residential shipments). The number of MHGFs impacted by this adjustment is 5.4 percent. CBECS 2003 reports the fraction heating energy use by the furnace with the variable FURNP8 (see appendix 7A).

Table 7B.2.12 Heat Provided by Main Heating Equipment (RECS 2009)

Reported Main Heating Product Use	RECS Value	Triangular Distribution Parameters			Fraction of Residential NWGF Shipments	
		Minimum	Likeliest	Maximum	Furnace is Primary	Furnace is Secondary
Almost all	1	5%	10%	15%	11.4%	0.2%
About three fourths	2	15%	25%	35%	1.6%	0.1%
Close to half of all heat	3	35%	40%	45%	0.8%	0.1%
Not adjusted	-	100%	100%	100%	84.3%	1.7%

7B.2.3 Assigning Furnace Product Characteristics to Sampled Households

To determine the heating load of each sample housing unit, DOE represented the existing furnace by assigning an input capacity, furnace fan size, and AFUE to the existing furnace in the RECS sample building units and, for NWGFs in commercial applications, in the CBECS sample building units. DOE assumed that the size of the existing product would be the same as for the new furnace product.

7B.2.3.1 Input Capacity of Existing and New Products

The Department assigned an input capacity for the existing furnace of each housing unit based on an algorithm that correlates the housing unit size and outdoor design temperature with the distribution of input capacity of furnaces. DOE assumed that, for the new furnace installation, the input capacity would remain the same. The following steps describe the assignment process for NWGFs and MHGFs:

1) The Department ranked all the RECS housing units in ascending order by size (heating square foot) multiplied by a scaling factor to account for the outdoor design temperature (see Eq. 7B.11) and calculated the percentile rank of each housing unit using the statistical weight of each of the sample records.
2) The Department constructed percentile tables by input capacity of furnaces based on the historical shipment information and number of models in AHRI Directory (see Table 7B.2.13).
3) After selecting a housing unit from the RECS database during each Monte Carlo iteration, DOE noted the size of the selected housing unit and determined the percentile rank from Step 1.
4) To avoid a one-to-one deterministic relation between the housing unit size and input capacity, DOE added a random term to the percentile identified in Step 3 so that the correlation was not perfect. The Department used a normal distribution to characterize the random term. The random term has a mean of zero and a standard deviation of 8 percent.

5) Using the percentile from Step 4, DOE looked up the input capacity from the input capacity percentile table in Step 2.

DOE used ASHRAE design data to develop estimates of the average 1 percent design dry bulb temperature for each household (see appendix 7C for more details). Using this data, DOE then developed a scaling factor to be applied to the home heating square footage and equal to:

$$SF_{design,h} = (65 - T_{design,\,h}) / (65 - 42)$$

Eq. 7B.11

Where:

$SF_{design,h}$ = heating design scaling factor, and
$T_{design,\,h}$ = average 1 percent ASHRAE design dry bulb temperature (°F) for heating.

The design scaling factor is used as a proxy to represent lower heating loads for the same household area in cooler climates and supports the allocation of the sizes across observations, but the total relative allocation of sizes is unaffected. The end result was a distribution of sizes assigned to the weighted RECS samples that matches the distribution of sizes for shipments of residential furnaces by input capacity. Table 7B.2.13 shows the distribution of input capacities for the most commonly available input capacity bins based on the February 2013 AHRI Residential Furnace Directory and AHRI shipment data.[3, 7]

Table 7B.2.13 Distribution of Input Capacity for NWGF and MHGF

Input Capacity *kBtu/h*	**AHRI 2001 Gas Furnace Shipments** *%*	**2013 AHRI Directory Fraction of Models** *%*	
		NWGF	***MHGF***
40	9.4	7.7%	10.0%
50		4.1%	5.7%
60	8.6	11.4%	20.0%
70	24.8	7.2%	10.0%
80	13.7	18.4%	25.7%
90	23.2	11.3%	7.1%
100		14.9%	12.9%
110	20.4	7.9%	0.0%
120		9.6%	7.1%
130		4.8%	0.0%
140		1.6%	1.4%
150		1.1%	0.0%
160		0.1%	0.0%

7B.2.3.2 Airflow Capacity of Existing Product

The equipment cost and electricity use of a furnace varies significantly with furnace fan airflow capacity. Also, condensing furnaces tend to have a more restricted airflow path than non-condensing furnaces because of the secondary heat exchanger. In general, the furnace fan requires more energy to produce the equivalent airflow output for a condensing furnace compared to a similar non-condensing furnace. To account for this additional energy consumption and resulting additional heat released by the furnace fan motor that needs to be compensated by the central air conditioner, DOE classified furnaces by nominal maximum airflow in cfm at 0.5 in. w.g. of external static pressure. DOE assigned the airflow capacity of existing furnaces for housing units that had air conditioners in a manner similar to how it assigned furnace input capacity. Larger air conditioners are assigned to larger housing units, according to the distribution of sizes of air conditioners sold in the year the air conditioner was installed in that housing unit. The Department used an air conditioner nominal size of 2, 3, 4, or 5 tons to determine the airflow capacity using a ratio of 400 cfm per ton of cooling. The steps were:

1) The Department ranked all the RECS 2009 housing units in ascending order by size (cooling square footage) multiplied by a scaling factor to account for the outdoor design temperature (see Eq. 7B.12) and calculated the percentile rank of each housing unit using the statistical weight of each of the sample records.

2) Based on historical shipment information of residential central air conditioners by capacity, DOE constructed the airflow capacity percentiles table for air conditioners. The Department restricted the airflow sizes to two, three, four, or five tons—the equivalent of 800, 1,200, or 2,000 cfm at 0.5 in. w.g. static pressure. Since there are no available shipment data on the airflow capacity of furnaces, the Department used the airflow capacity of residential central air conditioners as a proxy.

3) After selecting a housing unit from the RECS 2009 database during each Monte Carlo iteration, DOE noted the size of the selected housing unit and determined the percentile rank from Step 1.

4) To avoid a one-to-one deterministic relation between the housing unit size and input capacity, DOE added a random term to the percentile identified in Step 3 so that the correlation was not perfect. The Department used a normal distribution to characterize the random term. The random term has a mean of zero and a standard deviation of 8 percent.

5) Using the percentile from Step 4, DOE looked up the airflow from the airflow percentile table in Step 2. The Department selected an input capacity and airflow combination with the identified airflow capacity, based on commonly available models (see Table 7B.2.14). If no input capacity and airflow combination with the identified airflow capacity was available, the Department selected the input capacity and airflow combination with the same input capacity and the closest airflow capacity as a substitute.

DOE used ASHRAE design data to develop estimates of the average 1 percent design dry bulb temperature for each household (see appendix 7C for more details). Using these data, DOE then developed a scaling factor that is applied to the home cooling square footage and is equal to:

$$SF_{design,c} = (T_{design,\,c} - 65) / (95 - 65)$$

Eq. 7B.12

Where:

$SF_{design,c}$ = cooling design scaling factor, and
$T_{design,\,c}$ = average 1 percent ASHRAE design dry bulb temperature (°F) for cooling.

The design scaling factor is used as a proxy to represent lower cooling loads for the same household area in warmer climates and supports the allocation of the sizes across observations, but the total relative allocation of sizes is unaffected. The end result was a distribution of sizes assigned to the weighted RECS 2009 and CBECS 2003 sample that matches the distribution of sizes for shipments of residential furnaces. Table 7B.2.14 shows the distribution of input capacities for the representative product classes listed above, based on 2004-2013 AHRI shipment data.[8]

Table 7B.2.14 Distribution of Airflow for Furnaces

Airflow Rating ***cfm***	**2004-2013 AHRI Shipments** ***%***
800	36.9%
1200	46.0%
2000	17.1%

7B.2.3.3 Derivation of Existing AFUE

The AFUE of the existing furnace ($AFUE_{ex}$) was determined by matching historical AFUE data to the reported age of the furnace in RECS 2009 for residential applications, or to the assigned age of the furnace for commercial applications.[i] As described in section 7B.2.2, the AFUE of the existing product is required to calculate the building heating load. DOE developed the historical distributions of efficiencies for existing NWGFs and MHGFs based on historical shipment data by efficiency from the Air-Conditioning, Heating, and Refrigeration Institute (AHRI, formerly the Gas Appliance Manufacturers Association (GAMA)), and the distribution of shipments in 2003 for condensing furnaces.[7, 9]

The Department assigned the AFUE of existing furnaces based on the product age of the existing furnace as provided by RECS 2009 and historical shipments by efficiency. The following steps describe this process:

1) Based on the historical furnace shipment information sorted by AFUE, DOE constructed percentile tables by AFUE shipments of furnaces for 2009 and prior years (see Table 7B.2.15). AHRI shipments data for NWGFs and MHGFs indicate that housing units in

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[i] CBECS 2003 does not report the age of the equipment, so DOE created a uniform distribution (from 0 to 30 years, the upper limit being the age of the building or 13 year for buildings reporting that they had upgraded their equipment after 1990 and a lower limit of 13 for buildings reporting that they had upgraded their equipment after 1990) to estimate the age of the product.

the North region receive more-efficient furnaces than the Rest of Country. Therefore, DOE developed two historical AFUE shipment distributions—one for the North and one for the Rest of Country—for NWGFs and MHGFs.

2) After DOE selected a housing unit from the RECS database during each Monte Carlo iteration, it randomly assigned a percentile value and extracted the furnace age information from RECS 2009. Using the extracted furnace age, DOE assigned an installation year from the installation year range for the applicable RECS 2009 product age bin.

3) DOE determined the AFUE by looking it up from the AFUE percentile table from Step (2) corresponding to the age of the existing product in the housing unit and whether the housing unit was located in the North or Rest of Country region.

DOE derived distribution of shipments from 1966-2009 for each RECS 2009 and CBECS 2003 region. The shipments for each year were disaggregated by condensing and non-condensing shipments. AHRI shipments data of condensing and non-condensing by state from 1992 to 2003 (except 1993) was used to derive the fraction of condensing furnaces by RECS 2009 and CBECS 2003 regions for all years from 1966 to 2009 by assuming that the fraction of shipments for each state changed proportionally to the change in regional (North or Rest of Country) or national condensing market share. Table 7B.2.15 shows the condensing fractions of shipments by RECS 2009 region. AHRI also provided percentage of condensing furnaces shipments data was also available from 1978 to 1991 nationally and from 2004-2009 by North and South regions.[7, 9] AHRI also provided percentage of non-condensing furnaces shipments by efficiency bins from 1978 to 1993.[7] Condensing shipments where disaggregated using the distribution of condensing furnace shipments by efficiency in 2003 provided by AHRI.[10] Table 7B.2.16 shows the resulting fraction of shipments from 1966-2009.

Table 7B.2.15 1992, 1994-2003 Fraction of Condensing NWGF Shipments by RECS 2009 Regions (AHRI Data)

Region	States	2003	2002	2001	2000	1999	1998	1997	1996	1995	1994	1992
1	CT, ME, NH, RI, VT	59%	58%	54%	45%	47%	53%	51%	45%	39%	33%	38%
2	Massachusetts	68%	66%	65%	62%	57%	47%	46%	43%	34%	36%	32%
3	New York	42%	36%	36%	32%	30%	33%	37%	36%	29%	28%	33%
4	New Jersey	41%	32%	28%	24%	27%	25%	23%	20%	15%	17%	17%
5	Pennsylvania	55%	50%	49%	46%	43%	47%	48%	44%	36%	33%	32%
6	Illinois	36%	33%	32%	24%	27%	27%	30%	27%	25%	27%	30%
7	Indiana, Ohio	48%	41%	42%	36%	35%	35%	35%	33%	30%	30%	28%
8	Michigan	49%	44%	47%	39%	39%	39%	43%	39%	37%	39%	48%
9	Wisconsin	82%	78%	79%	73%	70%	68%	72%	73%	68%	74%	77%
10	IA, MN, ND, SD	67%	63%	65%	55%	48%	51%	54%	53%	52%	47%	46%
11	Kansas, Nebraska	38%	32%	38%	30%	28%	30%	32%	35%	30%	33%	23%
12	Missouri	35%	33%	37%	29%	29%	29%	30%	27%	22%	23%	19%
13	Virginia	43%	38%	37%	36%	37%	36%	39%	34%	27%	22%	22%
14	DE, DC, MD	41%	38%	35%	33%	32%	31%	41%	40%	37%	31%	35%
15	Georgia	9%	9%	8%	7%	7%	7%	7%	7%	9%	9%	6%
16	NC, SC	36%	32%	32%	31%	28%	30%	24%	18%	14%	18%	15%
17	Florida	3%	0%	2%	1%	2%	1%	5%	4%	9%	6%	3%
18	AL, KY, MS	24%	20%	21%	17%	16%	16%	16%	13%	13%	10%	15%
19	Tennessee	26%	22%	22%	21%	18%	18%	20%	17%	17%	14%	13%
20	AR, LA, OK	6%	6%	6%	4%	4%	3%	4%	2%	6%	7%	6%
21	Texas	4%	4%	1%	1%	1%	1%	5%	4%	5%	5%	5%
22	Colorado	22%	16%	14%	10%	10%	9%	10%	7%	9%	10%	11%
23	ID, MT, UT, WY	31%	29%	31%	26%	26%	26%	28%	25%	22%	30%	29%
24	Arizona	16%	15%	11%	9%	8%	10%	9%	8%	8%	5%	7%
25	NV, NM	11%	8%	6%	4%	5%	5%	6%	4%	5%	9%	7%
26	California	12%	11%	11%	6%	6%	6%	9%	7%	9%	12%	8%
27	OR, WA	28%	26%	27%	20%	20%	19%	20%	18%	15%	21%	20%
28	Alaska	24%	23%	21%	16%	18%	21%	14%	5%	14%	21%	36%
29	Hawaii	100%	100%	7%	37%	67%	10%	100%	100%	15%	64%	0%
30	West Virginia	70%	66%	61%	59%	59%	57%	58%	54%	45%	43%	44%

Table 7B.2.16 Historical Fraction of NWGF Shipments by AFUE Bins

Year	North Region			Rest of Country Region			National		
	>78 AFUE	78 to <90 AFUE	≥90 AFUE	>78 AFUE	78 to <90 AFUE	≥90 AFUE	>78 AFUE	78 to <90 AFUE	≥90 AFUE
2009	0.0%	32.4%	67.6%	0.0%	71.0%	29.0%	0.0%	49.8%	50.2%
2008	0.0%	40.8%	59.2%	0.0%	75.8%	24.2%	0.0%	56.7%	43.3%
2007	0.0%	47.0%	53.0%	0.0%	78.8%	21.2%	0.0%	62.9%	37.1%
2006	0.0%	45.8%	54.2%	0.0%	80.1%	19.9%	0.0%	63.5%	36.5%
2005	0.0%	48.8%	51.2%	0.0%	81.6%	18.4%	0.0%	65.6%	34.4%
2004	0.0%	52.2%	47.8%	0.0%	83.6%	16.4%	0.0%	68.4%	31.6%
2003	0.0%	53.9%	46.1%	0.0%	84.9%	15.1%	0.0%	68.6%	31.4%
2002	0.0%	59.1%	40.9%	0.0%	86.5%	13.5%	0.0%	72.2%	27.8%
2001	0.0%	57.7%	42.3%	0.0%	87.6%	12.4%	0.0%	72.1%	27.9%
2000	0.0%	64.6%	35.4%	0.0%	89.6%	10.4%	0.0%	76.6%	23.4%
1999	0.0%	64.9%	35.1%	0.0%	89.5%	10.5%	0.0%	76.7%	23.3%
1998	0.0%	64.6%	35.4%	0.0%	89.8%	10.2%	0.0%	76.8%	23.2%
1997	0.0%	62.9%	37.1%	0.0%	87.8%	12.2%	0.0%	74.7%	25.3%
1996	0.0%	64.7%	35.3%	0.0%	89.8%	10.2%	0.0%	76.5%	23.5%
1995	0.0%	68.3%	31.7%	0.0%	88.9%	11.1%	0.0%	77.7%	22.3%
1994	0.0%	66.6%	33.4%	0.0%	87.6%	12.4%	0.0%	76.2%	23.8%
1993	2.2%	64.1%	33.7%	2.9%	85.5%	11.6%	2.5%	73.9%	23.6%
1992	6.7%	59.3%	33.9%	9.1%	80.2%	10.7%	7.8%	68.8%	23.4%
1991	46.4%	24.0%	29.7%	59.8%	30.9%	9.3%	52.4%	27.1%	20.5%
1990	52.4%	22.3%	25.3%	64.6%	27.4%	7.9%	57.9%	24.6%	17.5%
1989	58.3%	17.4%	24.3%	71.2%	21.2%	7.6%	64.1%	19.1%	16.8%
1988	54.8%	19.6%	25.6%	67.8%	24.2%	8.1%	60.7%	21.6%	17.7%
1987	58.0%	18.3%	23.7%	70.4%	22.2%	7.4%	63.6%	20.1%	16.4%
1986	71.1%	18.7%	10.2%	76.7%	20.1%	3.2%	73.6%	19.3%	7.0%
1985	66.5%	17.3%	16.1%	75.3%	19.6%	5.1%	70.5%	18.4%	11.1%
1984	64.0%	18.2%	17.8%	73.5%	20.9%	5.6%	68.3%	19.4%	12.3%
1983	69.3%	7.8%	22.9%	83.4%	9.4%	7.2%	75.6%	8.6%	15.8%
1982	72.3%	8.5%	19.2%	84.0%	9.9%	6.0%	77.6%	9.2%	13.3%
1981	75.7%	8.8%	15.5%	85.2%	9.9%	4.9%	80.0%	9.3%	10.7%
1980	79.2%	9.0%	11.9%	86.5%	9.8%	3.7%	82.5%	9.3%	8.2%
1979	92.7%	1.3%	5.9%	96.7%	1.4%	1.9%	94.5%	1.4%	4.1%
1978	98.6%	1.4%	0.0%	98.6%	1.4%	0.0%	98.6%	1.4%	0.0%
1966-1977	100.0%	0.0%	0.0%	100.0%	0.0%	0.0%	100.0%	0.0%	0.0%

Figure 7B.2.1 shows the shipment-weighted AFUE for NWGFs by North and Rest of Country regions and nationally.

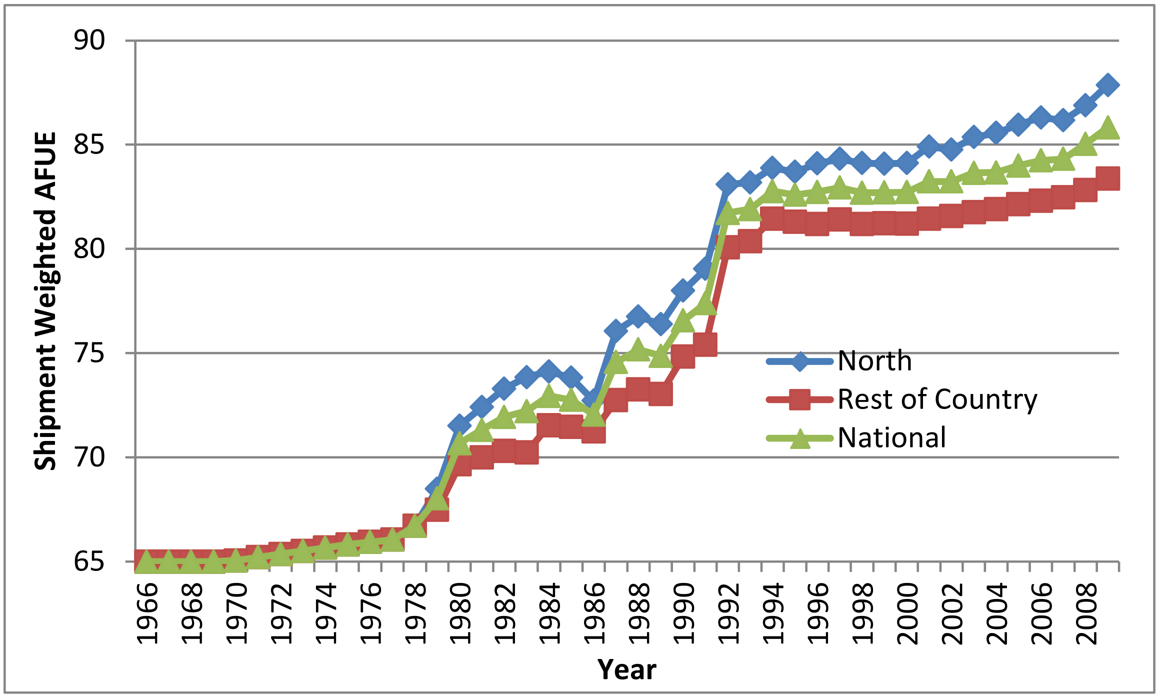

Figure 7B.2.2 **Shipment-Weighted AFUE (SWAFUE) of Non-Weatherized Gas Furnaces**

7B.3 DETERMINATION OF ANNUAL ELECTRICAL ENERGY CONSUMPTION

The Department calculated furnace electricity consumption when the furnace is in operation (active mode) and when the furnace is in standby or off mode as:

$$ElecUse = ElecUse_{ActiveMode} + ElecUse_{Stby}$$

Eq. 7B.13

Where:

$ElecUse_{ActiveMode}$ = electricity use of electrical components during furnace operation, (kWh/yr) (Eq. 7B.14), and

$ElecUse_{Stby}$ = electricity use of electrical components during standby or off mode (Eq. 7B.17), (kWh/yr).

7B.3.1 Active Mode Electricity Consumption

The Department calculated furnace electricity consumption when the furnace is in operation (active mode) as follows:

$$ElecUse_{ActiveMode} = ElecPower_{ElecComp} \times OH_{ElecComp} + ElecUse_{Aux} + DiffElecUse_{fan}$$

Eq. 7B.14

Where:

$ElecPower_{ElecComp}$ = power of multiple electrical components required during furnace operation, (kW) (refer to the test procedure variables that relate to electricity consuming components as detailed in section 7B.3.1.1),
$OH_{ElecComp}$ = operating hours of the electrical components, (h), (refer to the test procedure variables that relate to electricity consuming components as detailed in section 7B.3.1.1),
$ElecUse_{Aux}$ = electricity use of the auxiliary equipment, such as condensate pumps and heat tape, (kWh) (see section 7B.3.1.2), and
$DiffElecUse_{Fan}$ = differential of electricity use of the furnace fan during cooling and continuous fan circulation, (kWh) (see section 7B.3.1.3).

7B.3.1.1 Furnace Electricity Consumption (Heating Season)

The active mode electricity consumption takes into account the electricity consumption of the electrical components of the furnace (such as blower, the draft inducer, and the ignitor). The blower (also referred to as the furnace fan) electricity use accounts for the minimum efficiency requirements set by the 2014 furnace fan final rule that will take effect on July 3, 2019. (10 CFR 430.32(y))

Using the ASHRAE 103-2007 test procedure, the average annual auxiliary electrical energy consumption (E_{AE}, which is equal to $ElecPower_{ElecComp}$ times $OH_{ElecComp}$ in equation Eq. 7B.14) is calculated in Appendix C section 3 as:

$$E_{AE} = BOH_{SS}(y_P \times PE + y_{IG} \times PE_{IG} + y \times BE), \text{ for single-stage furnaces,}$$

and

$$E_{AE} = BOH_R(y_{P,R} \times PE_R + y_{IG,R} \times PE_{IG,R} + y_R \times BE_R) + BOH_{H\ or\ M}(y_P \times PE_H + y_{IG} \times PE_{IG,H} + y \times BE_H),^{j2} \text{ for two-stage and continuous modulating furnaces} \quad \textbf{Eq. 7B.15}$$

Where:

BOH_{SS} = as defined in section 7B.2,
BOH_H = as defined in section 7B.2,
BOH_M = as defined in section 7B.2,
BOH_R = as defined in section 7B.2,
y_P = as defined in section 7B.2.1,
$y_{P,R}$ = as defined in section 7B.2.1,
PE = as defined in section 7B.2.1,
PE_R = as defined in section 7B.2.1,
PE_H = as defined in section 7B.2.1,
y_{IG} = as defined in section 7B.2.1,

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[j] The ASHRAE test procedure does not deal with ignitor energy consumption. The ratio of ignitor on-time to burner on-time and the ignitor power consumption variables come from the DOE test procedure.[2]

$y_{IG,R}$ = as defined in section 7B.2.1,
PE_{IG} = as defined in section 7B.2.1,
$PE_{IG,R}$ = as defined in section 7B.2.1,
$PE_{IG,H}$ = as defined in section 7B.2.1,
y = as defined in section 7B.2.1,
y_R = as defined in section 7B.2.1,
BE = as defined in section 7B.2.1,
BE_R = as defined in section 7B.2.1, and
BE_H = as defined in section 7B.2.1.

The draft inducer has an average electrical consumption (PE_H) of 100 watts for all furnaces based on furnace model data. In addition, for modulating and two-stage units, DOE assumed that the reduced inducer power (PE_R) would be 70 percent of the PE_H values.

The ratio of draft inducer on-time to burner on-time y_P and $y_{P,R}$ are calculated using t_P (post-purge time). Generally, the induced- and forced-draft fans operate during post-purge, as well as during the burner on-cycle. In general, the post-purge can range from 0 to 30 seconds. For this analysis, DOE used a draft inducer post-purge time (t_P) of 5 seconds.

Furnaces utilize spark ignition, hot surface ignition, and direct spark to pilot. Spark ignition is generally used in condensing products while the others are used in non-condensing products. In this analysis, DOE assumed spark ignition for all products with PE_{IG} equal to 400 watts and t_{IG} equal to 45 seconds to calculate y_{IG} and $y_{IG,R}$.

DOE calculated the ratio of blower on-time to burner on-time y and y_R using t^+ (blower off-delay) and t^- (blower on-delay). For this analysis, DOE assumed the shut-down time delay t^+ = 100 seconds and the start-up time delay t^- = 30 seconds, based on furnace model data.

The electricity consumption (and overall efficiency) of a blower motor depends on the speed at which the motor operates, the external static pressure difference across the blower, and the airflow through the blower. To calculate blower motor electricity consumption, DOE determined the operating conditions (the pressure and airflow) at which a particular furnace in a particular housing unit will operate. These operating conditions can be graphically displayed as the intersection of a system curve of the ducts in the housing unit (which plots the airflow across the supply and return air ducts as a function of static pressure) with the fan curve of the furnace (which plots the airflow through the furnace as a function of static pressure). The intersection of these two curves is the airflow and the static pressure at which the furnace will operate in that housing unit.

Furnace fan curves, reported as tables of airflow rise versus static pressure through the furnace, are available from manufacturers in the product literature for each furnace. Some of the manufacturers also supply blower-motor input power as a function of static pressure across the furnace.

Power is calculated from the air speed through the furnace and the pressure rise across the furnace. The overall air-moving efficiency is air power divided by the electric power to the blower motor. All the electric power of the blower motor eventually is converted to heat that contributes to meeting the building heating load.

The system curve of the air-distribution system is a graphical representation of the airflow through the supply and return ducts in a house for different static pressure. The airflow and pressure drop at which the furnace will operate can be determined by the intersection of the system curve of the house and the fan curve of the furnace circulating air blower.[11]

DOE modeled system curves as quadratic curves, which is standard in heating, ventilation, and air conditioning (HVAC) design and fan selection handbooks.[12] The curves are based on Bernoulli's equations for fluid flow and are expressed as the following equation:

$$Q = \sqrt{\frac{P}{\alpha}}$$

Eq. 7B.16

Where:

Q = airflow (cfm),
P = static pressure (in. w.g.), and
α = a constant coefficient.

For the 2014 furnace fan final rule analysis, DOE selected the coefficient in the system curve equation for each housing unit. It randomly sampled a coefficient from one of four distributions, depending on the nominal maximum airflow of the virtual model furnace selected for that housing unit. DOE designed each distribution so that 10 percent of samples would have static pressures below 0.5 in. w.g., and 1 percent of the samples would have static pressures greater than 1 in. w.g. at the nominal maximum airflow. This is in line with several field studies.[13] See Figure 7B.3.1 for an example of a plot of system curves intersecting a furnace fan curve.

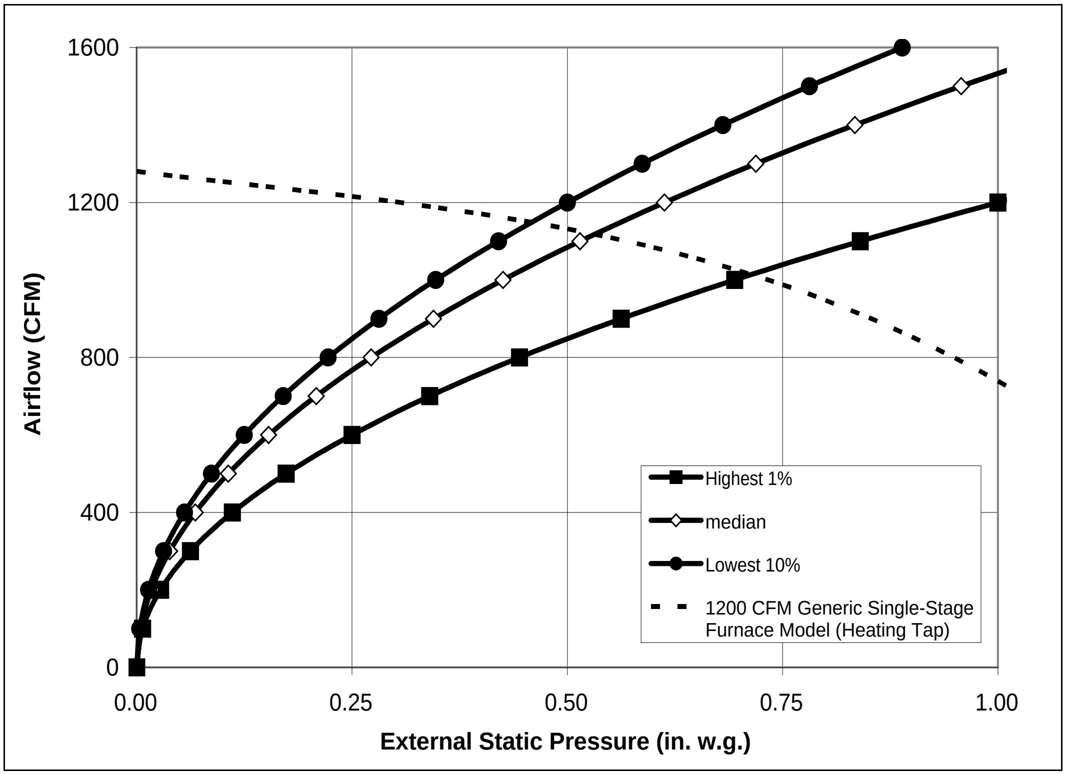

Figure 7B.3.1 Sample of System Curves with a Typical Fan Curve

For this analysis DOE used the average values derived from the 2014 furnace fan final rule for the minimum efficiency design options available for each product class (X13 with multi-stage for NWGFs and improved PSC for MHGFs) after the standard takes effect on July 3, 2019, as shown in Table 7B.3.1.

Table 7B.3.1 Furnace Fan Motor Power Consumption by Product Type and Furnace Fan Size

Furnace Fan Size (Ton)	NWGF		MHGF	
	Non-Condensing	*Condensing*	*Non-Condensing*	*Condensing*
2	276	290	256	269
3	467	490	424	445
5	934	981	842	884

DOE took into account that a fraction of furnace shipments will be installed with higher-efficiency furnace fans. Table 7B.3.1 and Table 7B.3.3 show the fraction of shipments by efficiency level and the percentage improvement in efficiency based on furnace model data for NWGFs and MHGFs, respectively.

Table 7B.3.2 Fraction of Shipments by Furnace Fan Motor Type for NWGFs

EL	AFUE	X13 Multi-Stage	BPM Multi-Stage
0	80%	85%	15%
1	90%	85%	15%
2	92%	85%	15%
3	95%	50%	50%
4	98%	0%	100%
		Efficiency Improvement	9%

Table 7B.3.3 Fraction of Shipments by Furnace Fan Motor Type for MHGFs

EL	AFUE	Improved PSC	X13 Single-Stage	BPM Multi-Stage
0	80%	100%	0%	0%
1	92%	100%	0%	0%
2	95%	50%	40%	10%
3	97%	50%	40%	10%
		Efficiency Improvement	33%	44%

7B.3.1.2 Electricity Consumption Auxiliary Equipment

DOE also included the electricity use of auxiliary equipment, such as condensate pumps and heat tape, which are sometimes installed with higher-efficiency products. The electricity consumption of the auxiliary equipment ($ElecUse_{Aux}$) is added to the total electricity consumption. If a household required a condensate pump, DOE assumed that it consumes 60 watts and operates at the same time as the burner. If a household required heat tape to prevent the condensate withdrawal pipe from freezing, DOE assumed that it consumes 3 watts per square foot (on average 45 watts total) and operates only when the average monthly outside temperature drops below 32°F (see appendix 7C for average temperatures by month by weather station). Details of how DOE determined whether a household required a condensate pump or heat tape can be found in chapter 8.

7B.3.1.3 Non-Heating Furnace Fan Energy Use Differential

The blower, in addition to moving heated air through the house, can operate during the cooling season (summer) if the house is air conditioned and could also operate for a fraction of homes in continuous furnace fan mode throughout the year. Therefore, DOE also considered the difference in electricity consumption of higher-efficiency products during the cooling season and continuous furnace fan operation ($DiffElecUse_{Fan}$).[k] From the 2014 furnace fan final rule, DOE determined that condensing furnaces on average consume 5 percent more electricity to operate the furnace fan during continuous fan and cooling season operation.

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[k] Condensing furnaces tend to have a more restricted airflow path (because of the secondary heat exchanger) than non-condensing furnaces. In general, the furnace fan requires more energy to produce the equivalent airflow output for a condensing furnace compared to a similar non-condensing furnace. The analysis accounts for this additional energy consumption and resulting additional heat released by the furnace fan motor that needs to be compensated by the central air conditioner.

7B.3.2 Standby Mode Electricity Consumption

For this analysis, DOE assumed that furnaces are not usually equipped with an off mode, so only the standby electricity consumption was considered. The Department calculated the standby electricity consumption as:

$$ElecUse_{Stby} = StbyE \times (8760 - BOH - COH - CFOH)$$

Eq. 7B.17

Where:

$StbyE$ = power consumption during standby (kW),
8760 = hours in a year,
BOH = burner operating hours,
COH = cooling operating hours, and
$CFOH$ = continuous fan operating hours.

DOE calculated the standby electricity consumption for each standby mode efficiency level described in chapter 5 using the base case burner operating hours (BOH). DOE assumed that the standby power was directly related to different furnace fan designs and took into account the furnace fan designs available after the furnace fan energy efficiency standard takes effect on July 3, 2019. The standby power consumption *StbyE* was determined in the engineering analysis described in chapter 5 and as shown in Table 7B.3.4.

Table 7B.3.4 Non-weatherized Gas Furnace and Mobile Home Gas Furnace Standby Mode Power Consumption

Efficiency Level	Description	Standby Mode Power Consumption (W)
Baseline	Linear Power Supply; Standard 40VA Transformer	11
1	Linear Power Supply with LLTX	9.5
2	Switching Mode Power Supply	9.2
3	Switching Mode Power Supply with LLTX	8.5

Cooling operating hours (COH) and continuous fan operating hours (CFOH) were determined for households that use the furnace fan for cooling and continuous fan operations. Details on the calculation of the COH and CFOH can be found below.

7B.3.2.1 Cooling Operating Hours

The annual number of hours that the furnace fan is used for cooling is determined in order to calculate the annual number of hours that the furnace fan is in standby mode. For each sampled building, if the household is reported to use a central air conditioner for cooling, then the annual cooling electricity usage is used to determine the operating hours of the product. DOE determined the annual cooling energy for each sampled household from RECS 2009 and CBECS

2003. DOE divided the annual cooling energy by the capacity of the air conditioner to determine the number of COH. The capacity of the air conditioner is assumed to be the same as the size of the furnace fan determined in section 7B.2.3.2.

7B.3.2.2 Continuous Fan Operation

The number of continuous circulation hours is based on data from two surveys. One survey was conducted in Wisconsin in 2003.[14] The second survey was conducted by the Center for Energy and the Environment (CEE) in Minnesota, the results of which were provided by CEE in a written comment for this standards rulemaking.[15] DOE combined both studies by adding the number of respondents and derived average annual furnace fan continuous circulation operating hours from the combined surveys, as shown in Table 7B.3.5.

DOE assumed a value for the average number of fan continuous circulation hours for each survey response, similar to what is assumed in the proposed furnace fan test procedure. For "no constant circulation" responses, DOE assumed zero continuous circulation hours. For "year-round" responses, DOE assumed 100 percent of non-heating or cooling furnace fan operating hours, which DOE calculated by subtracting furnace fan heating and cooling operating hours from the total annual hours (8,760). For "during heating season" responses, DOE assumed 15 percent of non-heating or cooling furnace fan operating hours. For "during cooling season" responses, DOE assumed 15 percent of non-heating or cooling furnace fan operating hours. For other or "some constant circulation" responses, DOE assumed 5 percent of non-heating or cooling furnace fan operating hours.

DOE did not use these data directly, because it believes they are not representative of consumer practices for the United States as a whole. In Wisconsin and Minnesota, many homes have low air infiltration, and there is a high awareness of indoor air quality issues, which leads to significant use of constant circulation. To account for this, DOE developed separate regional fractions that took into account information from manufacturer product literature and regional climate conditions. Furnace fan manufacturer literature states that constant circulation fan operation is not recommended for humid climates.

Table 7B.3.5 Results from Continuous Circulation Use Studies and Estimated National Continuous Circulation Practices

How Often is Constant Circulation Fan Used?	Combined Data from Studies		Estimated North Shares for LCC Analysis	Estimated Rest of Country Shares for LCC Analysis
	Number of Households	Percentage (%)		
No constant fan	69	68%	84%	97%
Year-round	14	14%	7.0%	1.5%
Heating or cooling season	8	8%	4.0%	1.0%
Part of Year	10	10%	5.0%	1.0%
Total	101	100%	100%	100%

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APPENDIX 7C. MAPPING OF WEATHER STATION DATA TO RECS AND CBECS BUILDINGS

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7C.1 INTRODUCTION

The Energy Information Administration's (EIA) 2009 Residential Energy Consumption Survey (RECS 2009)[1] and EIA's 2003 Commercial Building Energy Consumption Survey (CBECS 2003)[2] provide annual data on heating and cooling degree-days but not on other weather parameters needed for the analysis such as heating and cooling outdoor design temperature (ODT), monthly heating degree days (HDD) and monthly cooling degree days (CDD), and average outdoor temperature. ODTs are used for sizing non-weatherized gas furnace (NWGF) and mobile home gas furnace (MHGF) products as described in appendix 7B. Energy price data used in this analysis are available on a monthly basis. Monthly HDD 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 (see appendix 7B and appendix 8E). Average monthly outdoor temperature where used to determine hours of operation of heat tape as described in appendix 7B and appendix 8D.

7C.2 MAPPING METHODOLOGY

To derive the additional weather data that is needed for the analysis (e.g. ODT, monthly HDD), for each building in the sample, DOE developed an approach to assign a physical location to each RECS household and CBECS building. [a] The methodology consists of the following steps:

1. DOE assembled monthly weather data from 360 weather stations from the National Oceanic and Atmospheric Administration (NOAA) that provide the heating and cooling degree-days at base temperature 65°F for year 2009 (for the RECS sample) and year 2003 (for the CBECS sample), for these weather stations.[3] The 2009 and 2003 heating and cooling degree days match the period used to determine the degree-days in RECS 2009 and in CBECS 2003, respectively.
2. DOE gathered ODT data from the 1993 ASHRAE Handbook and only selected the weather stations for which NOAA provided HDD and CDD, which reduced the number of weather stations used in the matching process to 339.[4]
3. RECS and CBECS report both HDD and CDD to base temperature 65°F for each building record. DOE assigned each building to one of the 339 weather stations by calculating which weather station (within the appropriate region) was the closest using the best linear least squares fit of the RECS/CBECS data to the weather data. Eq. 7C.1 calculates the U.S. weather station closest (or with minimum "distance") to the RECS/CBECS 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 RECS/CBECS data,
CDD_1 = cooling degree days from U.S. weather data, and
CDD_2 = cooling degree days from RECS/CBECS data.

7C.3 MAPPING RESULTS

Table 7C.3.1 shows the imputation results for all RECS and CBECS locations. Note that some U.S. weather station data match with several of the RECS/CBECS weather data. The number of RECS/CBECS buildings that were matched to the specified weather station is indicated in the column "Count". Table 7C.3.1 shows the data matches (321 weather stations) including the heating and cooling ODT as well as annual average outdoor temperature for the weather stations.

Table 7C.3.1 Weather Station Mapping Statistics, Heating and Cooling ODT, and Average Outdoor Temperature

Station Location		Code	RECS 2009			CBECS 2003			Heating ODT	Cooling ODT	Average Outdoor Temp
State	City		HDD	CDD	Count	HDD	CDD	Count			
AK	Anchorage	ANC	10335	2	8	9300	25	1	-18	68	36
AK	Bethel	BET	12530	0	1	11261	14	1	-24	68	30
AK	Cold Bay	CDB	9668	0	2	-	-	-	10	57	38
AK	Cordova	CDV	9511	0	2	8332	0	1	1	67	38
AK	Homer	HOM	9817	0	10	-	-	-	4	62	38
AK	Juneau	JNU	8536	6	2	8198	2	1	1	70	42
AK	Kenai	ENA	10423	0	1	-	-	-	-14	65	36
AK	Ketchikan	KTN	7359	68	2	7160	0	11	20	68	38
AK	King Salmon	AKN	11088	0	1	9773	10	1	-19	67	35
AK	Kodiak	ADQ	8903	0	1	8051	15	1	13	65	41
AK	Sitka	SIT	-	-	-	6515	2	3	21	64	42
AK	St Paul Island	SNP	11420	0	4	-	-	-	3	52	35
AK	Talkeetna	TKA	-	-	-	8824	85	1	-21	73	34
AK	Valdez	VWS	7074	23	2	-	-	-	7	66	38
AK	Yakutat	YAK	9295	1	1	-	-	-	2	63	40
AL	Birmingham	BHM	2605	1958	25	2664	1874	20	21	93	62
AL	Huntsville	HSV	2982	1863	26	3121	1633	24	16	92	61
AL	Mobile	MOB	1594	2681	59	1667	2695	6	29	92	67
AL	Montgomery	MGM	2137	2367	3	2248	2212	9	25	94	65
AL	Muscle Shoals	MSL	2948	1773	12	3138	1533	9	21	93	61
AL	Tuscaloosa	TCL	2349	2136	10	2510	2047	13	23	93	64

Station Location		Code	RECS 2009			CBECS 2003			Heating ODT	Cooling ODT	Average Outdoor Temp
State	City		HDD	CDD	Count	HDD	CDD	Count			
AR	Fayetteville	FYV	3957	1185	48	4017	1202	12	12	93	58
AR	Fort Smith	FSM	3174	1906	3	-	-	-	17	96	61
AR	Little Rock	LIT	2946	1943	27	-	-	-	20	95	62
AR	Texarkana	TXK	2573	2006	10	2259	2573	5	23	96	61
AZ	Douglas	DUG	2160	2204	27	2340	2206	7	31	98	61
AZ	Flagstaff	FLG	6741	176	2	-	-	-	4	83	46
AZ	Phoenix	PHX	807	4942	26	702	4975	24	34	108	74
AZ	Tucson	TUS	1268	3626	85	1279	3480	15	32	104	69
AZ	Winslow	INW	4233	1395	4	4377	1459	16	10	93	55
AZ	Yuma	NYL	671	4757	82	558	4747	16	39	109	75
CA	Bakersfield	BFL	1873	2644	177	1931	2692	25	32	101	65
CA	Blythe	BLH	968	4580	8	853	4649	4	33	112	71
CA	Eureka	EKA	5137	2	2	4670	12	3	33	65	53
CA	Fresno	FAT	2239	2390	50	2147	2412	48	30	101	63
CA	Los Angeles	LAX	1294	569	117	1237	677	99	43	80	63
CA	Mt Shasta	MHS	5474	433	5	5294	418	24	21	88	49
CA	Paso Robles	PRB	2676	1095	144	2699	1219	14	29	98	58
CA	Red Bluff	RBL	2452	2122	70	2635	2097	8	32	102	62
CA	Redding	RDD	2750	2086	63	-	-	-	31	102	62
CA	Sacramento	SAC	2531	1357	30	2417	1463	49	32	98	61
CA	San Diego	SAN	1050	813	540	1060	724	98	44	81	64
CA	San Francisco	SFO	2614	220	278	2494	269	64	38	78	57
CA	Stockton	SCK	2451	1468	122	2497	1525	21	30	98	62
CO	Alamosa	ALS	8229	49	27	7762	151	4	-16	82	41
CO	Colorado Spring	COS	6301	356	90	5846	603	4	2	88	48
CO	Denver	DEN	5988	541	69	5796	800	6	1	92	50
CO	Eagle	EGE	7593	124	15	6889	369	5	-7	86	41
CO	Pueblo	PUB	5427	818	77	4891	1115	2	0	96	52
CO	Trinidad	TAD	5323	719	17	5109	944	31	3	90	51
CT	Bridgeport	BDR	5484	669	57	5800	824	47	9	85	52
CT	Hartford	BDL	6072	610	94	6359	723	32	7	88	50
DC	Washington	DCA	4124	1427	39	4338	1288	49	17	93	58
DE	Wilmington	ILG	4789	1031	14	5206	1010	15	14	89	54
FL	Daytona Beach	DAB	753	3321	99	849	3153	35	35	91	71
FL	Fort Myers	FMY	294	4151	63	370	4062	28	44	93	75
FL	Ft Lauderdale	FLL	118	4839	30	194	4622	10	46	91	75
FL	Gainesville	GNV	1181	2789	118	1288	2700	26	31	92	69
FL	Jacksonville	JAX	1339	2772	60	1450	2605	8	32	93	68
FL	Key West	EYW	108	5017	11	127	5071	11	57	89	78
FL	Melbourne	MLB	526	3718	80	632	3469	16	43	91	73
FL	Miami	MIA	109	4914	2	166	4721	9	47	91	77
FL	Orlando	MCO	588	3620	103	661	3528	11	38	93	73
FL	Pensacola	PNS	1443	2729	44	1565	2642	10	29	92	68
FL	Tallahassee	TLH	1574	2802	31	1673	2538	2	30	94	68
FL	Tampa	TPA	496	3876	112	639	3666	39	40	91	73
FL	Vero Beach	VRB	477	3604	26	544	3582	16	43	91	73

Station Location		Code	RECS 2009			CBECS 2003			Heating ODT	Cooling ODT	Average Outdoor Temp
State	City		HDD	CDD	Count	HDD	CDD	Count			
FL	West Palm Beach	PBI	239	4314	169	294	4388	26	45	90	75
GA	Albany	ABY	1767	2686	5	-	-	-	29	95	66
GA	Athens	AHN	2882	1903	253	2831	1564	45	22	93	62
GA	Atlanta	ATL	2813	1838	87	2732	1614	33	22	92	62
GA	Augusta	AGS	2475	2068	55	2561	1820	9	23	95	63
GA	Brunswick	SSI	-	-	-	1557	2513	15	32	91	69
GA	Columbus	CSG	2183	2194	2	2053	2284	2	24	94	65
GA	Macon	MCN	2288	2133	17	2261	2195	34	25	94	64
GA	Savannah	SAV	1739	2497	21	1851	2434	5	27	93	66
GA	Waycross	AYS				1424	2689	17	29	94	67
HI	Hilo-Hawaii	ITO	0	3050	14	0	3669	7	62	85	74
HI	Honolulu-Oahu	HNL	0	4816	14	0	5030	4	63	89	78
HI	Kahului-Maui	OGG	1	3746	21	0	4270	2	61	88	76
HI	Lihue-Kauai	LIH	2	3611	5	0	4136	3	62	85	76
IA	Burlington	BRL	5687	810	24	6031	870	10	-3	91	50
IA	Cedar Rapids	CID	6977	419	15	6861	721	17	-5	89	47
IA	Des Moines	DSM	6124	898	33	6263	1130	2	-5	90	50
IA	Dubuque	DBQ	7204	345	1	7189	602	10	-7	86	47
IA	Mason City	MCW	7856	338	15	7699	556	16	-11	88	47
IA	Ottumwa	OTM	6317	588	43	6335	883	12	-4	92	50
IA	Sioux City	SUX	6913	678	75	6699	833	17	-7	90	48
IA	Waterloo	ALO	7253	448	58	6962	849	8	-10	89	47
ID	Boise	BOI	5592	1199	9	4877	1316	1	10	95	52
ID	Burley	BYI	6697	397	1	5978	568	15	2	90	47
ID	Idaho Falls	IDA	-	-	-	7069	409	8	-6	89	47
ID	Lewiston	LWS	5386	1008	3	4803	1081	15	6	94	52
ID	Pocatello	PIH	7463	321	17	6443	675	16	-1	91	47
IL	Chicago	ORD	6417	585	40	6446	697	37	0	90	49
IL	Moline	MLI	6250	636	35	6207	933	17	-4	91	50
IL	Peoria	PIA	5841	752	62	5846	906	46	-4	90	51
IL	Quincy	UIN	5460	849	12	5580	938	7	3	90	51
IL	Rockford	RFD	6738	433	58	6738	732	52	-4	89	48
IL	Springfield	SPI	5234	933	41	5549	916	10	2	91	53
IN	Evansville	EVV	4397	1283	13	4530	1143	22	9	92	56
IN	Fort Wayne	FWA	6077	601	41	6481	576	24	1	88	50
IN	Indianapolis	IND	5203	953	22	5551	883	7	2	89	53
IN	South Bend	SBN	6426	545	54	6416	626	10	1	88	50
IN	West Lafayette	LAF	5436	826	32	5690	825	32	3	90	50
KS	Concordia	CNK	5558	1094	18	5231	1465	14	3	96	54
KS	Dodge City	DDC	4975	1257	27	4926	1490	8	5	97	55
KS	Garden City	GCK	5014	1154	31	5025	1367	24	4	97	55
KS	Goodland	GLD	6016	722	11	5494	1096	22	0	94	51
KS	Russell	RSL	5298	1194	46	5157	1459	3	4	96	54
KS	Salina	SLN	-	-	-	4608	1771	8	5	98	56
KS	Topeka	TOP	4968	1195	9	4887	1499	21	4	94	54
KS	Wichita	ICT	4552	1506	68	4502	1620	56	7	97	56

Station Location		Code	RECS 2009			CBECS 2003			Heating ODT	Cooling ODT	Average Outdoor Temp
State	City		HDD	CDD	Count	HDD	CDD	Count			
KY	Bowling Green	BWG	3808	1407	52	4087	1183	34	10	91	57
KY	Jackson	JKL	4237	984	15	4299	917	5	14	87	56
KY	Lexington	LEX	4670	1020	40	4750	954	8	8	89	55
KY	Louisville	SDF	4155	1316	29	4201	1307	9	10	91	57
KY	Paducah	PAH	4198	1239	39	4365	1258	10	12	93	57
LA	Baton Rouge	BTR	1404	2985	24	1683	2674	17	29	93	67
LA	Lafayette	LFT	1296	3086	3	1581	2787	14	30	93	68
LA	Lake Charles	LCH	1380	2980	10	1525	2823	18	31	93	68
LA	Monroe	MLU	2118	2547	11	2381	2353	7	25	95	66
LA	New Orleans	MSY	1156	3221	35	1327	3162	11	33	92	69
LA	Shreveport	SHV	-	-	-	2143	2504	3	25	95	66
MA	Boston	BOS	5694	581	243	6067	745	13	9	87	52
MA	Worcester	ORH	6699	370	258	7006	479	32	4	83	47
MD	Baltimore	BWI	4745	1088	34	5010	1020	22	13	91	55
MD	Salisbury	SBY	4345	1149	19	4870	1010	55	16	90	57
ME	Augusta	AUG	7487	276	18	7746	420	11	23	95	63
ME	Bangor	BGR	8098	246	19	8161	403	21	-6	84	46
ME	Caribou	CAR	9415	149	13	9754	214	2	-13	82	39
ME	Houlton	HUL	9316	178	24	9458	238	3	-13	85	40
ME	Portland	PWM	7107	294	108	7508	355	21	-1	83	46
MI	Alpena	APN	-	-	-	8468	241	7	-6	84	43
MI	Detroit	DTW	6224	588	81	6398	659	19	6	87	50
MI	Flint	FNT	7068	328	40	6891	494	22	1	86	47
MI	Grand Rapids	GRR	6580	444	35	7030	487	17	5	86	48
MI	Houghton Lake	HTL	-	-	-	8311	197	1	1	85	43
MI	Jackson	JXN	6585	420	11	6955	392	2	14	87	56
MI	Lansing	LAN	6830	372	36	7239	385	10	1	86	47
MI	Marquette	MQT	-	-	-	9288	248	3	-8	83	39
MI	Muskegon	MKG	6719	371	38	6740	516	32	6	83	47
MI	Saginaw	MBS	6960	350	19	7313	406	8	4	87	47
MI	Sault St Marie	SSM	-	-	-	8809	168	2	-8	80	40
MI	Traverse City	TVC	7695	253	14	7826	345	13	1	86	47
MN	Alexandria	AXN	8922	340	8	8675	553	9	-16	86	42
MN	Duluth	DLH	9517	118	10	-	-	-	-16	81	39
MN	Hibbing	HIB	10159	64	4	-	-	-	-20	81	37
MN	Int'l Falls	INL	10648	72	8	10115	220	5	-25	83	37
MN	Minneapolis	MSP	7613	646	48	7538	880	3	-12	88	45
MN	Rochester	RST	7884	321	9	7957	512	16	-12	85	43
MN	Saint Cloud	STC	8704	301	74	8489	496	2	-11	88	42
MO	Columbia	COU	4999	958	125	5010	1151	5	4	92	54
MO	Joplin	JLN	4216	1382	98	3974	1677	11	10	94	56
MO	Kansas City	MCI	5084	1093	213	-	-	-	6	93	54
MO	Saint Louis	STL	4438	1457	70	4445	1485	3	6	93	56
MO	Springfield	SGF	4596	1114	180	4529	1321	6	2	91	53
MS	Greenwood	GWO	2376	2250	1	-	-	-	20	94	61
MS	McComb	MCB	1833	2472	34	-	-	-	26	92	64

Station Location		Code	RECS 2009			CBECS 2003			Heating ODT	Cooling ODT	Average Outdoor Temp
State	City		HDD	CDD	Count	HDD	CDD	Count			
MS	Tupelo	TUP	2842	1947	20	3002	1722	4	19	94	61
MT	Billings	BIL	6948	627	9	-	-	-	-10	90	47
MT	Butte	BTM	-	-	-	8967	180	6	-17	84	40
MT	Cut Bank	CTB	-	-	-	8419	313	6	-20	84	40
MT	Great Falls	GTF	7941	300	1	7431	576	5	-15	89	44
MT	Havre	HVR	-	-	-	8190	683	6	-11	90	44
MT	Helena	HLN	7704	444	1	7066	798	2	-16	87	44
MT	Kalispell	FCA	-	-	-	7681	317	2	-7	86	43
MT	Lewistown	LWT	-	-	-	7878	493	4	-16	86	44
MT	Miles City	MLS	7700	716	1	-	-	-	-15	93	46
MT	Missoula	MSO	7588	355	2	7073	518	1	-6	88	45
NC	Asheville	AVL	4194	768	23	-	-	-	14	86	55
NC	Cape Hatteras	HAT	-	-	-	2446	1687	30	29	86	63
NC	Charlotte	CLT	3346	1611	71	3311	1308	50	22	91	61
NC	Greensboro	GSO	3605	1510	41	3622	1210	28	18	90	58
NC	Hickory	HKY	3593	1353	42	3703	1032	31	18	90	58
NC	New Bern	EWN	2769	1788	16	2797	1818	25	24	92	64
NC	Raleigh Durham	RDU	3164	1865	55	3413	1459	42	20	92	60
NC	Wilmington	ILM	2521	1937	14	2625	1864	2	14	89	54
ND	Bismarck	BIS	9130	332	16	8505	738	9	-19	90	42
ND	Devil's Lake	P11	10245	236	8	9544	454	3	-21	87	40
ND	Fargo	FAR	9304	362	17	8862	616	17	-18	88	42
ND	Grand Forks	GFK	9928	269	8	9575	417	3	-22	89	40
ND	Minot	MOT	9559	314	9	9066	609	20	-20	89	41
ND	Williston	ISN	9721	297	8	9603	670	14	-21	92	41
NE	Grand Island	GRI	6431	788	26	5942	1059	16	-3	93	50
NE	Lincoln	LNK	6159	912	14	6027	1131	5	-2	94	51
NE	Norfolk	OFK	6789	643	4	6312	962	8	-4	92	49
NE	North Platte	LBF	6946	534	14	6249	926	2	-4	92	49
NE	Omaha	OMA	6288	851	32	6130	1158	3	-3	90	51
NE	Scottsbluff	BFF	6689	579	6	6293	867	4	-3	92	48
NE	Valentine	VTN	7279	527	2	6861	917	4	-8	94	47
NH	Concord	CON	7462	325	5	7666	541	2	-3	87	46
NH	Lebanon	LEB	7312	371	18	8434	362	6	-3	86	46
NJ	Atlantic City	ACY	4693	994	57	5328	1012	58	13	89	54
NJ	Newark	EWR	4790	1021	147	5165	1098	38	14	91	55
NM	Albuquerque	ABQ	3823	1435	17	-	-	-	16	93	57
NM	Carlsbad	CNM	2398	2376	2	-	-	-	19	98	63
NM	Clayton	CAO	4517	1143	31	4390	1025	9	9	91	53
NM	Gallup	GUP	6134	442	6	5827	550	8	5	87	53
NM	Roswell	ROW	3098	1961	7	-	-	-	18	96	61
NV	Elko	EKO	6948	450	1	6266	597	25	-2	92	46
NV	Ely	ELY	7925	125	4	6856	404	8	-4	87	45
NV	Las Vegas	LAS	1882	3818	66	1882	3846	41	28	106	68
NV	Lovelock	LOL	-	-	-	5463	975	8	12	97	50
NV	Reno	RNO	-	-	-	4556	1184	11	10	92	51

Station Location		Code	RECS 2009			CBECS 2003			Heating ODT	Cooling ODT	Average Outdoor Temp
State	City		HDD	CDD	Count	HDD	CDD	Count			
NV	Tonopah	TPH	5298	874	5	5102	1127	4	10	92	51
NV	Winnemucca	WMC	6236	611	2	5696	736	13	3	94	49
NY	Albany	ALB	6644	433	149	7023	613	12	29	95	66
NY	Binghamton	BGM	7067	261	59	7580	316	3	1	82	46
NY	Buffalo	BUF	6651	361	54	6909	429	18	6	84	48
NY	Glens Falls	GFL	7612	285	26	8024	376	15	-5	85	46
NY	Massena	MSS	7980	298	2	8752	381	6	-8	84	46
NY	New York	LGA	4647	1041	469	5025	1155	43	15	89	55
NY	Rochester	ROC	6765	315	46	6986	477	9	-12	85	43
NY	Syracuse	SYR	6687	439	23	6939	522	15	2	86	47
NY	Utica	UCA	-	-	-	7580	386	33	-6	85	47
NY	Watertown	ART	7707	298	11	8018	379	5	-6	83	46
OH	Akron Canton	CAK	6131	497	6	6361	543	17	6	86	50
OH	Cincinnati	CVG	4950	874	13	5229	838	70	6	90	54
OH	Cleveland	CLE	5833	664	44	6077	685	50	5	87	50
OH	Columbus	CMH	5243	874	32	5504	765	46	24	94	65
OH	Dayton	DAY	5602	732	45	5832	676	65	4	88	52
OH	Findlay	FDY	5901	698	34	6156	643	52	3	87	50
OH	Mansfield	MFD	6214	468	10	6493	476	7	5	85	49
OH	Toledo	TOL	6283	592	32	6311	630	34	1	88	50
OH	Youngstown	YNG	6239	443	8	6566	394	6	4	86	49
OK	Hobart	HBR	3392	2034	1	3439	2129	6	16	101	60
OK	McAlester	MLC	3136	1845	6	3082	1973	47	19	96	60
OK	Oklahoma City	OKC	3519	1849	37	3529	1881	46	13	96	60
OK	Tulsa	TUL	3608	1885	24	3473	2053	13	13	97	61
OR	Astoria	AST	4871	39	4	-	-	-	29	72	51
OR	Baker	BKE	7529	220	2	6650	315	30	6	91	45
OR	Eugene	EUG	4999	331	89	4269	350	6	22	88	52
OR	Medford	MFR	-	-	-	4002	1060	4	23	95	54
OR	Pendleton	PDT	5713	720	6	4739	895	32	5	93	52
OR	Portland	PDX	4357	635	32	3908	623	13	-1	83	46
OR	Redmond	RDM	6737	313	17	6020	353	41	9	90	44
OR	Salem	SLE	4660	457	50	4162	467	4	23	88	53
PA	Allentown	ABE	5725	622	22	5935	797	61	9	88	51
PA	Altoona	AOO	6109	433	17	6515	439	12	5	86	50
PA	Bradford	BFD	-	-	-	8029	125	1	-1	80	50
PA	Du Bois	DUJ	6753	254	5	7092	243	9	5	84	50
PA	Erie	ERI	6183	423	9	6496	489	42	9	84	50
PA	Harrisburg	CXY	5097	866	111	5534	856	76	11	90	53
PA	Philadelphia	PHL	4557	1219	46	4894	1269	106	14	90	55
PA	Pittsburgh	PIT	5661	617	6	5892	587	51	5	87	51
PA	Williamsport	IPT	5636	644	69	6233	611	62	7	87	50
RI	Providence	PVD	5717	579	69	5961	742	13	9	86	51
SC	Charleston	CHS	1941	2390	13	1981	2272	3	27	93	65
SC	Columbia	CAE	2561	2220	19	2562	1908	33	4	92	54
SC	Florence	FLO	2541	2061	13	2644	1839	11	25	94	64

Station Location		Code	RECS 2009			CBECS 2003			Heating ODT	Cooling ODT	Average Outdoor Temp
State	City		HDD	CDD	Count	HDD	CDD	Count			
SC	Greenville	GSP	3116	1735	42	3108	1379	58	22	91	60
SD	Aberdeen	ABR	8872	329	13	8324	605	33	-15	91	44
SD	Huron	HON	8070	469	105	7598	860	7	-14	91	45
SD	Pierre	PIR	7738	577	36	7200	961	5	-10	95	48
SD	Rapid City	RAP	7738	362	12	7034	905	5	-7	91	47
SD	Sioux Falls	FSD	7670	481	42	7463	724	17	-11	90	45
TN	Bristol	TRI	4267	930	28	4294	860	1	14	87	55
TN	Chattanooga	CHA	3168	1808	35	3206	1498	34	18	92	60
TN	Crossville	CSV	4100	940	33	4240	839	4	15	87	54
TN	Jackson	MKL	3379	1597	22	3603	1394	14	14	87	56
TN	Knoxville	TYS	3643	1392	91	3584	1282	34	19	90	58
TN	Memphis	MEM	2906	2091	3	2954	1961	17	18	94	62
TN	Nashville	BNA	3615	1558	37	3595	1449	23	14	92	59
TX	Abilene	ABI	2359	2494	217	2366	2374	3	20	97	64
TX	Alice	ALI	738	4832	23	1022	3628	28	34	99	72
TX	Amarillo	AMA	4034	1340	33	3787	1410	43	11	95	57
TX	Austin	AUS	1722	3214	45	1888	2793	4	28	96	69
TX	Brownsville	BRO	525	4300	20	587	4025	8	39	94	73
TX	College Station	CLL	1404	3476	29	1662	2965	34	29	96	69
TX	Corpus Christi	CRP	811	4058	8	968	3462	8	35	94	72
TX	Dallas-Ft. Worth	DFW	2097	2745	61	2239	2752	25	22	98	66
TX	Del Rio	DRT	1252	3807	29	1338	3406	16	31	98	70
TX	El Paso	ELP	2106	2783	43	2207	2696	4	24	98	65
TX	Galveston	GLS	907	3640	3	1058	3343	17	36	91	71
TX	Houston	IAH	1267	3410	170	1386	3185	20	32	96	69
TX	Laredo	LRD	602	5330	1	826	4348	37	36	101	73
TX	Lubbock	LBB	3178	1965	10	2960	1950	28	15	96	60
TX	Lufkin	LFK	1803	2839	64	1966	2600	7	29	95	69
TX	McAllen	MFE	393	5387	3	707	4415	26	39	99	73
TX	Midland Odessa	MAF	2495	2445	81	2366	2509	15	21	98	63
TX	San Angelo	SJT	2020	2814	56	-	-	-	22	97	65
TX	San Antonio	SAT	1270	3598	28	1485	3039	25	30	97	69
TX	Victoria	VCT	1123	3608	35	1270	3217	10	32	95	70
TX	Waco	ACT	1927	3086	18	1975	2776	16	26	99	67
TX	Wichita Falls	SPS	2838	2394	14	2752	2485	20	18	100	63
UT	Cedar City	CDC	6058	645	56	5606	810	17	5	91	52
UT	Salt Lake City	SLC	5716	1147	29	-	-	-	8	95	52
VA	Lynchburg	LYH	4433	1003	159	4434	884	6	16	90	55
VA	Norfolk	ORF	3330	1659	41	3279	1761	51	-4	92	49
VA	Richmond	RIC	3781	1564	47	3971	1336	51	17	92	58
VA	Roanoke	ROA	3931	1173	34	4216	1002	10	16	90	56
VT	Burlington	BTV	-	-	-	7833	576	1	-3	91	50
VT	Montpelier	MPV	7998	237	12	8793	305	13	-6	83	45
WA	Bellingham	BLI	5568	115	8	5124	54	5	15	76	51
WA	Olympia	OLM	5614	178	24	-	-	-	22	83	50
WA	Quillayute	UIL	5869	44	7	5411	20	2	27	74	49

Station Location		Code	RECS 2009			CBECS 2003			Heating ODT	Cooling ODT	Average Outdoor Temp
State	City		HDD	CDD	Count	HDD	CDD	Count			
WA	Seattle Tacoma	SEA	4879	319	94	4509	277	11	26	81	52
WA	Spokane	GEG	6942	599	5	-	-	-	2	89	47
WA	Walla Walla	ALW	5062	1144	12	-	-	-	7	95	54
WA	Yakima	YKM	6204	699	25	-	-	-	5	92	49
WI	Eau Claire	EAU	8208	333	23	7949	623	20	-11	87	44
WI	Green Bay	GRB	8005	275	55	7878	386	18	-9	85	44
WI	Lacrosse	LSE	7334	536	16	7126	854	14	-9	89	47
WI	Madison	MSN	7343	368	66	7356	560	58	-7	87	46
WI	Milwaukee	MKE	6816	474	28	7058	601	48	-4	87	48
WI	Wausau	AUW	8337	277	54	8299	466	14	-12	85	44
WV	Beckley	BKW	5325	404	16	5439	487	2	4	84	52
WV	Charleston	CRW	4443	960	3	4628	789	3	27	93	65
WV	Elkins	EKN	5993	284	3	6291	322	2	6	83	50
WV	Huntington	HTS	4557	922	3	4487	881	6	10	89	55
WV	Martinsburg	MRB	5046	854	63	5411	783	19	10	91	54
WV	Morgantown	MGW	4957	836	15	5358	628	1	8	87	54
WV	Parkersburg	PKB	4910	850	19	5138	729	4	11	88	54
WY	Casper	CPR	-	-	-	7192	587	6	-5	91	45
WY	Cheyenne	CYS	7390	203	11	6680	577	11	-1	86	45
WY	Cody	COD	7551	410	2	6992	686	7	-13	87	45
WY	Lander	LND	7743	351	1	-	-	-	-11	87	45
WY	Rock Springs	RKS	8204	230	3	7574	540	2	-3	84	43
WY	Sheridan	SHR	7844	287	2	7401	652	5	-8	90	45
WY	Worland	WRL	7757	467	2	-	-	-	-13	93	45

7C.3.1 Developing Monthly Heating and Cooling Degree Day Fractions

Table 7C.3.2 and Table 7C.3.3 show the 10-year average monthly HDD and CDD data based on NOAA data for each weather station.[3] This data was then used to determine the monthly fractions of HDD and CDD as shown in Table 7C.3.4 and Table 7C.3.5. Monthly HDD are used to disaggregate the annual energy use provided by RECS and CBECS by month. The monthly energy use is then combined with monthly energy prices to find the monthly operating cost (see appendix 7B and appendix 8E for more details).

Table 7C.3.2 Weather Station Monthly Heating Degree Day Data (10-Year Average)

Station Location		Code	Monthly Heating Degree Days											
State	City		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
AK	Anchorage	ANC	1558	1202	1238	824	510	292	184	234	464	855	1316	1421
AK	Bethel	BET	1914	1447	1684	1155	661	355	273	318	547	1004	1477	1690
AK	Cold Bay	CDB	1167	971	1177	939	755	559	440	388	497	744	944	1068
AK	Cordova	CDV	1225	1001	1074	797	594	413	321	330	490	762	1064	1127
AK	Homer	HOM	1314	1052	1163	829	622	436	320	337	487	786	1127	1201

Station Location		Code	Monthly Heating Degree Days											
State	City		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
AK	Juneau	JNU	1138	971	1006	720	492	310	248	280	444	707	980	1110
AK	Kenai	ENA	1608	1223	1285	838	560	362	248	292	478	828	1303	1439
AK	Ketchikan	KTN	930	823	861	666	479	298	212	203	349	600	805	924
AK	King Salmon	AKN	1632	1199	1427	932	620	406	299	307	505	886	1342	1474
AK	Kodiak	ADQ	1090	928	1063	806	621	442	313	294	454	724	969	1059
AK	Sitka	SIT	895	787	868	670	513	354	258	233	345	577	779	876
AK	St Paul Island	SNP	1277	1131	1314	1086	910	671	552	489	572	802	965	1127
AK	Talkeetna	TKA	1636	1267	1281	836	494	234	155	239	504	909	1394	1529
AK	Valdez	VWS	1212	912	952	622	371	194	136	154	319	594	996	1036
AK	Yakutat	YAK	1144	966	1045	796	602	404	297	316	462	719	987	1086
AL	Birmingham	BHM	635	502	261	105	21	0	0	0	4	114	312	563
AL	Huntsville	HSV	722	578	324	135	25	0	0	0	9	145	371	641
AL	Mobile	MOB	427	331	143	45	4	0	0	0	0	55	201	385
AL	Montgomery	MGM	543	417	198	70	9	0	0	0	2	80	265	481
AL	Muscle Shoals	MSL	716	576	317	135	25	0	0	0	7	149	366	640
AL	Tuscaloosa	TCL	606	477	234	95	16	0	0	0	2	110	299	539
AR	Fayetteville	FYV	859	724	446	230	76	2	0	1	32	233	458	803
AR	Fort Smith	FSM	745	599	313	120	26	0	0	0	4	122	343	685
AR	Little Rock	LIT	708	579	310	114	22	0	0	0	3	122	341	654
AR	Texarkana	TXK	606	488	240	84	15	0	0	0	1	96	274	559
AZ	Douglas	DUG	555	426	298	118	14	0	0	0	0	70	307	571
AZ	Flagstaff	FLG	1066	946	828	640	389	136	13	36	202	533	797	1085
AZ	Phoenix	PHX	234	172	63	11	0	0	0	0	0	4	68	283
AZ	Tucson	TUS	342	280	143	44	2	0	0	0	0	15	140	381
AZ	Winslow	INW	918	716	526	311	97	4	0	0	20	256	586	913
AZ	Yuma	NYL	148	128	46	13	0	0	0	0	0	2	54	227
CA	Bakersfield	BFL	484	327	217	133	21	2	0	0	1	51	274	491
CA	Blythe	BLH	271	191	73	13	0	0	0	0	0	5	105	337
CA	Eureka	EKA	557	513	527	496	414	314	276	258	308	365	467	579
CA	Fresno	FAT	527	367	250	146	25	1	0	0	2	52	289	518
CA	Los Angeles	LAX	215	220	200	152	68	13	2	2	4	33	124	251
CA	Mt Shasta	MHS	876	754	707	568	322	126	11	20	114	414	704	908
CA	Paso Robles	PRB	507	418	341	257	89	22	2	2	17	123	344	535
CA	Red Bluff	RBL	530	408	325	218	54	7	0	0	4	86	343	558
CA	Redding	RDD	551	423	351	241	61	9	0	0	5	100	374	583
CA	Sacramento	SAC	544	397	307	211	56	8	0	0	6	84	340	549
CA	San Diego	SAN	214	196	157	107	47	14	2	0	0	15	105	243
CA	San Francisco	SFO	438	344	308	262	187	105	61	52	53	104	266	427
CA	Stockton	SCK	549	393	299	190	45	5	0	0	3	72	327	541
CO	Alamosa	ALS	1432	1202	914	655	390	139	25	63	283	642	1012	1438
CO	Colorado Spring	COS	1025	942	712	503	259	57	7	19	133	443	736	1074
CO	Denver	DEN	1016	946	687	487	252	54	4	10	107	422	727	1075
CO	Eagle	EGE	1322	1086	854	621	367	112	8	26	223	567	918	1305
CO	Pueblo	PUB	1020	895	623	393	151	17	1	4	71	377	698	1062
CO	Trinidad	TAD	960	861	626	412	176	26	2	6	79	357	665	1005
CT	Bridgeport	BDR	1076	920	758	432	190	27	0	1	35	283	544	886

Station Location		**Code**	**Monthly Heating Degree Days**											
State	**City**		**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
CT	Hartford	BDL	1204	1013	811	441	195	32	1	5	74	376	649	1007
DC	Washington	DCA	885	753	520	245	68	3	0	0	9	191	438	755
DE	Wilmington	ILG	1000	867	639	341	124	13	0	1	26	274	529	849
FL	Daytona Beach	DAB	240	173	75	21	1	0	0	0	0	11	60	172
FL	Fort Myers	FMY	119	65	24	3	0	0	0	0	0	3	15	75
FL	Ft Lauderdale	FLL	61	34	11	1	0	0	0	0	0	0	4	37
FL	Gainesville	GNV	345	249	116	37	1	0	0	0	0	28	120	279
FL	Jacksonville	JAX	385	287	140	51	3	0	0	0	0	32	148	313
FL	Key West	EYW	42	19	5	0	0	0	3	0	0	0	1	16
FL	Melbourne	MLB	181	117	49	15	0	0	0	0	0	9	35	116
FL	Miami	MIA	54	29	8	1	0	0	0	0	0	0	3	31
FL	Orlando	MCO	196	124	48	11	0	0	0	0	0	9	40	134
FL	Pensacola	PNS	394	306	128	36	1	0	0	0	0	36	159	344
FL	Tallahassee	TLH	424	328	149	53	2	0	0	0	0	42	189	368
FL	Tampa	TPA	183	117	46	10	0	0	0	0	0	6	32	129
FL	Vero Beach	VRB	165	107	47	13	0	0	0	0	0	6	26	102
FL	West Palm Beach	PBI	92	53	20	4	0	0	0	0	0	3	11	55
GA	Albany	ABY	469	370	173	56	2	0	0	0	0	51	217	418
GA	Athens	AHN	662	522	304	131	23	0	0	0	4	126	352	602
GA	Atlanta	ATL	650	519	292	118	21	0	0	0	3	110	325	581
GA	Augusta	AGS	598	475	265	106	11	0	0	0	2	100	314	532
GA	Brunswick	SSI	411	328	151	58	3	0	0	0	0	36	154	333
GA	Columbus	CSG	543	421	204	67	5	0	0	0	1	68	240	472
GA	Macon	MCN	563	445	239	91	10	0	0	0	2	89	295	510
GA	Savannah	SAV	478	373	191	69	6	0	0	0	0	50	215	399
GA	Waycross	AYS	412	317	143	50	2	12	0	0	0	40	180	369
HI	Hilo-Hawaii	ITO	0	0	0	0	0	0	0	0	0	0	0	0
HI	Honolulu-Oahu	HNL	0	0	0	0	0	0	0	0	0	0	0	0
HI	Kahului-Maui	OGG	0	0	0	0	0	0	0	0	0	0	0	0
HI	Lihue-Kauai	LIH	0	0	0	0	0	0	0	0	0	0	0	0
IA	Burlington	BRL	1233	1043	667	337	125	8	1	5	71	339	617	1078
IA	Cedar Rapids	CID	1404	1197	807	441	187	21	5	14	128	450	763	1259
IA	Des Moines	DSM	1310	1109	716	360	128	6	0	4	72	359	697	1159
IA	Dubuque	DBQ	1421	1215	846	475	219	31	6	16	141	466	774	1275
IA	Mason City	MCW	1514	1288	924	514	230	33	6	23	153	505	865	1370
IA	Ottumwa	OTM	1310	1110	724	395	159	15	2	9	103	396	699	1152
IA	Sioux City	SUX	1393	1177	792	424	166	17	2	8	112	435	807	1282
IA	Waterloo	ALO	1449	1225	841	468	192	19	3	14	128	458	802	1304
ID	Boise	BOI	985	785	611	430	220	54	0	6	62	356	722	993
ID	Burley	BYI	1119	945	747	559	339	124	5	24	170	496	817	1106
ID	Idaho Falls	IDA	1379	1179	885	610	385	159	11	36	220	585	934	1270
ID	Lewiston	LWS	867	718	593	416	211	57	1	4	58	376	699	937
ID	Pocatello	PIH	1229	1046	806	589	366	128	5	22	182	535	887	1196
IL	Chicago	ORD	1256	1078	773	451	208	30	2	6	79	371	678	1109
IL	Moline	MLI	1280	1095	716	375	147	13	1	5	82	369	675	1145
IL	Peoria	PIA	1221	1034	666	346	134	10	0	5	64	348	646	1086

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State	City		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
IL	Quincy	UIN	1178	996	628	328	120	8	0	5	66	332	611	1041
IL	Rockford	RFD	1330	1137	794	437	192	22	4	9	96	403	724	1193
IL	Springfield	SPI	1155	972	606	308	111	9	0	5	61	323	586	1006
IN	Evansville	EVV	981	828	505	242	73	4	0	1	27	247	516	863
IN	Fort Wayne	FWA	1247	1086	751	414	174	18	1	7	86	388	669	1074
IN	Indianapolis	IND	1131	968	620	316	120	10	1	3	46	314	592	987
IN	South Bend	SBN	1253	1090	783	442	210	29	2	11	96	404	685	1079
IN	West Lafayette	LAF	1178	1006	653	350	145	14	0	5	63	345	612	1022
KS	Concordia	CNK	1117	938	595	329	121	7	0	2	57	306	641	1067
KS	Dodge City	DDC	979	847	555	317	110	5	0	2	45	276	609	978
KS	Garden City	GCK	1010	868	572	336	112	6	1	2	43	294	624	1007
KS	Goodland	GLD	1059	946	668	436	196	24	3	5	89	394	720	1078
KS	Russell	RSL	1074	911	582	328	116	7	0	2	50	297	638	1050
KS	Salina	SLN	1043	872	532	279	87	3	0	1	36	256	570	997
KS	Topeka	TOP	1079	892	545	271	86	3	0	2	46	274	574	972
KS	Wichita	ICT	985	810	487	240	69	2	0	0	24	227	528	924
KY	Bowling Green	BWG	877	727	438	220	59	3	0	1	21	215	467	779
KY	Jackson	JKL	924	774	479	230	88	7	1	2	37	242	464	802
KY	Lexington	LEX	993	842	547	278	99	6	0	2	42	278	540	874
KY	Louisville	SDF	932	780	473	210	58	3	0	0	19	213	462	809
KY	Paducah	PAH	933	779	484	240	71	5	0	2	35	253	515	842
LA	Baton Rouge	BTR	398	310	128	40	3	0	0	0	0	48	182	376
LA	Lafayette	LFT	380	289	116	29	1	0	0	0	0	40	149	349
LA	Lake Charles	LCH	383	299	121	32	1	0	0	0	0	33	153	348
LA	Monroe	MLU	548	439	208	63	7	0	0	0	1	80	257	501
LA	New Orleans	MSY	347	263	99	23	0	0	0	0	0	24	124	309
LA	Shreveport	SHV	521	418	193	58	7	0	0	0	0	69	236	490
MA	Boston	BOS	1111	947	792	467	230	56	3	5	55	315	574	905
MA	Worcester	ORH	1273	1083	892	514	268	79	9	16	107	435	682	1057
MD	Baltimore	BWI	969	837	602	309	109	8	0	0	26	265	511	836
MD	Salisbury	SBY	929	806	599	328	141	14	1	1	29	254	481	775
ME	Augusta	AUG	1410	1181	992	594	317	101	12	23	148	484	769	1168
ME	Bangor	BGR	1475	1245	1039	633	333	106	14	30	177	510	808	1212
ME	Caribou	CAR	1680	1420	1228	766	423	153	36	79	268	628	944	1401
ME	Houlton	HUL	1630	1393	1184	756	438	172	48	84	272	620	907	1359
ME	Portland	PWM	1318	1116	950	598	332	103	11	19	138	463	727	1089
MI	Alpena	APN	1419	1264	1076	685	387	118	31	54	209	545	826	1219
MI	Detroit	DTW	1226	1077	812	445	192	22	2	5	77	378	665	1049
MI	Flint	FNT	1306	1148	884	513	252	47	11	19	130	452	733	1116
MI	Grand Rapids	GRR	1264	1118	853	488	229	34	5	11	108	434	713	1077
MI	Houghton Lake	HTL	1433	1280	1044	629	335	103	37	65	223	562	836	1225
MI	Jackson	JXN	1286	1126	842	483	238	45	9	17	131	451	713	1100
MI	Lansing	LAN	1303	1148	873	510	250	46	10	19	130	455	729	1110
MI	Marquette	MQT	1515	1339	1152	765	441	162	64	82	264	616	945	1356
MI	Muskegon	MKG	1215	1097	875	528	268	54	8	17	119	432	701	1043
MI	Saginaw	MBS	1323	1172	917	540	261	48	10	20	129	450	738	1129

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MI	Sault St Marie	SSM	1526	1324	1144	715	404	152	51	61	217	571	869	1299
MI	Traverse City	TVC	1312	1186	980	630	342	90	21	26	155	486	763	1132
MN	Alexandria	AXN	1675	1443	1085	589	298	66	10	29	183	561	967	1497
MN	Duluth	DLH	1676	1419	1140	713	430	156	45	69	256	630	1004	1506
MN	Hibbing	HIB	1780	1506	1170	737	454	181	75	126	334	695	1073	1599
MN	Int'l Falls	INL	1853	1586	1229	734	443	167	69	125	328	695	1099	1660
MN	Minneapolis	MSP	1512	1267	921	466	203	25	2	8	116	460	842	1353
MN	Rochester	RST	1531	1308	944	512	236	38	8	25	147	489	851	1377
MN	Saint Cloud	STC	1625	1385	1036	565	288	56	10	29	184	553	949	1463
MO	Columbia	COU	1077	896	547	274	96	5	0	3	48	287	557	955
MO	Joplin	JLN	914	751	439	218	70	3	0	1	28	217	445	821
MO	Kansas City	MCI	1104	918	564	280	92	5	0	1	46	281	575	993
MO	Saint Louis	STL	1002	835	498	230	67	3	0	1	26	227	498	883
MO	Springfield	SGF	970	800	498	258	89	4	0	2	39	261	511	881
MS	Greenwood	GWO	628	506	255	98	17	0	0	0	5	123	282	565
MS	McComb	MCB	490	384	174	61	9	0	0	0	1	71	230	446
MS	Tupelo	TUP	692	555	294	124	23	0	0	0	6	134	343	621
MT	Billings	BIL	1148	1004	776	536	332	93	3	13	146	499	829	1170
MT	Butte	BTM	1349	1201	996	783	564	301	67	117	366	724	1096	1424
MT	Cut Bank	CTB	1288	1157	981	709	487	238	50	88	300	671	984	1319
MT	Great Falls	GTF	1189	1070	889	641	431	188	22	50	231	575	900	1211
MT	Havre	HVR	1435	1273	990	608	380	142	13	42	234	612	1003	1418
MT	Helena	HLN	1252	1035	837	594	370	140	7	30	188	566	935	1285
MT	Kalispell	FCA	1145	946	764	513	281	132	20	45	216	517	882	1158
MT	Lewistown	LWT	1254	1139	939	702	490	235	41	72	275	631	956	1279
MT	Miles City	MLS	1368	1191	866	519	312	82	2	12	155	535	918	1331
MT	Missoula	MSO	1201	979	807	598	384	168	15	33	205	600	960	1246
NC	Asheville	AVL	857	712	500	267	89	6	0	0	33	272	521	786
NC	Cape Hatteras	HAT	440	383	263	90	21	0	0	0	1	24	102	292
NC	Charlotte	CLT	734	598	373	172	40	0	0	0	9	169	412	658
NC	Greensboro	GSO	780	648	415	192	55	2	0	0	14	187	429	700
NC	Hickory	HKY	780	647	412	190	53	3	0	0	15	189	427	706
NC	New Bern	EWN	659	548	352	148	29	0	0	0	2	117	315	552
NC	Raleigh Durham	RDU	729	599	384	170	43	1	0	0	9	163	385	642
NC	Wilmington	ILM	617	510	324	128	24	0	0	0	1	103	297	517
ND	Bismarck	BIS	1595	1394	1044	589	328	80	8	28	198	594	1015	1472
ND	Devil's Lake	P11	1771	1580	1237	670	373	117	21	45	227	630	1091	1612
ND	Fargo	FAR	1718	1498	1119	575	288	56	12	31	185	557	992	1522
ND	Grand Forks	GFK	1803	1593	1226	639	355	83	22	46	223	618	1078	1609
ND	Minot	MOT	1606	1438	1119	609	360	101	17	37	204	624	1051	1512
ND	Williston	ISN	1635	1447	1089	620	381	119	13	36	226	654	1090	1553
NE	Grand Island	GRI	1231	1042	698	398	160	17	2	5	86	389	739	1172
NE	Lincoln	LNK	1261	1055	680	377	137	10	1	5	83	371	717	1169
NE	Norfolk	OFK	1313	1106	752	426	176	22	3	8	109	417	777	1223
NE	North Platte	LBF	1210	1048	752	487	234	37	3	10	135	477	821	1219
NE	Omaha	OMA	1292	1088	705	363	133	10	1	5	75	360	714	1179

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State	City		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
NE	Scottsbluff	BFF	1138	1000	742	510	263	53	5	12	133	482	811	1190
NE	Valentine	VTN	1262	1117	816	510	260	51	4	12	143	496	848	1247
NH	Concord	CON	1380	1159	965	571	282	81	9	26	151	487	770	1150
NH	Lebanon	LEB	1439	1217	1000	598	285	81	9	28	152	511	794	1199
NJ	Atlantic City	ACY	975	847	663	366	151	20	0	1	31	263	512	817
NJ	Newark	EWR	1016	856	651	338	113	11	0	1	20	253	510	844
NM	Albuquerque	ABQ	821	668	469	236	58	1	0	0	15	199	536	859
NM	Carlsbad	CNM	617	470	255	86	21	0	0	0	4	94	349	638
NM	Clayton	CAO	853	788	564	343	126	11	2	5	52	278	558	888
NM	Gallup	GUP	1078	901	765	535	279	52	1	4	124	464	801	1090
NM	Roswell	ROW	701	545	314	123	27	0	0	0	7	127	418	740
NV	Elko	EKO	1221	990	795	593	349	109	2	16	156	516	863	1180
NV	Ely	ELY	1215	1032	864	663	434	151	6	33	218	569	884	1214
NV	Las Vegas	LAS	470	350	165	58	6	0	0	0	0	28	228	522
NV	Lovelock	LOL	987	771	617	431	183	35	0	4	71	373	741	1039
NV	Reno	RNO	886	727	585	431	190	43	0	3	47	303	637	912
NV	Tonopah	TPH	955	807	675	482	211	42	0	3	62	347	697	1011
NV	Winnemucca	WMC	1053	859	727	564	317	96	2	15	151	498	826	1097
NY	Albany	ALB	1303	1106	885	489	215	37	2	11	99	438	713	1092
NY	Binghamton	BGM	1328	1145	942	561	274	77	12	26	150	487	743	1133
NY	Buffalo	BUF	1242	1122	911	551	247	49	4	10	94	424	674	1041
NY	Glens Falls	GFL	1437	1236	996	581	282	74	12	34	177	518	789	1193
NY	Massena	MSS	1531	1318	1083	622	302	81	10	36	169	537	835	1287
NY	New York	LGA	976	834	657	338	118	12	0	1	11	206	456	786
NY	Rochester	ROC	1241	1106	888	537	254	54	6	15	107	427	692	1038
NY	Syracuse	SYR	1271	1125	908	523	232	46	3	12	99	417	690	1069
NY	Utica	UCA	1198	1011	784	386	142	32	2	11	57	307	599	991
NY	Watertown	ART	1434	1269	1007	607	308	89	14	35	157	486	757	1159
OH	Akron Canton	CAK	1208	1066	800	439	192	39	3	8	91	406	664	1036
OH	Cincinnati	CVG	1063	908	603	304	110	9	1	2	44	309	577	930
OH	Cleveland	CLE	1166	1030	795	451	197	32	2	5	71	365	619	994
OH	Columbus	CMH	1109	963	665	326	124	11	0	2	47	329	586	950
OH	Dayton	DAY	1171	1010	697	368	151	15	1	4	67	358	628	1013
OH	Findlay	FDY	1212	1055	755	412	166	19	1	5	81	371	639	1041
OH	Mansfield	MFD	1229	1079	799	447	203	42	6	11	100	415	664	1053
OH	Toledo	TOL	1231	1079	797	446	189	22	1	6	86	389	678	1067
OH	Youngstown	YNG	1215	1068	820	464	219	55	7	16	108	425	666	1037
OK	Hobart	HBR	769	642	367	174	41	0	0	0	6	149	401	753
OK	McAlester	MLC	731	588	308	140	33	0	0	0	9	135	335	673
OK	Oklahoma City	OKC	785	640	347	148	35	1	0	0	9	144	390	744
OK	Tulsa	TUL	809	663	363	155	37	1	0	0	11	151	388	751
OR	Astoria	AST	646	584	578	493	365	222	127	112	184	362	547	682
OR	Baker	BKE	1176	964	817	649	426	214	38	62	256	611	923	1191
OR	Eugene	EUG	723	629	558	455	305	147	22	23	100	358	595	763
OR	Medford	MFR	760	595	527	391	188	52	1	3	39	276	606	790
OR	Pendleton	PDT	910	745	606	454	248	85	5	8	88	399	715	972

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OR	Portland	PDX	718	594	523	388	217	89	8	8	59	290	554	755
OR	Redmond	RDM	946	835	760	640	414	214	42	60	214	540	801	1029
OR	Salem	SLE	712	616	554	443	269	121	14	14	86	336	583	755
PA	Allentown	ABE	1134	974	739	413	168	23	1	4	61	362	623	966
PA	Altoona	AOO	1176	1037	788	440	203	42	5	12	108	413	659	1028
PA	Bradford	BFD	1367	1213	991	621	350	138	58	75	229	574	797	1176
PA	Du Bois	DUJ	1276	1125	867	509	255	78	16	27	141	473	714	1103
PA	Erie	ERI	1167	1068	869	529	252	47	5	8	78	372	619	976
PA	Harrisburg	CXY	1049	918	670	355	133	15	0	2	44	318	573	908
PA	Philadelphia	PHL	986	848	613	308	94	7	0	1	15	238	490	822
PA	Pittsburgh	PIT	1141	997	731	386	165	27	2	5	76	381	631	981
PA	Williamsport	IPT	1165	1011	766	414	175	26	1	6	71	380	649	1001
RI	Providence	PVD	1104	946	781	453	218	44	2	3	57	331	585	916
SC	Charleston	CHS	504	393	205	72	7	0	0	0	1	62	226	412
SC	Columbia	CAE	606	478	269	103	12	0	0	0	3	101	321	543
SC	Florence	FLO	624	498	285	113	18	0	0	0	3	106	301	524
SC	Greenville	GSP	688	567	344	145	32	1	0	0	6	147	375	632
SD	Aberdeen	ABR	1624	1399	1024	572	285	57	7	28	192	573	993	1471
SD	Huron	HON	1494	1288	919	516	245	45	5	15	147	505	909	1378
SD	Pierre	PIR	1384	1215	887	513	267	51	3	9	129	495	893	1316
SD	Rapid City	RAP	1228	1116	840	559	332	88	6	16	154	509	863	1228
SD	Sioux Falls	FSD	1479	1265	900	502	239	35	4	15	141	488	872	1356
TN	Bristol	TRI	903	748	497	258	82	4	0	1	28	266	531	820
TN	Chattanooga	CHA	737	589	338	141	30	0	0	0	6	144	393	668
TN	Crossville	CSV	898	742	482	252	89	6	1	2	37	256	489	793
TN	Jackson	MKL	797	660	373	173	41	1	0	1	17	186	418	712
TN	Knoxville	TYS	808	654	397	182	46	1	0	0	11	191	444	738
TN	Memphis	MEM	700	566	296	111	18	0	0	0	3	115	329	623
TN	Nashville	BNA	813	665	392	175	45	2	0	0	12	175	422	718
TX	Abilene	ABI	584	469	230	79	20	0	0	0	3	87	279	570
TX	Alice	ALI	242	176	58	9	0	0	0	0	0	9	64	224
TX	Amarillo	AMA	820	717	457	242	81	2	0	1	25	218	501	821
TX	Austin	AUS	470	356	165	46	3	0	0	0	0	44	192	436
TX	Brownsville	BRO	144	109	28	7	0	0	0	0	0	1	28	145
TX	College Station	CLL	417	316	127	33	2	0	0	0	0	32	145	375
TX	Corpus Christi	CRP	252	177	58	11	0	0	0	0	0	9	66	226
TX	Dallas-Ft. Worth	DFW	550	438	195	53	9	0	0	0	0	53	213	506
TX	Del Rio	DRT	384	253	80	16	1	0	0	0	0	18	135	380
TX	El Paso	ELP	560	416	216	62	7	0	0	0	1	52	303	584
TX	Galveston	GLS	291	224	73	12	0	0	0	0	0	7	62	233
TX	Houston	IAH	362	271	106	23	0	0	0	0	0	23	129	332
TX	Laredo	LRD	216	146	31	6	0	0	0	0	0	5	47	199
TX	Lubbock	LBB	710	584	337	150	45	0	0	0	10	143	405	718
TX	Lufkin	LFK	474	368	165	49	4	0	0	0	0	53	202	433
TX	McAllen	MFE	160	117	22	10	0	0	0	0	0	3	31	149
TX	Midland Odessa	MAF	622	480	254	83	19	0	0	0	4	87	329	614

Station Location		Code	Monthly Heating Degree Days											
State	City		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
TX	San Angelo	SJT	548	422	196	67	10	0	0	0	1	72	259	524
TX	San Antonio	SAT	374	275	105	24	2	0	0	0	1	28	135	354
TX	Victoria	VCT	337	243	90	21	1	0	0	0	0	22	116	306
TX	Waco	ACT	521	404	184	55	6	0	0	0	0	54	211	485
TX	Wichita Falls	SPS	665	540	267	95	23	0	0	0	2	94	306	641
UT	Cedar City	CDC	1100	910	731	535	268	58	0	3	103	436	771	1110
UT	Salt Lake City	SLC	1092	857	641	432	218	45	0	3	58	350	718	1055
VA	Lynchburg	LYH	904	773	526	269	101	7	0	2	34	271	523	822
VA	Norfolk	ORF	737	632	440	201	55	1	0	0	3	129	349	605
VA	Richmond	RIC	821	694	463	213	60	2	0	0	10	181	409	704
VA	Roanoke	ROA	846	719	478	229	78	4	0	0	27	224	474	765
VT	Burlington	BTV	1427	1226	1002	581	263	61	5	23	133	495	768	1188
VT	Montpelier	MPV	1501	1280	1065	652	335	114	24	52	200	568	842	1269
WA	Bellingham	BLI	767	672	628	492	341	187	78	78	209	442	647	792
WA	Olympia	OLM	772	686	636	510	342	186	67	68	180	433	658	817
WA	Quillayute	UIL	702	639	651	549	430	282	179	160	237	441	619	742
WA	Seattle Tacoma	SEA	706	611	586	451	285	142	34	29	122	368	597	745
WA	Spokane	GEG	1094	904	769	556	320	141	17	23	147	511	879	1144
WA	Walla Walla	ALW	869	701	532	383	195	51	1	3	51	335	662	930
WA	Yakima	YKM	1029	785	662	476	242	84	8	15	124	456	817	1102
WI	Eau Claire	EAU	1546	1309	977	533	258	49	7	26	169	524	878	1386
WI	Green Bay	GRB	1452	1253	979	576	289	60	12	23	165	494	813	1274
WI	Lacrosse	LSE	1452	1226	870	457	197	27	2	11	117	442	790	1303
WI	Madison	MSN	1404	1202	887	510	240	36	6	17	140	462	784	1247
WI	Milwaukee	MKE	1288	1111	858	550	289	64	7	9	100	397	713	1135
WI	Wausau	AUW	1547	1312	1019	585	294	67	13	31	192	549	892	1369
WV	Beckley	BKW	1050	897	647	355	171	36	9	9	87	368	607	938
WV	Charleston	CRW	942	810	537	257	100	7	0	1	36	273	519	838
WV	Elkins	EKN	1130	996	750	455	225	62	17	11	122	436	693	1005
WV	Huntington	HTS	956	811	533	253	95	6	0	1	39	280	528	846
WV	Martinsburg	MRB	1020	884	642	341	138	15	0	1	48	323	569	906
WV	Morgantown	MGW	1040	904	633	337	138	19	3	2	52	333	558	890
WV	Parkersburg	PKB	1040	891	605	302	124	14	0	2	50	329	567	904
WY	Casper	CPR	1191	1088	864	644	408	129	12	28	208	574	880	1244
WY	Cheyenne	CYS	1084	1037	826	630	390	120	14	30	201	556	837	1163
WY	Cody	COD	1171	1048	793	600	382	139	14	36	196	551	869	1209
WY	Lander	LND	1301	1128	842	605	380	121	7	22	171	563	923	1328
WY	Rock Springs	RKS	1320	1173	941	691	444	159	8	35	219	598	980	1336
WY	Sheridan	SHR	1220	1081	843	612	404	138	11	30	197	555	908	1272
WY	Worland	WRL	1416	1161	795	529	321	85	5	16	167	553	934	1415

Table 7C.3.3 Weather Station Monthly Cooling Degree Day Data (10-Year Average)

Station Location		Code	Monthly Cooling Degree Days											
State	City		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
AK	Anchorage	ANC	0	0	0	0	0	1	4	1	0	0	0	0
AK	Bethel	BET	0	0	0	0	0	2	3	2	0	0	0	0

Station Location		Code	Monthly Cooling Degree Days											
State	City		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
AK	Cold Bay	CDB	0	0	0	0	0	0	0	0	0	0	0	0
AK	Cordova	CDV	0	0	0	0	0	0	0	0	0	0	0	0
AK	Homer	HOM	0	0	0	0	0	0	0	0	0	0	0	0
AK	Juneau	JNU	0	0	0	0	0	2	1	1	0	0	0	0
AK	Kenai	ENA	0	0	0	0	0	0	1	0	0	0	0	0
AK	Ketchikan	KTN	0	0	0	0	0	5	7	6	0	0	0	0
AK	King Salmon	AKN	0	0	0	0	0	0	1	2	0	0	0	0
AK	Kodiak	ADQ	0	0	0	0	0	0	3	1	0	0	0	0
AK	Sitka	SIT	0	0	0	0	0	1	0	3	0	0	0	0
AK	St Paul Island	SNP	0	0	0	0	0	0	0	0	0	0	0	0
AK	Talkeetna	TKA	0	0	0	0	0	5	12	5	0	0	0	0
AK	Valdez	VWS	0	0	0	0	3	3	6	4	0	0	0	0
AK	Yakutat	YAK	0	0	0	0	0	0	0	0	0	0	0	0
AL	Birmingham	BHM	1	3	34	81	234	427	515	513	312	89	15	2
AL	Huntsville	HSV	1	1	21	67	214	414	481	487	269	64	7	1
AL	Mobile	MOB	10	10	53	120	319	485	538	537	399	170	41	14
AL	Montgomery	MGM	2	6	40	90	272	480	553	556	374	126	23	5
AL	Muscle Shoals	MSL	1	2	22	74	225	398	496	500	259	62	9	2
AL	Tuscaloosa	TCL	2	5	33	83	270	459	535	536	324	94	18	3
AR	Fayetteville	FYV	1	0	10	35	119	293	428	430	152	31	3	1
AR	Fort Smith	FSM	1	0	26	69	221	443	586	577	294	82	10	1
AR	Little Rock	LIT	2	2	27	69	231	454	560	564	299	82	11	1
AR	Texarkana	TXK	4	3	41	97	275	470	579	590	326	113	28	4
AZ	Douglas	DUG	0	2	7	33	197	441	516	453	303	90	2	0
AZ	Flagstaff	FLG	0	0	0	0	0	20	96	42	2	0	0	0
AZ	Phoenix	PHX	4	9	111	251	551	813	974	921	745	410	92	1
AZ	Tucson	TUS	1	3	47	136	384	642	728	672	530	250	47	0
AZ	Winslow	INW	0	0	2	4	87	271	467	378	153	14	1	0
AZ	Yuma	NYL	22	17	131	242	511	737	946	930	744	406	98	6
CA	Bakersfield	BFL	0	0	18	54	209	398	635	572	402	117	6	0
CA	Blythe	BLH	3	4	95	206	512	725	956	922	690	330	58	1
CA	Eureka	EKA	0	0	0	0	1	0	0	2	1	2	0	0
CA	Fresno	FAT	0	0	8	42	194	378	612	549	384	106	4	0
CA	Los Angeles	LAX	12	5	12	19	24	43	143	155	130	77	29	2
CA	Mt Shasta	MHS	0	0	0	0	14	37	158	113	35	2	0	0
CA	Paso Robles	PRB	0	0	2	12	65	156	308	282	184	41	2	0
CA	Red Bluff	RBL	0	0	6	27	146	359	553	479	323	80	6	0
CA	Redding	RDD	0	0	7	26	145	356	575	488	313	72	4	0
CA	Sacramento	SAC	0	0	1	18	87	217	354	315	224	46	0	0
CA	San Diego	SAN	5	1	9	17	30	58	174	214	177	82	20	1
CA	San Francisco	SFO	0	0	2	6	11	22	24	35	57	26	2	0
CA	Stockton	SCK	0	0	3	23	108	243	399	360	246	54	1	0
CO	Alamosa	ALS	0	0	0	0	0	12	68	28	1	0	0	0
CO	Colorado Spring	COS	0	0	0	0	18	118	251	171	41	2	0	0
CO	Denver	DEN	0	0	0	2	32	145	337	264	74	8	0	0
CO	Eagle	EGE	0	0	0	0	2	30	132	72	3	1	0	0

Station Location		Code	Monthly Cooling Degree Days											
State	City		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
CO	Pueblo	PUB	0	0	1	4	45	212	392	303	80	7	0	0
CO	Trinidad	TAD	0	0	0	3	37	181	335	265	87	8	0	0
CT	Bridgeport	BDR	0	0	0	1	27	158	326	297	120	12	0	0
CT	Hartford	BDL	0	0	0	7	41	153	300	252	87	8	0	0
DC	Washington	DCA	0	0	3	28	126	332	490	450	227	39	2	0
DE	Wilmington	ILG	0	0	0	13	78	241	391	344	150	20	0	0
FL	Daytona Beach	DAB	28	40	91	163	349	467	531	547	468	306	109	55
FL	Fort Myers	FMY	76	107	194	277	460	532	577	587	530	404	201	122
FL	Ft Lauderdale	FLL	147	174	264	334	472	546	594	608	547	468	293	212
FL	Gainesville	GNV	15	22	67	135	332	464	520	528	423	227	57	23
FL	Jacksonville	JAX	11	14	53	118	306	457	529	537	409	205	46	20
FL	Key West	EYW	161	184	282	349	491	557	619	640	569	499	326	220
FL	Melbourne	MLB	52	70	145	208	389	483	532	552	489	352	160	97
FL	Miami	MIA	144	179	270	340	485	548	602	607	550	468	287	208
FL	Orlando	MCO	37	60	135	215	403	499	562	571	496	332	130	68
FL	Pensacola	PNS	10	10	53	123	338	511	557	552	438	201	46	14
FL	Tallahassee	TLH	6	8	51	112	330	495	552	554	426	196	36	12
FL	Tampa	TPA	45	59	154	243	440	529	573	584	523	368	153	82
FL	Vero Beach	VRB	55	76	145	205	377	475	530	549	484	364	177	109
FL	West Palm Beach	PBI	106	136	223	292	447	523	577	589	524	429	243	166
GA	Albany	ABY	7	5	46	114	335	508	571	561	403	159	30	10
GA	Athens	AHN	0	0	17	50	190	397	488	480	270	57	7	1
GA	Atlanta	ATL	0	0	21	56	205	403	480	484	286	72	9	1
GA	Augusta	AGS	2	2	20	62	228	426	520	514	318	84	9	2
GA	Brunswick	SSI	6	10	47	122	310	474	564	561	413	199	69	28
GA	Columbus	CSG	1	3	33	89	285	476	552	550	367	121	22	4
GA	Macon	MCN	1	1	22	68	252	454	538	530	331	97	17	2
GA	Savannah	SAV	5	6	34	103	283	463	547	542	379	148	27	10
GA	Waycross	AYS	8	10	54	131	330	479	550	546	400	173	41	15
HI	Hilo-Hawaii	ITO	219	192	230	229	298	321	359	367	346	338	278	245
HI	Honolulu-Oahu	HNL	279	261	315	355	427	477	518	533	496	477	387	323
HI	Kahului-Maui	OGG	234	201	255	280	349	396	443	463	426	414	327	272
HI	Lihue-Kauai	LIH	245	203	252	286	363	406	450	467	439	425	330	277
IA	Burlington	BRL	0	0	5	23	96	251	366	309	122	25	0	0
IA	Cedar Rapids	CID	0	0	4	12	55	169	269	204	67	15	0	0
IA	Des Moines	DSM	0	0	5	17	80	245	393	318	113	23	0	0
IA	Dubuque	DBQ	0	0	2	5	41	144	243	183	59	12	0	0
IA	Mason City	MCW	0	0	1	5	36	136	241	165	48	11	0	0
IA	Ottumwa	OTM	0	0	4	17	67	199	322	259	81	18	0	0
IA	Sioux City	SUX	0	0	3	13	72	205	345	256	82	17	0	0
IA	Waterloo	ALO	0	0	3	7	52	172	286	206	71	16	0	0
ID	Boise	BOI	0	0	0	4	45	145	444	359	127	13	0	0
ID	Burley	BYI	0	0	0	0	11	48	211	150	16	3	0	0
ID	Idaho Falls	IDA	0	0	0	0	7	27	151	106	6	1	0	0
ID	Lewiston	LWS	0	0	0	1	31	106	374	324	99	5	0	0
ID	Pocatello	PIH	0	0	0	0	9	46	222	163	16	1	0	0

Station Location		Code	Monthly Cooling Degree Days											
State	City		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
IL	Chicago	ORD	0	0	5	8	53	186	321	265	95	16	0	0
IL	Moline	MLI	0	0	4	13	77	224	349	280	99	19	0	0
IL	Peoria	PIA	0	0	5	15	84	236	363	301	120	22	0	0
IL	Quincy	UIN	0	0	5	24	95	250	378	329	116	23	0	0
IL	Rockford	RFD	0	0	5	5	52	178	291	228	84	16	0	0
IL	Springfield	SPI	0	0	7	24	111	255	363	317	129	27	0	0
IN	Evansville	EVV	0	0	9	32	134	321	422	401	176	33	1	0
IN	Fort Wayne	FWA	0	0	3	9	64	194	294	218	78	12	0	0
IN	Indianapolis	IND	0	0	7	18	92	252	362	331	141	24	0	0
IN	South Bend	SBN	0	0	5	9	56	176	279	215	81	14	0	0
IN	West Lafayette	LAF	0	0	8	19	84	220	320	275	112	21	1	0
KS	Concordia	CNK	0	0	5	17	97	300	464	380	139	26	0	0
KS	Dodge City	DDC	0	0	3	20	117	328	500	424	166	35	0	0
KS	Garden City	GCK	0	0	4	19	110	303	468	399	157	28	0	0
KS	Goodland	GLD	0	0	1	4	53	201	392	299	91	12	0	0
KS	Russell	RSL	0	0	4	19	114	322	509	412	155	29	0	0
KS	Salina	SLN	0	0	8	29	143	374	551	473	181	38	1	0
KS	Topeka	TOP	0	0	11	32	132	333	488	429	148	36	2	0
KS	Wichita	ICT	0	0	8	34	151	376	544	485	208	43	2	0
KY	Bowling Green	BWG	0	0	13	45	148	329	437	431	195	34	3	1
KY	Jackson	JKL	0	0	13	49	107	237	323	330	154	33	4	0
KY	Lexington	LEX	0	0	7	22	101	252	357	342	150	25	0	0
KY	Louisville	SDF	0	0	15	46	157	349	458	448	221	46	3	1
KY	Paducah	PAH	0	0	9	34	134	308	403	371	160	30	3	0
LA	Baton Rouge	BTR	18	20	75	152	354	516	568	578	419	186	46	19
LA	Lafayette	LFT	18	20	83	181	381	530	574	596	437	212	66	22
LA	Lake Charles	LCH	14	17	71	158	365	528	570	591	439	214	61	19
LA	Monroe	MLU	6	10	49	112	305	497	570	590	377	135	29	7
LA	New Orleans	MSY	21	23	85	183	395	541	577	595	476	244	68	26
LA	Shreveport	SHV	7	11	53	116	315	510	596	625	407	151	36	6
MA	Boston	BOS	0	0	1	5	31	136	296	258	91	10	0	0
MA	Worcester	ORH	0	0	0	4	29	97	216	180	50	6	0	0
MD	Baltimore	BWI	0	0	1	20	97	270	418	361	154	22	1	0
MD	Salisbury	SBY	0	0	2	22	89	235	397	338	157	31	2	0
ME	Augusta	AUG	0	0	0	0	11	64	174	135	28	3	0	0
ME	Bangor	BGR	0	0	0	0	7	51	156	115	24	1	0	0
ME	Caribou	CAR	0	0	0	0	4	36	87	60	9	1	0	0
ME	Houlton	HUL	0	0	0	0	5	35	87	68	14	1	0	0
ME	Portland	PWM	0	0	0	1	8	56	166	134	32	1	0	0
MI	Alpena	APN	0	0	1	0	15	63	132	98	25	6	0	0
MI	Detroit	DTW	0	0	2	6	49	180	300	250	88	11	0	0
MI	Flint	FNT	0	0	2	4	38	129	220	170	55	9	0	0
MI	Grand Rapids	GRR	0	0	3	6	43	150	261	204	68	10	0	0
MI	Houghton Lake	HTL	0	0	1	0	21	70	133	94	24	5	0	0
MI	Jackson	JXN	0	0	2	5	39	126	215	165	56	9	0	0
MI	Lansing	LAN	0	0	2	4	37	131	233	177	59	9	0	0

Station Location		Code	Monthly Cooling Degree Days											
State	City		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
MI	Marquette	MQT	0	0	0	0	11	48	110	73	25	3	0	0
MI	Muskegon	MKG	0	0	3	2	30	114	218	182	60	8	0	0
MI	Saginaw	MBS	0	0	2	2	38	133	218	161	52	11	0	0
MI	Sault St Marie	SSM	0	0	0	0	10	32	95	73	20	3	0	0
MI	Traverse City	TVC	0	0	3	2	25	94	188	149	51	11	0	0
MN	Alexandria	AXN	0	0	0	2	22	84	231	148	46	6	0	0
MN	Duluth	DLH	0	0	0	0	5	30	127	77	22	1	0	0
MN	Hibbing	HIB	0	0	0	0	8	20	77	48	12	1	0	0
MN	Int'l Falls	INL	0	0	0	0	6	27	79	51	15	2	0	0
MN	Minneapolis	MSP	0	0	2	5	46	177	347	241	88	17	0	0
MN	Rochester	RST	0	0	2	3	36	132	225	146	54	15	0	0
MN	Saint Cloud	STC	0	0	1	2	27	101	228	140	47	7	0	0
MO	Columbia	COU	0	0	9	30	109	281	421	381	135	28	1	0
MO	Joplin	JLN	1	0	21	59	155	357	506	490	194	53	8	0
MO	Kansas City	MCI	0	0	9	32	117	298	452	415	143	33	2	0
MO	Saint Louis	STL	0	0	16	48	158	367	505	459	194	45	3	1
MO	Springfield	SGF	0	0	10	30	119	309	451	429	160	32	2	0
MS	Greenwood	GWO	5	5	39	94	265	443	515	528	307	103	27	6
MS	McComb	MCB	8	10	50	106	287	467	540	539	379	146	29	11
MS	Tupelo	TUP	1	2	26	76	234	427	524	525	288	78	11	1
MT	Billings	BIL	0	0	0	2	17	84	326	239	58	7	0	0
MT	Butte	BTM	0	0	0	0	1	8	62	31	1	0	0	0
MT	Cut Bank	CTB	0	0	0	0	3	12	101	66	12	0	0	0
MT	Great Falls	GTF	0	0	1	0	5	27	191	133	33	1	0	0
MT	Havre	HVR	0	0	0	0	13	37	220	145	24	1	0	0
MT	Helena	HLN	0	0	0	0	11	50	250	165	32	0	0	0
MT	Kalispell	FCA	0	0	0	8	32	92	280	258	74	12	0	0
MT	Lewistown	LWT	0	0	0	0	2	18	137	95	19	1	0	0
MT	Miles City	MLS	0	0	0	2	19	105	365	269	68	7	0	0
MT	Missoula	MSO	0	0	0	0	5	37	204	137	16	0	0	0
NC	Asheville	AVL	0	0	0	7	61	197	283	276	94	9	1	0
NC	Cape Hatteras	HAT	21	20	71	152	297	512	608	614	491	280	85	39
NC	Charlotte	CLT	0	0	12	37	155	342	441	432	230	42	5	1
NC	Greensboro	GSO	0	0	10	38	143	329	434	424	204	36	4	0
NC	Hickory	HKY	0	0	8	34	130	315	400	394	185	30	3	0
NC	New Bern	EWN	1	2	15	60	177	375	481	467	276	84	12	5
NC	Raleigh Durham	RDU	1	1	14	52	172	374	489	462	245	54	8	1
NC	Wilmington	ILM	2	3	16	62	191	384	487	458	282	94	14	4
ND	Bismarck	BIS	0	0	0	1	12	77	248	170	44	3	0	0
ND	Devil's Lake	P11	0	0	0	0	7	61	179	120	32	5	0	0
ND	Fargo	FAR	0	0	1	2	25	108	233	151	55	10	0	0
ND	Grand Forks	GFK	0	0	0	1	11	67	180	117	36	3	0	0
ND	Minot	MOT	0	0	0	1	6	62	200	144	38	2	0	0
ND	Williston	ISN	0	0	0	0	8	50	225	158	31	2	0	0
NE	Grand Island	GRI	0	0	2	13	75	223	389	306	98	17	0	0
NE	Lincoln	LNK	0	0	4	18	86	253	428	343	107	23	1	0

Station Location		Code	Monthly Cooling Degree Days											
State	City		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
NE	Norfolk	OFK	0	0	2	16	68	199	366	279	88	19	0	0
NE	North Platte	LBF	0	0	1	3	38	156	353	257	73	9	0	0
NE	Omaha	OMA	0	0	5	19	87	252	424	337	115	24	1	0
NE	Scottsbluff	BFF	0	0	0	1	28	144	348	253	59	2	0	0
NE	Valentine	VTN	0	0	1	3	34	142	365	273	79	7	0	0
NH	Concord	CON	0	0	0	3	20	91	196	158	39	2	0	0
NH	Lebanon	LEB	0	0	0	2	22	87	174	145	36	3	0	0
NJ	Atlantic City	ACY	0	0	0	14	66	222	387	338	146	23	1	0
NJ	Newark	EWR	0	0	1	17	73	252	423	374	165	20	0	0
NM	Albuquerque	ABQ	0	0	0	8	118	354	471	393	179	18	0	0
NM	Carlsbad	CNM	0	3	22	93	283	509	522	515	278	78	5	0
NM	Clayton	CAO	0	0	1	9	75	240	378	318	121	20	1	0
NM	Gallup	GUP	0	0	0	0	5	71	221	148	23	0	0	0
NM	Roswell	ROW	0	0	7	55	217	461	508	475	247	53	2	0
NV	Elko	EKO	0	0	0	0	9	58	261	178	22	2	0	0
NV	Ely	ELY	0	0	0	0	3	25	151	95	7	0	0	0
NV	Las Vegas	LAS	0	0	39	121	419	685	910	830	572	202	17	0
NV	Lovelock	LOL	0	0	0	3	54	177	437	319	89	6	0	0
NV	Reno	RNO	0	0	0	3	47	172	421	328	123	6	0	0
NV	Tonopah	TPH	0	0	0	1	35	160	360	281	101	9	0	0
NV	Winnemucca	WMC	0	0	0	0	18	82	301	191	31	1	0	0
NY	Albany	ALB	0	0	0	6	36	134	251	203	58	4	0	0
NY	Binghamton	BGM	0	0	0	5	28	88	166	129	38	3	0	0
NY	Buffalo	BUF	0	0	1	2	34	117	224	188	62	7	0	0
NY	Glens Falls	GFL	0	0	0	1	21	82	160	131	29	1	0	0
NY	Massena	MSS	0	0	0	2	16	86	188	135	36	1	0	0
NY	New York	LGA	0	0	0	10	68	254	435	396	195	30	1	0
NY	Rochester	ROC	0	0	1	5	34	120	219	175	55	7	0	0
NY	Syracuse	SYR	0	0	0	6	39	129	241	196	61	4	0	0
NY	Utica	UCA	1	0	5	30	147	292	410	354	163	32	0	0
NY	Watertown	ART	0	0	0	2	23	82	162	157	46	4	0	0
OH	Akron Canton	CAK	0	0	2	6	53	145	247	208	69	9	0	0
OH	Cincinnati	CVG	0	0	7	18	89	233	348	341	143	22	0	0
OH	Cleveland	CLE	0	0	3	12	57	172	282	234	82	12	0	0
OH	Columbus	CMH	0	0	4	13	89	224	339	308	123	20	0	0
OH	Dayton	DAY	0	0	4	12	75	198	302	264	98	16	0	0
OH	Findlay	FDY	0	0	3	10	71	197	293	233	87	15	0	0
OH	Mansfield	MFD	0	0	2	8	56	142	230	199	65	10	0	0
OH	Toledo	TOL	0	0	2	8	52	179	286	226	78	11	0	0
OH	Youngstown	YNG	0	0	1	8	41	113	205	167	52	7	0	0
OK	Hobart	HBR	0	1	22	59	229	476	611	598	305	80	7	0
OK	McAlester	MLC	2	4	34	76	203	419	567	564	285	86	17	3
OK	Oklahoma City	OKC	0	1	22	60	205	427	580	562	272	70	9	1
OK	Tulsa	TUL	1	2	27	70	211	433	603	572	263	72	10	1
OR	Astoria	AST	0	0	0	0	3	3	8	6	6	0	0	0
OR	Baker	BKE	0	0	0	0	5	15	107	69	6	0	0	0

Station Location		Code	Monthly Cooling Degree Days											
State	City		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
OR	Eugene	EUG	0	0	0	0	4	18	115	107	33	1	0	0
OR	Medford	MFR	0	0	0	4	36	104	342	305	135	6	0	0
OR	Pendleton	PDT	0	0	0	1	22	70	278	233	57	4	0	0
OR	Portland	PDX	0	0	0	1	19	51	172	168	67	2	0	0
OR	Redmond	RDM	0	0	0	0	7	22	127	86	16	0	0	0
OR	Salem	SLE	0	0	0	0	12	33	144	132	46	1	0	0
PA	Allentown	ABE	0	0	0	8	57	176	308	253	86	9	0	0
PA	Altoona	AOO	0	0	1	7	45	127	213	172	51	7	0	0
PA	Bradford	BFD	0	0	0	1	13	42	79	58	17	1	0	0
PA	Du Bois	DUJ	0	0	0	4	32	78	147	126	35	5	0	0
PA	Erie	ERI	0	0	1	8	39	130	235	202	74	14	0	0
PA	Harrisburg	CXY	0	0	0	11	76	222	350	301	115	13	0	0
PA	Philadelphia	PHL	0	0	1	18	96	278	445	394	187	26	0	0
PA	Pittsburgh	PIT	0	0	1	9	59	151	263	231	76	9	0	0
PA	Williamsport	IPT	0	0	0	7	55	167	283	226	74	7	0	0
RI	Providence	PVD	0	0	0	3	27	137	301	266	88	10	0	0
SC	Charleston	CHS	3	4	30	97	268	454	542	529	360	134	26	7
SC	Columbia	CAE	1	2	27	83	252	448	540	527	329	86	12	2
SC	Florence	FLO	2	2	23	75	225	419	513	500	311	88	14	5
SC	Greenville	GSP	0	0	15	43	170	372	461	448	246	48	6	1
SD	Aberdeen	ABR	0	0	1	1	20	106	257	162	47	6	0	0
SD	Huron	HON	0	0	2	5	30	137	329	228	71	8	0	0
SD	Pierre	PIR	0	0	1	3	26	132	369	281	84	9	0	0
SD	Rapid City	RAP	0	0	0	1	15	94	320	240	61	6	0	0
SD	Sioux Falls	FSD	0	0	2	8	36	138	306	210	70	11	0	0
TN	Bristol	TRI	0	0	1	12	83	229	321	323	131	14	1	0
TN	Chattanooga	CHA	0	0	16	50	184	391	479	496	261	53	4	0
TN	Crossville	CSV	0	0	4	25	93	218	316	316	127	16	1	0
TN	Jackson	MKL	1	1	21	64	191	361	458	457	221	47	6	1
TN	Knoxville	TYS	0	0	10	41	152	336	426	427	211	36	3	0
TN	Memphis	MEM	1	2	35	86	266	481	562	569	334	100	12	1
TN	Nashville	BNA	0	1	16	56	170	370	477	475	243	48	5	0
TX	Abilene	ABI	2	9	45	128	289	487	581	583	327	121	27	3
TX	Alice	ALI	42	72	174	303	495	599	647	685	520	332	149	67
TX	Amarillo	AMA	0	0	7	24	134	338	440	403	173	34	1	0
TX	Austin	AUS	10	18	68	159	363	534	588	632	424	193	64	13
TX	Brownsville	BRO	73	101	213	348	510	596	629	664	532	382	200	88
TX	College Station	CLL	14	22	85	186	390	562	627	671	475	235	76	20
TX	Corpus Christi	CRP	36	60	156	283	448	549	601	653	510	335	139	56
TX	Dallas-Ft. Worth	DFW	6	11	53	127	338	561	680	702	429	173	45	7
TX	Del Rio	DRT	3	23	118	251	446	617	653	682	477	252	60	5
TX	El Paso	ELP	0	1	24	111	336	569	593	549	339	117	4	0
TX	Galveston	GLS	10	14	91	223	420	573	619	665	540	372	152	36
TX	Houston	IAH	17	27	92	193	408	565	609	649	472	251	80	27
TX	Laredo	LRD	48	90	260	431	625	744	743	800	598	416	187	57
TX	Lubbock	LBB	0	0	16	67	227	436	495	473	224	62	5	0

Station Location		Code	Monthly Cooling Degree Days											
State	City		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
TX	Lufkin	LFK	12	16	63	144	341	513	584	620	412	178	53	14
TX	McAllen	MFE	75	117	257	394	561	657	691	728	582	423	214	90
TX	Midland Odessa	MAF	0	2	32	121	309	527	544	535	300	104	9	1
TX	San Angelo	SJT	2	9	51	150	338	540	585	593	347	130	26	3
TX	San Antonio	SAT	10	28	90	205	409	568	617	665	463	245	79	16
TX	Victoria	VCT	17	36	105	211	412	552	597	642	475	263	92	31
TX	Waco	ACT	6	11	55	141	337	549	653	678	420	177	50	9
TX	Wichita Falls	SPS	1	5	39	107	284	514	650	649	348	117	19	2
UT	Cedar City	CDC	0	0	0	0	12	111	306	224	42	2	0	0
UT	Salt Lake City	SLC	0	0	0	5	55	204	507	411	136	13	0	0
VA	Lynchburg	LYH	0	0	3	21	84	225	349	333	124	16	1	0
VA	Norfolk	ORF	1	1	10	49	146	348	486	452	262	68	7	1
VA	Richmond	RIC	0	1	7	43	145	342	475	439	222	47	3	0
VA	Roanoke	ROA	0	0	8	30	110	271	385	371	152	26	2	0
VT	Burlington	BTV	0	0	1	4	24	108	208	166	47	2	0	0
VT	Montpelier	MPV	0	0	0	1	12	58	115	96	21	1	0	0
WA	Bellingham	BLI	0	0	0	0	1	4	27	21	2	0	0	0
WA	Olympia	OLM	0	0	0	0	2	12	56	44	7	0	0	0
WA	Quillayute	UIL	0	0	0	0	2	4	11	11	3	0	0	0
WA	Seattle Tacoma	SEA	0	0	0	0	6	26	89	76	23	0	0	0
WA	Spokane	GEG	0	0	0	0	14	49	231	186	44	1	0	0
WA	Walla Walla	ALW	0	0	0	1	38	112	374	331	104	7	0	0
WA	Yakima	YKM	0	0	0	0	23	80	256	198	42	1	0	0
WI	Eau Claire	EAU	0	0	2	2	30	117	241	165	57	10	0	0
WI	Green Bay	GRB	0	0	1	1	24	105	201	140	46	8	0	0
WI	Lacrosse	LSE	0	0	3	8	46	174	309	227	80	15	0	0
WI	Madison	MSN	0	0	3	2	36	139	250	186	63	10	0	0
WI	Milwaukee	MKE	0	0	2	4	26	129	260	227	79	11	0	0
WI	Wausau	AUW	0	0	1	1	23	95	200	138	41	6	0	0
WV	Beckley	BKW	0	0	2	13	42	111	193	187	61	6	1	0
WV	Charleston	CRW	0	0	9	29	95	229	332	326	137	19	1	0
WV	Elkins	EKN	0	0	0	1	24	81	154	156	39	4	0	0
WV	Huntington	HTS	0	0	11	29	95	237	340	334	140	20	2	0
WV	Martinsburg	MRB	0	0	1	13	70	205	336	295	107	13	0	0
WV	Morgantown	MGW	0	0	4	18	75	169	282	264	102	17	1	0
WV	Parkersburg	PKB	0	0	5	19	79	190	302	291	113	17	0	0
WY	Casper	CPR	0	0	0	0	6	54	238	162	25	1	0	0
WY	Cheyenne	CYS	0	0	0	0	5	54	204	141	22	1	0	0
WY	Cody	COD	0	0	0	1	12	59	240	167	34	4	0	0
WY	Lander	LND	0	0	0	0	9	71	270	194	30	1	0	0
WY	Rock Springs	RKS	0	0	0	0	3	43	196	123	8	0	0	0
WY	Sheridan	SHR	0	0	0	0	4	49	239	181	30	2	0	0
WY	Worland	WRL	0	0	1	3	15	94	305	220	37	7	0	0

Table 7C.3.4 Weather Station Monthly Heating Degree Day Data Fractions (10-Year Average)

Station Location		Code	Monthly Heating Degree Day Fractions											
State	**City**		**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
AK	Anchorage	ANC	15%	12%	12%	8%	5%	3%	2%	2%	5%	8%	13%	14%
AK	Bethel	BET	15%	12%	13%	9%	5%	3%	2%	3%	4%	8%	12%	13%
AK	Cold Bay	CDB	12%	10%	12%	10%	8%	6%	5%	4%	5%	8%	10%	11%
AK	Cordova	CDV	13%	11%	12%	9%	6%	4%	3%	4%	5%	8%	12%	12%
AK	Homer	HOM	14%	11%	12%	9%	6%	5%	3%	3%	5%	8%	12%	12%
AK	Juneau	JNU	14%	12%	12%	9%	6%	4%	3%	3%	5%	8%	12%	13%
AK	Kenai	ENA	15%	12%	12%	8%	5%	3%	2%	3%	5%	8%	12%	14%
AK	Ketchikan	KTN	13%	12%	12%	9%	7%	4%	3%	3%	5%	8%	11%	13%
AK	King Salmon	AKN	15%	11%	13%	8%	6%	4%	3%	3%	5%	8%	12%	13%
AK	Kodiak	ADQ	12%	11%	12%	9%	7%	5%	4%	3%	5%	8%	11%	12%
AK	Sitka	SIT	13%	11%	12%	9%	7%	5%	4%	3%	5%	8%	11%	12%
AK	St Paul Island	SNP	12%	10%	12%	10%	8%	6%	5%	4%	5%	7%	9%	10%
AK	Talkeetna	TKA	16%	12%	12%	8%	5%	2%	1%	2%	5%	9%	13%	15%
AK	Valdez	VWS	16%	12%	13%	8%	5%	3%	2%	2%	4%	8%	13%	14%
AK	Yakutat	YAK	13%	11%	12%	9%	7%	5%	3%	4%	5%	8%	11%	12%
AL	Birmingham	BHM	25%	20%	10%	4%	1%	0%	0%	0%	0%	5%	12%	22%
AL	Huntsville	HSV	24%	20%	11%	5%	1%	0%	0%	0%	0%	5%	13%	22%
AL	Mobile	MOB	27%	21%	9%	3%	0%	0%	0%	0%	0%	3%	13%	24%
AL	Montgomery	MGM	26%	20%	10%	3%	0%	0%	0%	0%	0%	4%	13%	23%
AL	Muscle Shoals	MSL	24%	20%	11%	5%	1%	0%	0%	0%	0%	5%	12%	22%
AL	Tuscaloosa	TCL	25%	20%	10%	4%	1%	0%	0%	0%	0%	5%	13%	23%
AR	Fayetteville	FYV	22%	19%	12%	6%	2%	0%	0%	0%	1%	6%	12%	21%
AR	Fort Smith	FSM	25%	20%	11%	4%	1%	0%	0%	0%	0%	4%	12%	23%
AR	Little Rock	LIT	25%	20%	11%	4%	1%	0%	0%	0%	0%	4%	12%	23%
AR	Texarkana	TXK	26%	21%	10%	4%	1%	0%	0%	0%	0%	4%	12%	24%
AZ	Douglas	DUG	24%	18%	13%	5%	1%	0%	0%	0%	0%	3%	13%	24%
AZ	Flagstaff	FLG	16%	14%	12%	10%	6%	2%	0%	1%	3%	8%	12%	16%
AZ	Phoenix	PHX	28%	21%	8%	1%	0%	0%	0%	0%	0%	1%	8%	34%
AZ	Tucson	TUS	25%	21%	11%	3%	0%	0%	0%	0%	0%	1%	10%	28%
AZ	Winslow	INW	21%	16%	12%	7%	2%	0%	0%	0%	0%	6%	13%	21%
AZ	Yuma	NYL	24%	21%	7%	2%	0%	0%	0%	0%	0%	0%	9%	37%
CA	Bakersfield	BFL	24%	16%	11%	7%	1%	0%	0%	0%	0%	3%	14%	25%
CA	Blythe	BLH	27%	19%	7%	1%	0%	0%	0%	0%	0%	1%	11%	34%
CA	Eureka	EKA	11%	10%	10%	10%	8%	6%	5%	5%	6%	7%	9%	11%
CA	Fresno	FAT	24%	17%	11%	7%	1%	0%	0%	0%	0%	2%	13%	24%
CA	Los Angeles	LAX	17%	17%	16%	12%	5%	1%	0%	0%	0%	3%	10%	20%
CA	Mt Shasta	MHS	16%	14%	13%	10%	6%	2%	0%	0%	2%	7%	13%	16%
CA	Paso Robles	PRB	19%	16%	13%	10%	3%	1%	0%	0%	1%	5%	13%	20%
CA	Red Bluff	RBL	21%	16%	13%	9%	2%	0%	0%	0%	0%	3%	14%	22%
CA	Redding	RDD	20%	16%	13%	9%	2%	0%	0%	0%	0%	4%	14%	22%
CA	Sacramento	SAC	22%	16%	12%	8%	2%	0%	0%	0%	0%	3%	14%	22%
CA	San Diego	SAN	19%	18%	14%	10%	4%	1%	0%	0%	0%	1%	10%	22%
CA	San Francisco	SFO	17%	13%	12%	10%	7%	4%	2%	2%	2%	4%	10%	16%
CA	Stockton	SCK	23%	16%	12%	8%	2%	0%	0%	0%	0%	3%	13%	22%

Station Location		Code	Monthly Heating Degree Day Fractions											
State	**City**		**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
CO	Alamosa	ALS	17%	15%	11%	8%	5%	2%	0%	1%	3%	8%	12%	18%
CO	Colorado Spring	COS	17%	16%	12%	9%	4%	1%	0%	0%	2%	7%	12%	18%
CO	Denver	DEN	18%	16%	12%	8%	4%	1%	0%	0%	2%	7%	13%	19%
CO	Eagle	EGE	18%	15%	12%	8%	5%	2%	0%	0%	3%	8%	12%	18%
CO	Pueblo	PUB	19%	17%	12%	7%	3%	0%	0%	0%	1%	7%	13%	20%
CO	Trinidad	TAD	19%	17%	12%	8%	3%	1%	0%	0%	2%	7%	13%	19%
CT	Bridgeport	BDR	21%	18%	15%	8%	4%	1%	0%	0%	1%	5%	11%	17%
CT	Hartford	BDL	21%	17%	14%	8%	3%	1%	0%	0%	1%	6%	11%	17%
DC	Washington	DCA	23%	19%	13%	6%	2%	0%	0%	0%	0%	5%	11%	20%
DE	Wilmington	ILG	21%	19%	14%	7%	3%	0%	0%	0%	1%	6%	11%	18%
FL	Daytona Beach	DAB	32%	23%	10%	3%	0%	0%	0%	0%	0%	2%	8%	23%
FL	Fort Myers	FMY	39%	21%	8%	1%	0%	0%	0%	0%	0%	1%	5%	25%
FL	Ft Lauderdale	FLL	41%	23%	7%	1%	0%	0%	0%	0%	0%	0%	3%	25%
FL	Gainesville	GNV	29%	21%	10%	3%	0%	0%	0%	0%	0%	2%	10%	24%
FL	Jacksonville	JAX	28%	21%	10%	4%	0%	0%	0%	0%	0%	2%	11%	23%
FL	Key West	EYW	49%	22%	6%	0%	0%	0%	4%	0%	0%	0%	1%	18%
FL	Melbourne	MLB	35%	22%	9%	3%	0%	0%	0%	0%	0%	2%	7%	22%
FL	Miami	MIA	43%	23%	7%	0%	0%	0%	0%	0%	0%	0%	3%	25%
FL	Orlando	MCO	35%	22%	9%	2%	0%	0%	0%	0%	0%	2%	7%	24%
FL	Pensacola	PNS	28%	22%	9%	3%	0%	0%	0%	0%	0%	3%	11%	24%
FL	Tallahassee	TLH	27%	21%	10%	3%	0%	0%	0%	0%	0%	3%	12%	24%
FL	Tampa	TPA	35%	22%	9%	2%	0%	0%	0%	0%	0%	1%	6%	25%
FL	Vero Beach	VRB	35%	23%	10%	3%	0%	0%	0%	0%	0%	1%	6%	22%
FL	West Palm Beach	PBI	39%	22%	8%	2%	0%	0%	0%	0%	0%	1%	5%	23%
GA	Albany	ABY	27%	21%	10%	3%	0%	0%	0%	0%	0%	3%	12%	24%
GA	Athens	AHN	24%	19%	11%	5%	1%	0%	0%	0%	0%	5%	13%	22%
GA	Atlanta	ATL	25%	20%	11%	5%	1%	0%	0%	0%	0%	4%	12%	22%
GA	Augusta	AGS	25%	20%	11%	4%	0%	0%	0%	0%	0%	4%	13%	22%
GA	Brunswick	SSI	28%	22%	10%	4%	0%	0%	0%	0%	0%	2%	10%	23%
GA	Columbus	CSG	27%	21%	10%	3%	0%	0%	0%	0%	0%	3%	12%	23%
GA	Macon	MCN	25%	20%	11%	4%	0%	0%	0%	0%	0%	4%	13%	23%
GA	Savannah	SAV	27%	21%	11%	4%	0%	0%	0%	0%	0%	3%	12%	22%
GA	Waycross	AYS	27%	21%	9%	3%	0%	1%	0%	0%	0%	3%	12%	24%
HI	Hilo-Hawaii	ITO	8%	8%	8%	8%	8%	8%	8%	8%	8%	8%	8%	8%
HI	Honolulu-Oahu	HNL	8%	8%	8%	8%	8%	8%	8%	8%	8%	8%	8%	8%
HI	Kahului-Maui	OGG	0%	50%	50%	0%	0%	0%	0%	0%	0%	0%	0%	0%
HI	Lihue-Kauai	LIH	0%	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
IA	Burlington	BRL	22%	19%	12%	6%	2%	0%	0%	0%	1%	6%	11%	20%
IA	Cedar Rapids	CID	21%	18%	12%	7%	3%	0%	0%	0%	2%	7%	11%	19%
IA	Des Moines	DSM	22%	19%	12%	6%	2%	0%	0%	0%	1%	6%	12%	20%
IA	Dubuque	DBQ	21%	18%	12%	7%	3%	0%	0%	0%	2%	7%	11%	19%
IA	Mason City	MCW	20%	17%	12%	7%	3%	0%	0%	0%	2%	7%	12%	18%
IA	Ottumwa	OTM	22%	18%	12%	6%	3%	0%	0%	0%	2%	7%	12%	19%
IA	Sioux City	SUX	21%	18%	12%	6%	3%	0%	0%	0%	2%	7%	12%	19%
IA	Waterloo	ALO	21%	18%	12%	7%	3%	0%	0%	0%	2%	7%	12%	19%
ID	Boise	BOI	19%	15%	12%	8%	4%	1%	0%	0%	1%	7%	14%	19%

Station Location		Code	Monthly Heating Degree Day Fractions											
State	City		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ID	Burley	BYI	17%	15%	12%	9%	5%	2%	0%	0%	3%	8%	13%	17%
ID	Idaho Falls	IDA	18%	15%	12%	8%	5%	2%	0%	0%	3%	8%	12%	17%
ID	Lewiston	LWS	18%	15%	12%	8%	4%	1%	0%	0%	1%	8%	14%	19%
ID	Pocatello	PIH	18%	15%	12%	8%	5%	2%	0%	0%	3%	8%	13%	17%
IL	Chicago	ORD	21%	18%	13%	7%	3%	0%	0%	0%	1%	6%	11%	18%
IL	Moline	MLI	22%	19%	12%	6%	2%	0%	0%	0%	1%	6%	11%	19%
IL	Peoria	PIA	22%	19%	12%	6%	2%	0%	0%	0%	1%	6%	12%	20%
IL	Quincy	UIN	22%	19%	12%	6%	2%	0%	0%	0%	1%	6%	12%	20%
IL	Rockford	RFD	21%	18%	13%	7%	3%	0%	0%	0%	2%	6%	11%	19%
IL	Springfield	SPI	22%	19%	12%	6%	2%	0%	0%	0%	1%	6%	11%	20%
IN	Evansville	EVV	23%	19%	12%	6%	2%	0%	0%	0%	1%	6%	12%	20%
IN	Fort Wayne	FWA	21%	18%	13%	7%	3%	0%	0%	0%	1%	7%	11%	18%
IN	Indianapolis	IND	22%	19%	12%	6%	2%	0%	0%	0%	1%	6%	12%	19%
IN	South Bend	SBN	21%	18%	13%	7%	3%	0%	0%	0%	2%	7%	11%	18%
IN	West Lafayette	LAF	22%	19%	12%	6%	3%	0%	0%	0%	1%	6%	11%	19%
KS	Concordia	CNK	22%	18%	11%	6%	2%	0%	0%	0%	1%	6%	12%	21%
KS	Dodge City	DDC	21%	18%	12%	7%	2%	0%	0%	0%	1%	6%	13%	21%
KS	Garden City	GCK	21%	18%	12%	7%	2%	0%	0%	0%	1%	6%	13%	21%
KS	Goodland	GLD	19%	17%	12%	8%	3%	0%	0%	0%	2%	7%	13%	19%
KS	Russell	RSL	21%	18%	12%	6%	2%	0%	0%	0%	1%	6%	13%	21%
KS	Salina	SLN	22%	19%	11%	6%	2%	0%	0%	0%	1%	5%	12%	21%
KS	Topeka	TOP	23%	19%	11%	6%	2%	0%	0%	0%	1%	6%	12%	20%
KS	Wichita	ICT	23%	19%	11%	6%	2%	0%	0%	0%	1%	5%	12%	22%
KY	Bowling Green	BWG	23%	19%	11%	6%	2%	0%	0%	0%	1%	6%	12%	20%
KY	Jackson	JKL	23%	19%	12%	6%	2%	0%	0%	0%	1%	6%	11%	20%
KY	Lexington	LEX	22%	19%	12%	6%	2%	0%	0%	0%	1%	6%	12%	19%
KY	Louisville	SDF	24%	20%	12%	5%	1%	0%	0%	0%	0%	5%	12%	20%
KY	Paducah	PAH	22%	19%	12%	6%	2%	0%	0%	0%	1%	6%	12%	20%
LA	Baton Rouge	BTR	27%	21%	9%	3%	0%	0%	0%	0%	0%	3%	12%	25%
LA	Lafayette	LFT	28%	21%	9%	2%	0%	0%	0%	0%	0%	3%	11%	26%
LA	Lake Charles	LCH	28%	22%	9%	2%	0%	0%	0%	0%	0%	2%	11%	25%
LA	Monroe	MLU	26%	21%	10%	3%	0%	0%	0%	0%	0%	4%	12%	24%
LA	New Orleans	MSY	29%	22%	8%	2%	0%	0%	0%	0%	0%	2%	10%	26%
LA	Shreveport	SHV	26%	21%	10%	3%	0%	0%	0%	0%	0%	3%	12%	25%
MA	Boston	BOS	20%	17%	15%	9%	4%	1%	0%	0%	1%	6%	11%	17%
MA	Worcester	ORH	20%	17%	14%	8%	4%	1%	0%	0%	2%	7%	11%	16%
MD	Baltimore	BWI	22%	19%	13%	7%	2%	0%	0%	0%	1%	6%	11%	19%
MD	Salisbury	SBY	21%	19%	14%	8%	3%	0%	0%	0%	1%	6%	11%	18%
ME	Augusta	AUG	20%	16%	14%	8%	4%	1%	0%	0%	2%	7%	11%	16%
ME	Bangor	BGR	19%	16%	14%	8%	4%	1%	0%	0%	2%	7%	11%	16%
ME	Caribou	CAR	19%	16%	14%	8%	5%	2%	0%	1%	3%	7%	10%	16%
ME	Houlton	HUL	18%	16%	13%	9%	5%	2%	1%	1%	3%	7%	10%	15%
ME	Portland	PWM	19%	16%	14%	9%	5%	1%	0%	0%	2%	7%	11%	16%
MI	Alpena	APN	18%	16%	14%	9%	5%	2%	0%	1%	3%	7%	11%	16%
MI	Detroit	DTW	21%	18%	14%	7%	3%	0%	0%	0%	1%	6%	11%	18%
MI	Flint	FNT	20%	17%	13%	8%	4%	1%	0%	0%	2%	7%	11%	17%

Station Location		Code	Monthly Heating Degree Day Fractions											
State	City		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
MI	Grand Rapids	GRR	20%	18%	13%	8%	4%	1%	0%	0%	2%	7%	11%	17%
MI	Houghton Lake	HTL	18%	16%	13%	8%	4%	1%	0%	1%	3%	7%	11%	16%
MI	Jackson	JXN	20%	17%	13%	7%	4%	1%	0%	0%	2%	7%	11%	17%
MI	Lansing	LAN	20%	17%	13%	8%	4%	1%	0%	0%	2%	7%	11%	17%
MI	Marquette	MQT	17%	15%	13%	9%	5%	2%	1%	1%	3%	7%	11%	16%
MI	Muskegon	MKG	19%	17%	14%	8%	4%	1%	0%	0%	2%	7%	11%	16%
MI	Saginaw	MBS	20%	17%	14%	8%	4%	1%	0%	0%	2%	7%	11%	17%
MI	Sault St Marie	SSM	18%	16%	14%	9%	5%	2%	1%	1%	3%	7%	10%	16%
MI	Traverse City	TVC	18%	17%	14%	9%	5%	1%	0%	0%	2%	7%	11%	16%
MN	Alexandria	AXN	20%	17%	13%	7%	4%	1%	0%	0%	2%	7%	12%	18%
MN	Duluth	DLH	19%	16%	13%	8%	5%	2%	0%	1%	3%	7%	11%	17%
MN	Hibbing	HIB	18%	15%	12%	8%	5%	2%	1%	1%	3%	7%	11%	16%
MN	Int'l Falls	INL	19%	16%	12%	7%	4%	2%	1%	1%	3%	7%	11%	17%
MN	Minneapolis	MSP	21%	18%	13%	6%	3%	0%	0%	0%	2%	6%	12%	19%
MN	Rochester	RST	21%	18%	13%	7%	3%	1%	0%	0%	2%	7%	11%	18%
MN	Saint Cloud	STC	20%	17%	13%	7%	4%	1%	0%	0%	2%	7%	12%	18%
MO	Columbia	COU	23%	19%	12%	6%	2%	0%	0%	0%	1%	6%	12%	20%
MO	Joplin	JLN	23%	19%	11%	6%	2%	0%	0%	0%	1%	6%	11%	21%
MO	Kansas City	MCI	23%	19%	12%	6%	2%	0%	0%	0%	1%	6%	12%	20%
MO	Saint Louis	STL	23%	20%	12%	5%	2%	0%	0%	0%	1%	5%	12%	21%
MO	Springfield	SGF	22%	19%	12%	6%	2%	0%	0%	0%	1%	6%	12%	20%
MS	Greenwood	GWO	25%	20%	10%	4%	1%	0%	0%	0%	0%	5%	11%	23%
MS	McComb	MCB	26%	21%	9%	3%	0%	0%	0%	0%	0%	4%	12%	24%
MS	Tupelo	TUP	25%	20%	11%	4%	1%	0%	0%	0%	0%	5%	12%	22%
MT	Billings	BIL	18%	15%	12%	8%	5%	1%	0%	0%	2%	8%	13%	18%
MT	Butte	BTM	15%	13%	11%	9%	6%	3%	1%	1%	4%	8%	12%	16%
MT	Cut Bank	CTB	16%	14%	12%	9%	6%	3%	1%	1%	4%	8%	12%	16%
MT	Great Falls	GTF	16%	14%	12%	9%	6%	3%	0%	1%	3%	8%	12%	16%
MT	Havre	HVR	18%	16%	12%	7%	5%	2%	0%	1%	3%	8%	12%	17%
MT	Helena	HLN	17%	14%	12%	8%	5%	2%	0%	0%	3%	8%	13%	18%
MT	Kalispell	FCA	17%	14%	12%	8%	4%	2%	0%	1%	3%	8%	13%	17%
MT	Lewistown	LWT	16%	14%	12%	9%	6%	3%	1%	1%	3%	8%	12%	16%
MT	Miles City	MLS	19%	16%	12%	7%	4%	1%	0%	0%	2%	7%	13%	18%
MT	Missoula	MSO	17%	14%	11%	8%	5%	2%	0%	0%	3%	8%	13%	17%
NC	Asheville	AVL	21%	18%	12%	7%	2%	0%	0%	0%	1%	7%	13%	19%
NC	Cape Hatteras	HAT	27%	24%	16%	6%	1%	0%	0%	0%	0%	1%	6%	18%
NC	Charlotte	CLT	23%	19%	12%	5%	1%	0%	0%	0%	0%	5%	13%	21%
NC	Greensboro	GSO	23%	19%	12%	6%	2%	0%	0%	0%	0%	5%	13%	20%
NC	Hickory	HKY	23%	19%	12%	6%	2%	0%	0%	0%	0%	6%	12%	21%
NC	New Bern	EWN	24%	20%	13%	5%	1%	0%	0%	0%	0%	4%	12%	20%
NC	Raleigh Durham	RDU	23%	19%	12%	5%	1%	0%	0%	0%	0%	5%	12%	21%
NC	Wilmington	ILM	24%	20%	13%	5%	1%	0%	0%	0%	0%	4%	12%	21%
ND	Bismarck	BIS	19%	17%	13%	7%	4%	1%	0%	0%	2%	7%	12%	18%
ND	Devil's Lake	P11	19%	17%	13%	7%	4%	1%	0%	0%	2%	7%	12%	17%
ND	Fargo	FAR	20%	18%	13%	7%	3%	1%	0%	0%	2%	7%	12%	18%
ND	Grand Forks	GFK	19%	17%	13%	7%	4%	1%	0%	0%	2%	7%	12%	17%

Station Location		Code	Monthly Heating Degree Day Fractions											
State	City		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ND	Minot	MOT	19%	17%	13%	7%	4%	1%	0%	0%	2%	7%	12%	17%
ND	Williston	ISN	18%	16%	12%	7%	4%	1%	0%	0%	3%	7%	12%	18%
NE	Grand Island	GRI	21%	18%	12%	7%	3%	0%	0%	0%	1%	7%	12%	20%
NE	Lincoln	LNK	21%	18%	12%	6%	2%	0%	0%	0%	1%	6%	12%	20%
NE	Norfolk	OFK	21%	17%	12%	7%	3%	0%	0%	0%	2%	7%	12%	19%
NE	North Platte	LBF	19%	16%	12%	8%	4%	1%	0%	0%	2%	7%	13%	19%
NE	Omaha	OMA	22%	18%	12%	6%	2%	0%	0%	0%	1%	6%	12%	20%
NE	Scottsbluff	BFF	18%	16%	12%	8%	4%	1%	0%	0%	2%	8%	13%	19%
NE	Valentine	VTN	19%	17%	12%	8%	4%	1%	0%	0%	2%	7%	13%	18%
NH	Concord	CON	20%	16%	14%	8%	4%	1%	0%	0%	2%	7%	11%	16%
NH	Lebanon	LEB	20%	17%	14%	8%	4%	1%	0%	0%	2%	7%	11%	16%
NJ	Atlantic City	ACY	21%	18%	14%	8%	3%	0%	0%	0%	1%	6%	11%	18%
NJ	Newark	EWR	22%	19%	14%	7%	2%	0%	0%	0%	0%	5%	11%	18%
NM	Albuquerque	ABQ	21%	17%	12%	6%	2%	0%	0%	0%	0%	5%	14%	22%
NM	Carlsbad	CNM	24%	19%	10%	3%	1%	0%	0%	0%	0%	4%	14%	25%
NM	Clayton	CAO	19%	18%	13%	8%	3%	0%	0%	0%	1%	6%	13%	20%
NM	Gallup	GUP	18%	15%	13%	9%	5%	1%	0%	0%	2%	8%	13%	18%
NM	Roswell	ROW	23%	18%	10%	4%	1%	0%	0%	0%	0%	4%	14%	25%
NV	Elko	EKO	18%	15%	12%	9%	5%	2%	0%	0%	2%	8%	13%	17%
NV	Ely	ELY	17%	14%	12%	9%	6%	2%	0%	0%	3%	8%	12%	17%
NV	Las Vegas	LAS	26%	19%	9%	3%	0%	0%	0%	0%	0%	2%	12%	29%
NV	Lovelock	LOL	19%	15%	12%	8%	3%	1%	0%	0%	1%	7%	14%	20%
NV	Reno	RNO	19%	15%	12%	9%	4%	1%	0%	0%	1%	6%	13%	19%
NV	Tonopah	TPH	18%	15%	13%	9%	4%	1%	0%	0%	1%	7%	13%	19%
NV	Winnemucca	WMC	17%	14%	12%	9%	5%	2%	0%	0%	2%	8%	13%	18%
NY	Albany	ALB	20%	17%	14%	8%	3%	1%	0%	0%	2%	7%	11%	17%
NY	Binghamton	BGM	19%	17%	14%	8%	4%	1%	0%	0%	2%	7%	11%	16%
NY	Buffalo	BUF	19%	18%	14%	9%	4%	1%	0%	0%	1%	7%	11%	16%
NY	Glens Falls	GFL	20%	17%	14%	8%	4%	1%	0%	0%	2%	7%	11%	16%
NY	Massena	MSS	20%	17%	14%	8%	4%	1%	0%	0%	2%	7%	11%	16%
NY	New York	LGA	22%	19%	15%	8%	3%	0%	0%	0%	0%	5%	10%	18%
NY	Rochester	ROC	19%	17%	14%	8%	4%	1%	0%	0%	2%	7%	11%	16%
NY	Syracuse	SYR	20%	18%	14%	8%	4%	1%	0%	0%	2%	7%	11%	17%
NY	Utica	UCA	22%	18%	14%	7%	3%	1%	0%	0%	1%	6%	11%	18%
NY	Watertown	ART	20%	17%	14%	8%	4%	1%	0%	0%	2%	7%	10%	16%
OH	Akron Canton	CAK	20%	18%	13%	7%	3%	1%	0%	0%	2%	7%	11%	17%
OH	Cincinnati	CVG	22%	19%	12%	6%	2%	0%	0%	0%	1%	6%	12%	19%
OH	Cleveland	CLE	20%	18%	14%	8%	3%	1%	0%	0%	1%	6%	11%	17%
OH	Columbus	CMH	22%	19%	13%	6%	2%	0%	0%	0%	1%	6%	11%	19%
OH	Dayton	DAY	21%	18%	13%	7%	3%	0%	0%	0%	1%	7%	11%	18%
OH	Findlay	FDY	21%	18%	13%	7%	3%	0%	0%	0%	1%	6%	11%	18%
OH	Mansfield	MFD	20%	18%	13%	7%	3%	1%	0%	0%	2%	7%	11%	17%
OH	Toledo	TOL	21%	18%	13%	7%	3%	0%	0%	0%	1%	6%	11%	18%
OH	Youngstown	YNG	20%	18%	13%	8%	4%	1%	0%	0%	2%	7%	11%	17%
OK	Hobart	HBR	23%	19%	11%	5%	1%	0%	0%	0%	0%	5%	12%	23%
OK	McAlester	MLC	25%	20%	10%	5%	1%	0%	0%	0%	0%	5%	11%	23%

Station Location		**Code**	**Monthly Heating Degree Day Fractions**											
State	**City**		**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
OK	Oklahoma City	OKC	24%	20%	11%	5%	1%	0%	0%	0%	0%	4%	12%	23%
OK	Tulsa	TUL	24%	20%	11%	5%	1%	0%	0%	0%	0%	5%	12%	23%
OR	Astoria	AST	13%	12%	12%	10%	7%	5%	3%	2%	4%	7%	11%	14%
OR	Baker	BKE	16%	13%	11%	9%	6%	3%	1%	1%	3%	8%	13%	16%
OR	Eugene	EUG	15%	13%	12%	10%	7%	3%	0%	0%	2%	8%	13%	16%
OR	Medford	MFR	18%	14%	12%	9%	4%	1%	0%	0%	1%	7%	14%	19%
OR	Pendleton	PDT	17%	14%	12%	9%	5%	2%	0%	0%	2%	8%	14%	19%
OR	Portland	PDX	17%	14%	12%	9%	5%	2%	0%	0%	1%	7%	13%	18%
OR	Redmond	RDM	15%	13%	12%	10%	6%	3%	1%	1%	3%	8%	12%	16%
OR	Salem	SLE	16%	14%	12%	10%	6%	3%	0%	0%	2%	7%	13%	17%
PA	Allentown	ABE	21%	18%	14%	8%	3%	0%	0%	0%	1%	7%	11%	18%
PA	Altoona	AOO	20%	18%	13%	7%	3%	1%	0%	0%	2%	7%	11%	17%
PA	Bradford	BFD	18%	16%	13%	8%	5%	2%	1%	1%	3%	8%	11%	15%
PA	Du Bois	DUJ	19%	17%	13%	8%	4%	1%	0%	0%	2%	7%	11%	17%
PA	Erie	ERI	19%	18%	15%	9%	4%	1%	0%	0%	1%	6%	10%	16%
PA	Harrisburg	CXY	21%	18%	13%	7%	3%	0%	0%	0%	1%	6%	11%	18%
PA	Philadelphia	PHL	22%	19%	14%	7%	2%	0%	0%	0%	0%	5%	11%	19%
PA	Pittsburgh	PIT	21%	18%	13%	7%	3%	0%	0%	0%	1%	7%	11%	18%
PA	Williamsport	IPT	21%	18%	14%	7%	3%	0%	0%	0%	1%	7%	11%	18%
RI	Providence	PVD	20%	17%	14%	8%	4%	1%	0%	0%	1%	6%	11%	17%
SC	Charleston	CHS	27%	21%	11%	4%	0%	0%	0%	0%	0%	3%	12%	22%
SC	Columbia	CAE	25%	20%	11%	4%	1%	0%	0%	0%	0%	4%	13%	22%
SC	Florence	FLO	25%	20%	12%	5%	1%	0%	0%	0%	0%	4%	12%	21%
SC	Greenville	GSP	23%	19%	12%	5%	1%	0%	0%	0%	0%	5%	13%	22%
SD	Aberdeen	ABR	20%	17%	12%	7%	3%	1%	0%	0%	2%	7%	12%	18%
SD	Huron	HON	20%	17%	12%	7%	3%	1%	0%	0%	2%	7%	12%	18%
SD	Pierre	PIR	19%	17%	12%	7%	4%	1%	0%	0%	2%	7%	12%	18%
SD	Rapid City	RAP	18%	16%	12%	8%	5%	1%	0%	0%	2%	7%	12%	18%
SD	Sioux Falls	FSD	20%	17%	12%	7%	3%	0%	0%	0%	2%	7%	12%	19%
TN	Bristol	TRI	22%	18%	12%	6%	2%	0%	0%	0%	1%	6%	13%	20%
TN	Chattanooga	CHA	24%	19%	11%	5%	1%	0%	0%	0%	0%	5%	13%	22%
TN	Crossville	CSV	22%	18%	12%	6%	2%	0%	0%	0%	1%	6%	12%	20%
TN	Jackson	MKL	24%	20%	11%	5%	1%	0%	0%	0%	0%	6%	12%	21%
TN	Knoxville	TYS	23%	19%	11%	5%	1%	0%	0%	0%	0%	6%	13%	21%
TN	Memphis	MEM	25%	21%	11%	4%	1%	0%	0%	0%	0%	4%	12%	23%
TN	Nashville	BNA	24%	19%	11%	5%	1%	0%	0%	0%	0%	5%	12%	21%
TX	Abilene	ABI	25%	20%	10%	3%	1%	0%	0%	0%	0%	4%	12%	25%
TX	Alice	ALI	31%	23%	7%	1%	0%	0%	0%	0%	0%	1%	8%	29%
TX	Amarillo	AMA	21%	18%	12%	6%	2%	0%	0%	0%	1%	6%	13%	21%
TX	Austin	AUS	27%	21%	10%	3%	0%	0%	0%	0%	0%	3%	11%	25%
TX	Brownsville	BRO	31%	24%	6%	2%	0%	0%	0%	0%	0%	0%	6%	31%
TX	College Station	CLL	29%	22%	9%	2%	0%	0%	0%	0%	0%	2%	10%	26%
TX	Corpus Christi	CRP	32%	22%	7%	1%	0%	0%	0%	0%	0%	1%	8%	28%
TX	Dallas-Ft. Worth	DFW	27%	22%	10%	3%	0%	0%	0%	0%	0%	3%	11%	25%
TX	Del Rio	DRT	30%	20%	6%	1%	0%	0%	0%	0%	0%	1%	11%	30%
TX	El Paso	ELP	25%	19%	10%	3%	0%	0%	0%	0%	0%	2%	14%	27%

Station Location		Code	Monthly Heating Degree Day Fractions											
State	**City**		**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
TX	Galveston	GLS	32%	25%	8%	1%	0%	0%	0%	0%	0%	1%	7%	26%
TX	Houston	IAH	29%	22%	8%	2%	0%	0%	0%	0%	0%	2%	10%	27%
TX	Laredo	LRD	33%	22%	5%	1%	0%	0%	0%	0%	0%	1%	7%	31%
TX	Lubbock	LBB	23%	19%	11%	5%	1%	0%	0%	0%	0%	5%	13%	23%
TX	Lufkin	LFK	27%	21%	9%	3%	0%	0%	0%	0%	0%	3%	12%	25%
TX	McAllen	MFE	33%	24%	5%	2%	0%	0%	0%	0%	0%	1%	6%	30%
TX	Midland Odessa	MAF	25%	19%	10%	3%	1%	0%	0%	0%	0%	3%	13%	25%
TX	San Angelo	SJT	26%	20%	9%	3%	0%	0%	0%	0%	0%	3%	12%	25%
TX	San Antonio	SAT	29%	21%	8%	2%	0%	0%	0%	0%	0%	2%	10%	27%
TX	Victoria	VCT	30%	21%	8%	2%	0%	0%	0%	0%	0%	2%	10%	27%
TX	Waco	ACT	27%	21%	10%	3%	0%	0%	0%	0%	0%	3%	11%	25%
TX	Wichita Falls	SPS	25%	21%	10%	4%	1%	0%	0%	0%	0%	4%	12%	24%
UT	Cedar City	CDC	18%	15%	12%	9%	4%	1%	0%	0%	2%	7%	13%	18%
UT	Salt Lake City	SLC	20%	16%	12%	8%	4%	1%	0%	0%	1%	6%	13%	19%
VA	Lynchburg	LYH	21%	18%	12%	6%	2%	0%	0%	0%	1%	6%	12%	19%
VA	Norfolk	ORF	23%	20%	14%	6%	2%	0%	0%	0%	0%	4%	11%	19%
VA	Richmond	RIC	23%	20%	13%	6%	2%	0%	0%	0%	0%	5%	11%	20%
VA	Roanoke	ROA	22%	19%	12%	6%	2%	0%	0%	0%	1%	6%	12%	20%
VT	Burlington	BTV	20%	17%	14%	8%	4%	1%	0%	0%	2%	7%	11%	17%
VT	Montpelier	MPV	19%	16%	13%	8%	4%	1%	0%	1%	3%	7%	11%	16%
WA	Bellingham	BLI	14%	13%	12%	9%	6%	4%	1%	1%	4%	8%	12%	15%
WA	Olympia	OLM	14%	13%	12%	10%	6%	3%	1%	1%	3%	8%	12%	15%
WA	Quillayute	UIL	12%	11%	12%	10%	8%	5%	3%	3%	4%	8%	11%	13%
WA	Seattle Tacoma	SEA	15%	13%	13%	10%	6%	3%	1%	1%	3%	8%	13%	16%
WA	Spokane	GEG	17%	14%	12%	9%	5%	2%	0%	0%	2%	8%	14%	18%
WA	Walla Walla	ALW	18%	15%	11%	8%	4%	1%	0%	0%	1%	7%	14%	20%
WA	Yakima	YKM	18%	14%	11%	8%	4%	1%	0%	0%	2%	8%	14%	19%
WI	Eau Claire	EAU	20%	17%	13%	7%	3%	1%	0%	0%	2%	7%	11%	18%
WI	Green Bay	GRB	20%	17%	13%	8%	4%	1%	0%	0%	2%	7%	11%	17%
WI	Lacrosse	LSE	21%	18%	13%	7%	3%	0%	0%	0%	2%	6%	11%	19%
WI	Madison	MSN	20%	17%	13%	7%	3%	1%	0%	0%	2%	7%	11%	18%
WI	Milwaukee	MKE	20%	17%	13%	8%	4%	1%	0%	0%	2%	6%	11%	17%
WI	Wausau	AUW	20%	17%	13%	7%	4%	1%	0%	0%	2%	7%	11%	17%
WV	Beckley	BKW	20%	17%	12%	7%	3%	1%	0%	0%	2%	7%	12%	18%
WV	Charleston	CRW	22%	19%	12%	6%	2%	0%	0%	0%	1%	6%	12%	19%
WV	Elkins	EKN	19%	17%	13%	8%	4%	1%	0%	0%	2%	7%	12%	17%
WV	Huntington	HTS	22%	19%	12%	6%	2%	0%	0%	0%	1%	6%	12%	19%
WV	Martinsburg	MRB	21%	18%	13%	7%	3%	0%	0%	0%	1%	7%	12%	19%
WV	Morgantown	MGW	21%	18%	13%	7%	3%	0%	0%	0%	1%	7%	11%	18%
WV	Parkersburg	PKB	22%	18%	13%	6%	3%	0%	0%	0%	1%	7%	12%	19%
WY	Casper	CPR	16%	15%	12%	9%	6%	2%	0%	0%	3%	8%	12%	17%
WY	Cheyenne	CYS	16%	15%	12%	9%	6%	2%	0%	0%	3%	8%	12%	17%
WY	Cody	COD	17%	15%	11%	9%	5%	2%	0%	1%	3%	8%	12%	17%
WY	Lander	LND	18%	15%	11%	8%	5%	2%	0%	0%	2%	8%	12%	18%
WY	Rock Springs	RKS	17%	15%	12%	9%	6%	2%	0%	0%	3%	8%	12%	17%
WY	Sheridan	SHR	17%	15%	12%	8%	6%	2%	0%	0%	3%	8%	12%	17%

Station Location		Code	Monthly Heating Degree Day Fractions											
State	City		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
WY	Worland	WRL	19%	16%	11%	7%	4%	1%	0%	0%	2%	7%	13%	19%

Table 7C.3.5 Weather Station Monthly Cooling Degree Day Data Fractions (10-Year Average)

Station Location		Code	Monthly Cooling Degree Day Fractions											
State	City		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
AK	Anchorage	ANC	0%	0%	0%	0%	0%	12%	71%	17%	0%	0%	0%	0%
AK	Bethel	BET	0%	0%	0%	0%	0%	28%	38%	35%	0%	0%	0%	0%
AK	Cold Bay	CDB	8%	8%	8%	8%	8%	8%	8%	8%	8%	8%	8%	8%
AK	Cordova	CDV	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%
AK	Homer	HOM	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%
AK	Juneau	JNU	0%	0%	0%	0%	0%	51%	29%	20%	0%	0%	0%	0%
AK	Kenai	ENA	0%	0%	0%	0%	0%	0%	56%	11%	0%	0%	33%	0%
AK	Ketchikan	KTN	0%	0%	0%	0%	0%	27%	42%	31%	0%	0%	0%	0%
AK	King Salmon	AKN	0%	0%	0%	0%	0%	4%	30%	65%	0%	0%	0%	0%
AK	Kodiak	ADQ	0%	0%	0%	0%	0%	5%	73%	22%	0%	0%	0%	0%
AK	Sitka	SIT	0%	0%	0%	0%	0%	24%	11%	66%	0%	0%	0%	0%
AK	St Paul Island	SNP	8%	8%	8%	8%	8%	8%	8%	8%	8%	8%	8%	8%
AK	Talkeetna	TKA	0%	0%	0%	0%	0%	23%	53%	24%	0%	0%	0%	0%
AK	Valdez	VWS	0%	0%	0%	0%	20%	16%	36%	28%	0%	0%	0%	0%
AK	Yakutat	YAK	0%	0%	0%	0%	0%	0%	25%	75%	0%	0%	0%	0%
AL	Birmingham	BHM	0%	0%	2%	4%	11%	19%	23%	23%	14%	4%	1%	0%
AL	Huntsville	HSV	0%	0%	1%	3%	11%	20%	24%	24%	13%	3%	0%	0%
AL	Mobile	MOB	0%	0%	2%	4%	12%	18%	20%	20%	15%	6%	2%	1%
AL	Montgomery	MGM	0%	0%	2%	4%	11%	19%	22%	22%	15%	5%	1%	0%
AL	Muscle Shoals	MSL	0%	0%	1%	4%	11%	19%	24%	24%	13%	3%	0%	0%
AL	Tuscaloosa	TCL	0%	0%	1%	4%	11%	19%	23%	23%	14%	4%	1%	0%
AR	Fayetteville	FYV	0%	0%	1%	2%	8%	20%	28%	29%	10%	2%	0%	0%
AR	Fort Smith	FSM	0%	0%	1%	3%	10%	19%	25%	25%	13%	4%	0%	0%
AR	Little Rock	LIT	0%	0%	1%	3%	10%	20%	24%	25%	13%	4%	0%	0%
AR	Texarkana	TXK	0%	0%	2%	4%	11%	19%	23%	23%	13%	4%	1%	0%
AZ	Douglas	DUG	0%	0%	0%	2%	10%	22%	25%	22%	15%	4%	0%	0%
AZ	Flagstaff	FLG	0%	0%	0%	0%	0%	13%	60%	26%	1%	0%	0%	0%
AZ	Phoenix	PHX	0%	0%	2%	5%	11%	17%	20%	19%	15%	8%	2%	0%
AZ	Tucson	TUS	0%	0%	1%	4%	11%	19%	21%	20%	15%	7%	1%	0%
AZ	Winslow	INW	0%	0%	0%	0%	6%	20%	34%	27%	11%	1%	0%	0%
AZ	Yuma	NYL	0%	0%	3%	5%	11%	15%	20%	19%	16%	8%	2%	0%
CA	Bakersfield	BFL	0%	0%	1%	2%	9%	17%	26%	24%	17%	5%	0%	0%
CA	Blythe	BLH	0%	0%	2%	5%	11%	16%	21%	20%	15%	7%	1%	0%
CA	Eureka	EKA	0%	0%	0%	4%	10%	5%	5%	24%	17%	31%	4%	0%
CA	Fresno	FAT	0%	0%	0%	2%	9%	17%	27%	24%	17%	5%	0%	0%
CA	Los Angeles	LAX	2%	1%	2%	3%	4%	7%	22%	24%	20%	12%	4%	0%
CA	Mt Shasta	MHS	0%	0%	0%	0%	4%	10%	44%	32%	10%	0%	0%	0%
CA	Paso Robles	PRB	0%	0%	0%	1%	6%	15%	29%	27%	18%	4%	0%	0%
CA	Red Bluff	RBL	0%	0%	0%	1%	7%	18%	28%	24%	16%	4%	0%	0%

Station Location		Code	Monthly Cooling Degree Day Fractions											
State	City		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
CA	Redding	RDD	0%	0%	0%	1%	7%	18%	29%	25%	16%	4%	0%	0%
CA	Sacramento	SAC	0%	0%	0%	1%	7%	17%	28%	25%	18%	4%	0%	0%
CA	San Diego	SAN	1%	0%	1%	2%	4%	7%	22%	27%	22%	10%	3%	0%
CA	San Francisco	SFO	0%	0%	1%	3%	6%	12%	13%	19%	31%	14%	1%	0%
CA	Stockton	SCK	0%	0%	0%	2%	7%	17%	28%	25%	17%	4%	0%	0%
CO	Alamosa	ALS	0%	0%	0%	0%	0%	11%	62%	26%	1%	0%	0%	0%
CO	Colorado Spring	COS	0%	0%	0%	0%	3%	20%	42%	28%	7%	0%	0%	0%
CO	Denver	DEN	0%	0%	0%	0%	4%	17%	39%	31%	9%	1%	0%	0%
CO	Eagle	EGE	0%	0%	0%	0%	1%	13%	55%	30%	1%	0%	0%	0%
CO	Pueblo	PUB	0%	0%	0%	0%	4%	20%	38%	29%	8%	1%	0%	0%
CO	Trinidad	TAD	0%	0%	0%	0%	4%	20%	37%	29%	9%	1%	0%	0%
CT	Bridgeport	BDR	0%	0%	0%	0%	3%	17%	35%	32%	13%	1%	0%	0%
CT	Hartford	BDL	0%	0%	0%	1%	5%	18%	35%	30%	10%	1%	0%	0%
DC	Washington	DCA	0%	0%	0%	2%	7%	20%	29%	27%	13%	2%	0%	0%
DE	Wilmington	ILG	0%	0%	0%	1%	6%	19%	32%	28%	12%	2%	0%	0%
FL	Daytona Beach	DAB	1%	1%	3%	5%	11%	15%	17%	17%	15%	10%	3%	2%
FL	Fort Myers	FMY	2%	3%	5%	7%	11%	13%	14%	14%	13%	10%	5%	3%
FL	Ft Lauderdale	FLL	3%	4%	6%	7%	10%	12%	13%	13%	12%	10%	6%	5%
FL	Gainesville	GNV	1%	1%	2%	5%	12%	16%	18%	19%	15%	8%	2%	1%
FL	Jacksonville	JAX	0%	1%	2%	4%	11%	17%	20%	20%	15%	8%	2%	1%
FL	Key West	EYW	3%	4%	6%	7%	10%	11%	13%	13%	12%	10%	7%	4%
FL	Melbourne	MLB	1%	2%	4%	6%	11%	14%	15%	16%	14%	10%	5%	3%
FL	Miami	MIA	3%	4%	6%	7%	10%	12%	13%	13%	12%	10%	6%	4%
FL	Orlando	MCO	1%	2%	4%	6%	11%	14%	16%	16%	14%	9%	4%	2%
FL	Pensacola	PNS	0%	0%	2%	4%	12%	18%	20%	19%	15%	7%	2%	0%
FL	Tallahassee	TLH	0%	0%	2%	4%	12%	18%	20%	20%	15%	7%	1%	0%
FL	Tampa	TPA	1%	2%	4%	6%	12%	14%	15%	16%	14%	10%	4%	2%
FL	Vero Beach	VRB	2%	2%	4%	6%	11%	13%	15%	15%	14%	10%	5%	3%
FL	West Palm Beach	PBI	2%	3%	5%	7%	11%	12%	14%	14%	12%	10%	6%	4%
GA	Albany	ABY	0%	0%	2%	4%	12%	18%	21%	20%	15%	6%	1%	0%
GA	Athens	AHN	0%	0%	1%	3%	10%	20%	25%	25%	14%	3%	0%	0%
GA	Atlanta	ATL	0%	0%	1%	3%	10%	20%	24%	24%	14%	4%	0%	0%
GA	Augusta	AGS	0%	0%	1%	3%	10%	19%	24%	24%	15%	4%	0%	0%
GA	Brunswick	SSI	0%	0%	2%	4%	11%	17%	20%	20%	15%	7%	2%	1%
GA	Columbus	CSG	0%	0%	1%	4%	11%	19%	22%	22%	15%	5%	1%	0%
GA	Macon	MCN	0%	0%	1%	3%	11%	20%	23%	23%	14%	4%	1%	0%
GA	Savannah	SAV	0%	0%	1%	4%	11%	18%	21%	21%	15%	6%	1%	0%
GA	Waycross	AYS	0%	0%	2%	5%	12%	17%	20%	20%	15%	6%	1%	1%
HI	Hilo-Hawaii	ITO	6%	6%	7%	7%	9%	9%	10%	11%	10%	10%	8%	7%
HI	Honolulu-Oahu	HNL	6%	5%	7%	7%	9%	10%	11%	11%	10%	10%	8%	7%
HI	Kahului-Maui	OGG	6%	5%	6%	7%	9%	10%	11%	11%	10%	10%	8%	7%
HI	Lihue-Kauai	LIH	6%	5%	6%	7%	9%	10%	11%	11%	11%	10%	8%	7%
IA	Burlington	BRL	0%	0%	0%	2%	8%	21%	31%	26%	10%	2%	0%	0%
IA	Cedar Rapids	CID	0%	0%	0%	1%	7%	21%	34%	26%	8%	2%	0%	0%
IA	Des Moines	DSM	0%	0%	0%	1%	7%	21%	33%	27%	9%	2%	0%	0%
IA	Dubuque	DBQ	0%	0%	0%	1%	6%	21%	35%	27%	9%	2%	0%	0%

Station Location		Code	Monthly Cooling Degree Day Fractions											
State	City		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
IA	Mason City	MCW	0%	0%	0%	1%	6%	21%	37%	26%	8%	2%	0%	0%
IA	Ottumwa	OTM	0%	0%	0%	2%	7%	21%	33%	27%	8%	2%	0%	0%
IA	Sioux City	SUX	0%	0%	0%	1%	7%	21%	35%	26%	8%	2%	0%	0%
IA	Waterloo	ALO	0%	0%	0%	1%	6%	21%	35%	25%	9%	2%	0%	0%
ID	Boise	BOI	0%	0%	0%	0%	4%	13%	39%	32%	11%	1%	0%	0%
ID	Burley	BYI	0%	0%	0%	0%	3%	11%	48%	34%	4%	1%	0%	0%
ID	Idaho Falls	IDA	0%	0%	0%	0%	2%	9%	51%	35%	2%	0%	0%	0%
ID	Lewiston	LWS	0%	0%	0%	0%	3%	11%	40%	34%	11%	1%	0%	0%
ID	Pocatello	PIH	0%	0%	0%	0%	2%	10%	49%	36%	3%	0%	0%	0%
IL	Chicago	ORD	0%	0%	0%	1%	6%	20%	34%	28%	10%	2%	0%	0%
IL	Moline	MLI	0%	0%	0%	1%	7%	21%	33%	26%	9%	2%	0%	0%
IL	Peoria	PIA	0%	0%	0%	1%	7%	21%	32%	26%	10%	2%	0%	0%
IL	Quincy	UIN	0%	0%	0%	2%	8%	20%	31%	27%	9%	2%	0%	0%
IL	Rockford	RFD	0%	0%	1%	1%	6%	21%	34%	27%	10%	2%	0%	0%
IL	Springfield	SPI	0%	0%	1%	2%	9%	21%	29%	26%	10%	2%	0%	0%
IN	Evansville	EVV	0%	0%	1%	2%	9%	21%	28%	26%	11%	2%	0%	0%
IN	Fort Wayne	FWA	0%	0%	0%	1%	7%	22%	34%	25%	9%	1%	0%	0%
IN	Indianapolis	IND	0%	0%	1%	2%	8%	21%	29%	27%	11%	2%	0%	0%
IN	South Bend	SBN	0%	0%	1%	1%	7%	21%	33%	26%	10%	2%	0%	0%
IN	West Lafayette	LAF	0%	0%	1%	2%	8%	21%	30%	26%	11%	2%	0%	0%
KS	Concordia	CNK	0%	0%	0%	1%	7%	21%	32%	27%	10%	2%	0%	0%
KS	Dodge City	DDC	0%	0%	0%	1%	7%	21%	31%	27%	10%	2%	0%	0%
KS	Garden City	GCK	0%	0%	0%	1%	7%	20%	31%	27%	11%	2%	0%	0%
KS	Goodland	GLD	0%	0%	0%	0%	5%	19%	37%	28%	9%	1%	0%	0%
KS	Russell	RSL	0%	0%	0%	1%	7%	21%	33%	26%	10%	2%	0%	0%
KS	Salina	SLN	0%	0%	0%	2%	8%	21%	31%	26%	10%	2%	0%	0%
KS	Topeka	TOP	0%	0%	1%	2%	8%	21%	30%	27%	9%	2%	0%	0%
KS	Wichita	ICT	0%	0%	0%	2%	8%	20%	29%	26%	11%	2%	0%	0%
KY	Bowling Green	BWG	0%	0%	1%	3%	9%	20%	27%	26%	12%	2%	0%	0%
KY	Jackson	JKL	0%	0%	1%	4%	9%	19%	26%	26%	12%	3%	0%	0%
KY	Lexington	LEX	0%	0%	1%	2%	8%	20%	28%	27%	12%	2%	0%	0%
KY	Louisville	SDF	0%	0%	1%	3%	9%	20%	26%	26%	13%	3%	0%	0%
KY	Paducah	PAH	0%	0%	1%	2%	9%	21%	28%	26%	11%	2%	0%	0%
LA	Baton Rouge	BTR	1%	1%	3%	5%	12%	17%	19%	20%	14%	6%	2%	1%
LA	Lafayette	LFT	1%	1%	3%	6%	12%	17%	18%	19%	14%	7%	2%	1%
LA	Lake Charles	LCH	0%	1%	2%	5%	12%	17%	19%	19%	14%	7%	2%	1%
LA	Monroe	MLU	0%	0%	2%	4%	11%	18%	21%	22%	14%	5%	1%	0%
LA	New Orleans	MSY	1%	1%	3%	6%	12%	17%	18%	18%	15%	8%	2%	1%
LA	Shreveport	SHV	0%	0%	2%	4%	11%	18%	21%	22%	14%	5%	1%	0%
MA	Boston	BOS	0%	0%	0%	1%	4%	16%	36%	31%	11%	1%	0%	0%
MA	Worcester	ORH	0%	0%	0%	1%	5%	17%	37%	31%	9%	1%	0%	0%
MD	Baltimore	BWI	0%	0%	0%	1%	7%	20%	31%	27%	11%	2%	0%	0%
MD	Salisbury	SBY	0%	0%	0%	2%	7%	18%	31%	27%	12%	2%	0%	0%
ME	Augusta	AUG	0%	0%	0%	0%	3%	15%	42%	33%	7%	1%	0%	0%
ME	Bangor	BGR	0%	0%	0%	0%	2%	15%	44%	33%	7%	0%	0%	0%
ME	Caribou	CAR	0%	0%	0%	0%	2%	18%	44%	30%	4%	0%	0%	0%

Station Location		Code	Monthly Cooling Degree Day Fractions											
State	City		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ME	Houlton	HUL	0%	0%	0%	0%	3%	17%	42%	32%	7%	0%	0%	0%
ME	Portland	PWM	0%	0%	0%	0%	2%	14%	42%	34%	8%	0%	0%	0%
MI	Alpena	APN	0%	0%	0%	0%	4%	18%	39%	29%	7%	2%	0%	0%
MI	Detroit	DTW	0%	0%	0%	1%	6%	20%	34%	28%	10%	1%	0%	0%
MI	Flint	FNT	0%	0%	0%	1%	6%	21%	35%	27%	9%	1%	0%	0%
MI	Grand Rapids	GRR	0%	0%	0%	1%	6%	20%	35%	27%	9%	1%	0%	0%
MI	Houghton Lake	HTL	0%	0%	0%	0%	6%	20%	38%	27%	7%	1%	0%	0%
MI	Jackson	JXN	0%	0%	0%	1%	6%	20%	35%	27%	9%	1%	0%	0%
MI	Lansing	LAN	0%	0%	0%	1%	6%	20%	36%	27%	9%	1%	0%	0%
MI	Marquette	MQT	0%	0%	0%	0%	4%	18%	41%	27%	9%	1%	0%	0%
MI	Muskegon	MKG	0%	0%	0%	0%	5%	18%	35%	29%	10%	1%	0%	0%
MI	Saginaw	MBS	0%	0%	0%	0%	6%	21%	35%	26%	8%	2%	0%	0%
MI	Sault St Marie	SSM	0%	0%	0%	0%	4%	14%	41%	31%	8%	1%	0%	0%
MI	Traverse City	TVC	0%	0%	1%	0%	5%	18%	36%	29%	10%	2%	0%	0%
MN	Alexandria	AXN	0%	0%	0%	0%	4%	16%	43%	27%	8%	1%	0%	0%
MN	Duluth	DLH	0%	0%	0%	0%	2%	11%	48%	29%	9%	0%	0%	0%
MN	Hibbing	HIB	0%	0%	0%	0%	5%	12%	46%	29%	7%	0%	0%	0%
MN	Int'l Falls	INL	0%	0%	0%	0%	3%	15%	44%	28%	8%	1%	0%	0%
MN	Minneapolis	MSP	0%	0%	0%	1%	5%	19%	38%	26%	10%	2%	0%	0%
MN	Rochester	RST	0%	0%	0%	1%	6%	22%	37%	24%	9%	2%	0%	0%
MN	Saint Cloud	STC	0%	0%	0%	0%	5%	18%	41%	25%	8%	1%	0%	0%
MO	Columbia	COU	0%	0%	1%	2%	8%	20%	30%	27%	10%	2%	0%	0%
MO	Joplin	JLN	0%	0%	1%	3%	8%	19%	27%	27%	11%	3%	0%	0%
MO	Kansas City	MCI	0%	0%	1%	2%	8%	20%	30%	28%	10%	2%	0%	0%
MO	Saint Louis	STL	0%	0%	1%	3%	9%	20%	28%	26%	11%	2%	0%	0%
MO	Springfield	SGF	0%	0%	1%	2%	8%	20%	29%	28%	10%	2%	0%	0%
MS	Greenwood	GWO	0%	0%	2%	4%	11%	19%	22%	23%	13%	4%	1%	0%
MS	McComb	MCB	0%	0%	2%	4%	11%	18%	21%	21%	15%	6%	1%	0%
MS	Tupelo	TUP	0%	0%	1%	3%	11%	19%	24%	24%	13%	4%	0%	0%
MT	Billings	BIL	0%	0%	0%	0%	2%	11%	44%	33%	8%	1%	0%	0%
MT	Butte	BTM	0%	0%	0%	0%	1%	8%	61%	30%	1%	0%	0%	0%
MT	Cut Bank	CTB	0%	0%	0%	0%	2%	6%	52%	34%	6%	0%	0%	0%
MT	Great Falls	GTF	0%	0%	0%	0%	1%	7%	49%	34%	8%	0%	0%	0%
MT	Havre	HVR	0%	0%	0%	0%	3%	8%	50%	33%	5%	0%	0%	0%
MT	Helena	HLN	0%	0%	0%	0%	2%	10%	49%	33%	6%	0%	0%	0%
MT	Kalispell	FCA	0%	0%	0%	1%	4%	12%	37%	34%	10%	2%	0%	0%
MT	Lewistown	LWT	0%	0%	0%	0%	1%	7%	51%	35%	7%	0%	0%	0%
MT	Miles City	MLS	0%	0%	0%	0%	2%	13%	44%	32%	8%	1%	0%	0%
MT	Missoula	MSO	0%	0%	0%	0%	1%	9%	51%	34%	4%	0%	0%	0%
NC	Asheville	AVL	0%	0%	0%	1%	7%	21%	31%	30%	10%	1%	0%	0%
NC	Cape Hatteras	HAT	1%	1%	2%	5%	9%	16%	19%	19%	15%	9%	3%	1%
NC	Charlotte	CLT	0%	0%	1%	2%	9%	20%	26%	25%	14%	2%	0%	0%
NC	Greensboro	GSO	0%	0%	1%	2%	9%	20%	27%	26%	13%	2%	0%	0%
NC	Hickory	HKY	0%	0%	1%	2%	9%	21%	27%	26%	12%	2%	0%	0%
NC	New Bern	EWN	0%	0%	1%	3%	9%	19%	25%	24%	14%	4%	1%	0%
NC	Raleigh Durham	RDU	0%	0%	1%	3%	9%	20%	26%	25%	13%	3%	0%	0%

Station Location		Code	Monthly Cooling Degree Day Fractions											
State	City		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
NC	Wilmington	ILM	0%	0%	1%	3%	10%	19%	24%	23%	14%	5%	1%	0%
ND	Bismarck	BIS	0%	0%	0%	0%	2%	14%	45%	31%	8%	0%	0%	0%
ND	Devil's Lake	P11	0%	0%	0%	0%	2%	15%	44%	30%	8%	1%	0%	0%
ND	Fargo	FAR	0%	0%	0%	0%	4%	18%	40%	26%	9%	2%	0%	0%
ND	Grand Forks	GFK	0%	0%	0%	0%	3%	16%	44%	28%	9%	1%	0%	0%
ND	Minot	MOT	0%	0%	0%	0%	1%	14%	44%	32%	8%	0%	0%	0%
ND	Williston	ISN	0%	0%	0%	0%	2%	10%	48%	33%	7%	0%	0%	0%
NE	Grand Island	GRI	0%	0%	0%	1%	7%	20%	35%	27%	9%	2%	0%	0%
NE	Lincoln	LNK	0%	0%	0%	1%	7%	20%	34%	27%	8%	2%	0%	0%
NE	Norfolk	OFK	0%	0%	0%	2%	7%	19%	35%	27%	8%	2%	0%	0%
NE	North Platte	LBF	0%	0%	0%	0%	4%	18%	40%	29%	8%	1%	0%	0%
NE	Omaha	OMA	0%	0%	0%	2%	7%	20%	34%	27%	9%	2%	0%	0%
NE	Scottsbluff	BFF	0%	0%	0%	0%	3%	17%	42%	30%	7%	0%	0%	0%
NE	Valentine	VTN	0%	0%	0%	0%	4%	16%	40%	30%	9%	1%	0%	0%
NH	Concord	CON	0%	0%	0%	0%	4%	18%	39%	31%	8%	0%	0%	0%
NH	Lebanon	LEB	0%	0%	0%	0%	5%	19%	37%	31%	8%	1%	0%	0%
NJ	Atlantic City	ACY	0%	0%	0%	1%	6%	19%	32%	28%	12%	2%	0%	0%
NJ	Newark	EWR	0%	0%	0%	1%	5%	19%	32%	28%	12%	2%	0%	0%
NM	Albuquerque	ABQ	0%	0%	0%	1%	8%	23%	31%	25%	12%	1%	0%	0%
NM	Carlsbad	CNM	0%	0%	1%	4%	12%	22%	23%	22%	12%	3%	0%	0%
NM	Clayton	CAO	0%	0%	0%	1%	6%	21%	33%	27%	10%	2%	0%	0%
NM	Gallup	GUP	0%	0%	0%	0%	1%	15%	47%	32%	5%	0%	0%	0%
NM	Roswell	ROW	0%	0%	0%	3%	11%	23%	25%	23%	12%	3%	0%	0%
NV	Elko	EKO	0%	0%	0%	0%	2%	11%	49%	34%	4%	0%	0%	0%
NV	Ely	ELY	0%	0%	0%	0%	1%	9%	54%	34%	3%	0%	0%	0%
NV	Las Vegas	LAS	0%	0%	1%	3%	11%	18%	24%	22%	15%	5%	0%	0%
NV	Lovelock	LOL	0%	0%	0%	0%	5%	16%	40%	29%	8%	1%	0%	0%
NV	Reno	RNO	0%	0%	0%	0%	4%	16%	38%	30%	11%	1%	0%	0%
NV	Tonopah	TPH	0%	0%	0%	0%	4%	17%	38%	30%	11%	1%	0%	0%
NV	Winnemucca	WMC	0%	0%	0%	0%	3%	13%	48%	31%	5%	0%	0%	0%
NY	Albany	ALB	0%	0%	0%	1%	5%	19%	36%	29%	8%	1%	0%	0%
NY	Binghamton	BGM	0%	0%	0%	1%	6%	19%	36%	28%	8%	1%	0%	0%
NY	Buffalo	BUF	0%	0%	0%	0%	5%	18%	35%	30%	10%	1%	0%	0%
NY	Glens Falls	GFL	0%	0%	0%	0%	5%	19%	38%	31%	7%	0%	0%	0%
NY	Massena	MSS	0%	0%	0%	0%	4%	18%	41%	29%	8%	0%	0%	0%
NY	New York	LGA	0%	0%	0%	1%	5%	18%	31%	29%	14%	2%	0%	0%
NY	Rochester	ROC	0%	0%	0%	1%	6%	20%	36%	28%	9%	1%	0%	0%
NY	Syracuse	SYR	0%	0%	0%	1%	6%	19%	36%	29%	9%	1%	0%	0%
NY	Utica	UCA	0%	0%	0%	2%	10%	20%	29%	25%	11%	2%	0%	0%
NY	Watertown	ART	0%	0%	0%	0%	5%	17%	34%	33%	10%	1%	0%	0%
OH	Akron Canton	CAK	0%	0%	0%	1%	7%	20%	33%	28%	9%	1%	0%	0%
OH	Cincinnati	CVG	0%	0%	1%	1%	7%	19%	29%	28%	12%	2%	0%	0%
OH	Cleveland	CLE	0%	0%	0%	1%	7%	20%	33%	27%	10%	1%	0%	0%
OH	Columbus	CMH	0%	0%	0%	1%	8%	20%	30%	28%	11%	2%	0%	0%
OH	Dayton	DAY	0%	0%	0%	1%	8%	20%	31%	27%	10%	2%	0%	0%
OH	Findlay	FDY	0%	0%	0%	1%	8%	22%	32%	26%	10%	2%	0%	0%

Station Location		Code	Monthly Cooling Degree Day Fractions											
State	City		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
OH	Mansfield	MFD	0%	0%	0%	1%	8%	20%	32%	28%	9%	1%	0%	0%
OH	Toledo	TOL	0%	0%	0%	1%	6%	21%	34%	27%	9%	1%	0%	0%
OH	Youngstown	YNG	0%	0%	0%	1%	7%	19%	35%	28%	9%	1%	0%	0%
OK	Hobart	HBR	0%	0%	1%	2%	10%	20%	26%	25%	13%	3%	0%	0%
OK	McAlester	MLC	0%	0%	1%	3%	9%	19%	25%	25%	13%	4%	1%	0%
OK	Oklahoma City	OKC	0%	0%	1%	3%	9%	19%	26%	25%	12%	3%	0%	0%
OK	Tulsa	TUL	0%	0%	1%	3%	9%	19%	27%	25%	12%	3%	0%	0%
OR	Astoria	AST	0%	0%	0%	0%	12%	10%	29%	24%	25%	0%	0%	0%
OR	Baker	BKE	0%	0%	0%	0%	2%	7%	53%	34%	3%	0%	0%	0%
OR	Eugene	EUG	0%	0%	0%	0%	2%	7%	41%	38%	12%	0%	0%	0%
OR	Medford	MFR	0%	0%	0%	0%	4%	11%	37%	33%	14%	1%	0%	0%
OR	Pendleton	PDT	0%	0%	0%	0%	3%	11%	42%	35%	9%	1%	0%	0%
OR	Portland	PDX	0%	0%	0%	0%	4%	11%	36%	35%	14%	0%	0%	0%
OR	Redmond	RDM	0%	0%	0%	0%	3%	8%	50%	33%	6%	0%	0%	0%
OR	Salem	SLE	0%	0%	0%	0%	3%	9%	39%	36%	12%	0%	0%	0%
PA	Allentown	ABE	0%	0%	0%	1%	6%	20%	34%	28%	10%	1%	0%	0%
PA	Altoona	AOO	0%	0%	0%	1%	7%	20%	34%	28%	8%	1%	0%	0%
PA	Bradford	BFD	0%	0%	0%	0%	6%	20%	38%	28%	8%	0%	0%	0%
PA	Du Bois	DUJ	0%	0%	0%	1%	7%	18%	34%	29%	8%	1%	0%	0%
PA	Erie	ERI	0%	0%	0%	1%	6%	19%	33%	29%	11%	2%	0%	0%
PA	Harrisburg	CXY	0%	0%	0%	1%	7%	20%	32%	28%	11%	1%	0%	0%
PA	Philadelphia	PHL	0%	0%	0%	1%	7%	19%	31%	27%	13%	2%	0%	0%
PA	Pittsburgh	PIT	0%	0%	0%	1%	7%	19%	33%	29%	10%	1%	0%	0%
PA	Williamsport	IPT	0%	0%	0%	1%	7%	20%	35%	28%	9%	1%	0%	0%
RI	Providence	PVD	0%	0%	0%	0%	3%	16%	36%	32%	11%	1%	0%	0%
SC	Charleston	CHS	0%	0%	1%	4%	11%	18%	22%	22%	15%	5%	1%	0%
SC	Columbia	CAE	0%	0%	1%	4%	11%	19%	23%	23%	14%	4%	1%	0%
SC	Florence	FLO	0%	0%	1%	3%	10%	19%	24%	23%	14%	4%	1%	0%
SC	Greenville	GSP	0%	0%	1%	2%	9%	21%	25%	25%	14%	3%	0%	0%
SD	Aberdeen	ABR	0%	0%	0%	0%	3%	18%	43%	27%	8%	1%	0%	0%
SD	Huron	HON	0%	0%	0%	1%	4%	17%	41%	28%	9%	1%	0%	0%
SD	Pierre	PIR	0%	0%	0%	0%	3%	15%	41%	31%	9%	1%	0%	0%
SD	Rapid City	RAP	0%	0%	0%	0%	2%	13%	43%	32%	8%	1%	0%	0%
SD	Sioux Falls	FSD	0%	0%	0%	1%	5%	18%	39%	27%	9%	1%	0%	0%
TN	Bristol	TRI	0%	0%	0%	1%	7%	21%	29%	29%	12%	1%	0%	0%
TN	Chattanooga	CHA	0%	0%	1%	3%	10%	20%	25%	26%	13%	3%	0%	0%
TN	Crossville	CSV	0%	0%	0%	2%	8%	20%	28%	28%	11%	1%	0%	0%
TN	Jackson	MKL	0%	0%	1%	3%	10%	20%	25%	25%	12%	3%	0%	0%
TN	Knoxville	TYS	0%	0%	1%	2%	9%	20%	26%	26%	13%	2%	0%	0%
TN	Memphis	MEM	0%	0%	1%	4%	11%	20%	23%	23%	14%	4%	0%	0%
TN	Nashville	BNA	0%	0%	1%	3%	9%	20%	26%	26%	13%	3%	0%	0%
TX	Abilene	ABI	0%	0%	2%	5%	11%	19%	22%	22%	13%	5%	1%	0%
TX	Alice	ALI	1%	2%	4%	7%	12%	15%	16%	17%	13%	8%	4%	2%
TX	Amarillo	AMA	0%	0%	0%	2%	9%	22%	28%	26%	11%	2%	0%	0%
TX	Austin	AUS	0%	1%	2%	5%	12%	17%	19%	21%	14%	6%	2%	0%
TX	Brownsville	BRO	2%	2%	5%	8%	12%	14%	15%	15%	12%	9%	5%	2%

Station Location		Code	Monthly Cooling Degree Day Fractions											
State	City		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
TX	College Station	CLL	0%	1%	3%	6%	12%	17%	19%	20%	14%	7%	2%	1%
TX	Corpus Christi	CRP	1%	2%	4%	7%	12%	14%	16%	17%	13%	9%	4%	1%
TX	Dallas-Ft. Worth	DFW	0%	0%	2%	4%	11%	18%	22%	22%	14%	6%	1%	0%
TX	Del Rio	DRT	0%	1%	3%	7%	12%	17%	18%	19%	13%	7%	2%	0%
TX	El Paso	ELP	0%	0%	1%	4%	13%	22%	22%	21%	13%	4%	0%	0%
TX	Galveston	GLS	0%	0%	2%	6%	11%	15%	17%	18%	15%	10%	4%	1%
TX	Houston	IAH	1%	1%	3%	6%	12%	17%	18%	19%	14%	7%	2%	1%
TX	Laredo	LRD	1%	2%	5%	9%	13%	15%	15%	16%	12%	8%	4%	1%
TX	Lubbock	LBB	0%	0%	1%	3%	11%	22%	25%	24%	11%	3%	0%	0%
TX	Lufkin	LFK	0%	1%	2%	5%	12%	17%	20%	21%	14%	6%	2%	0%
TX	McAllen	MFE	2%	2%	5%	8%	12%	14%	14%	15%	12%	9%	4%	2%
TX	Midland Odessa	MAF	0%	0%	1%	5%	12%	21%	22%	22%	12%	4%	0%	0%
TX	San Angelo	SJT	0%	0%	2%	5%	12%	19%	21%	21%	12%	5%	1%	0%
TX	San Antonio	SAT	0%	1%	3%	6%	12%	17%	18%	20%	14%	7%	2%	0%
TX	Victoria	VCT	1%	1%	3%	6%	12%	16%	17%	19%	14%	8%	3%	1%
TX	Waco	ACT	0%	0%	2%	5%	11%	18%	21%	22%	14%	6%	2%	0%
TX	Wichita Falls	SPS	0%	0%	1%	4%	10%	19%	24%	24%	13%	4%	1%	0%
UT	Cedar City	CDC	0%	0%	0%	0%	2%	16%	44%	32%	6%	0%	0%	0%
UT	Salt Lake City	SLC	0%	0%	0%	0%	4%	15%	38%	31%	10%	1%	0%	0%
VA	Lynchburg	LYH	0%	0%	0%	2%	7%	19%	30%	29%	11%	1%	0%	0%
VA	Norfolk	ORF	0%	0%	1%	3%	8%	19%	27%	25%	14%	4%	0%	0%
VA	Richmond	RIC	0%	0%	0%	3%	8%	20%	28%	25%	13%	3%	0%	0%
VA	Roanoke	ROA	0%	0%	1%	2%	8%	20%	28%	27%	11%	2%	0%	0%
VT	Burlington	BTV	0%	0%	0%	1%	4%	19%	37%	30%	8%	0%	0%	0%
VT	Montpelier	MPV	0%	0%	0%	0%	4%	19%	38%	32%	7%	0%	0%	0%
WA	Bellingham	BLI	0%	0%	0%	0%	1%	8%	49%	38%	4%	0%	0%	0%
WA	Olympia	OLM	0%	0%	0%	0%	2%	10%	46%	36%	5%	0%	0%	0%
WA	Quillayute	UIL	0%	0%	0%	0%	5%	14%	36%	35%	10%	0%	0%	0%
WA	Seattle Tacoma	SEA	0%	0%	0%	0%	3%	12%	40%	35%	11%	0%	0%	0%
WA	Spokane	GEG	0%	0%	0%	0%	3%	9%	44%	35%	8%	0%	0%	0%
WA	Walla Walla	ALW	0%	0%	0%	0%	4%	12%	39%	34%	11%	1%	0%	0%
WA	Yakima	YKM	0%	0%	0%	0%	4%	13%	43%	33%	7%	0%	0%	0%
WI	Eau Claire	EAU	0%	0%	0%	0%	5%	19%	39%	26%	9%	2%	0%	0%
WI	Green Bay	GRB	0%	0%	0%	0%	5%	20%	38%	27%	9%	1%	0%	0%
WI	Lacrosse	LSE	0%	0%	0%	1%	5%	20%	36%	26%	9%	2%	0%	0%
WI	Madison	MSN	0%	0%	0%	0%	5%	20%	36%	27%	9%	1%	0%	0%
WI	Milwaukee	MKE	0%	0%	0%	0%	4%	18%	35%	31%	11%	2%	0%	0%
WI	Wausau	AUW	0%	0%	0%	0%	5%	19%	40%	27%	8%	1%	0%	0%
WV	Beckley	BKW	0%	0%	0%	2%	7%	18%	31%	30%	10%	1%	0%	0%
WV	Charleston	CRW	0%	0%	1%	2%	8%	19%	28%	28%	12%	2%	0%	0%
WV	Elkins	EKN	0%	0%	0%	0%	5%	18%	34%	34%	8%	1%	0%	0%
WV	Huntington	HTS	0%	0%	1%	2%	8%	20%	28%	28%	12%	2%	0%	0%
WV	Martinsburg	MRB	0%	0%	0%	1%	7%	20%	32%	28%	10%	1%	0%	0%
WV	Morgantown	MGW	0%	0%	0%	2%	8%	18%	30%	28%	11%	2%	0%	0%
WV	Parkersburg	PKB	0%	0%	0%	2%	8%	19%	30%	29%	11%	2%	0%	0%
WY	Casper	CPR	0%	0%	0%	0%	1%	11%	49%	33%	5%	0%	0%	0%

Station Location		Code	Monthly Cooling Degree Day Fractions											
State	City		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
WY	Cheyenne	CYS	0%	0%	0%	0%	1%	13%	48%	33%	5%	0%	0%	0%
WY	Cody	COD	0%	0%	0%	0%	2%	11%	46%	32%	7%	1%	0%	0%
WY	Lander	LND	0%	0%	0%	0%	2%	12%	47%	34%	5%	0%	0%	0%
WY	Rock Springs	RKS	0%	0%	0%	0%	1%	12%	53%	33%	2%	0%	0%	0%
WY	Sheridan	SHR	0%	0%	0%	0%	1%	10%	47%	36%	6%	0%	0%	0%
WY	Worland	WRL	0%	0%	0%	0%	2%	14%	45%	32%	5%	1%	0%	0%

7C.3.2 Monthly Average Outdoor Temperature Data by Weather Station

Table 7C.3.1 shows for each weather station the 30-year (1970-2000) monthly average outdoor temperature data based on NOAA data.[5] Average monthly outdoor temperature where used to determine hours of operation of heat tape in condensate withdrawal systems that require it for high efficiency furnaces as described in appendix 7B and appendix 8D.

Table 7C.3.1 Weather Station Monthly Average Outdoor Temperature (1970-2000)

Station Location		Code	Monthly Average Outdoor Temperature											
State	City		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
AK	Anchorage	ANC	16	19	26	36	47	55	58	56	48	34	22	18
AK	Bethel	BET	7	8	15	26	41	51	56	54	45	30	17	9
AK	Cold Bay	CDB	28	28	30	34	40	46	51	52	48	40	35	31
AK	Cordova	CDV	28	28	30	34	40	46	51	52	48	40	35	31
AK	Homer	HOM	23	25	29	36	44	50	54	54	48	38	29	26
AK	Juneau	JNU	26	29	34	41	48	54	57	56	50	42	33	29
AK	Kenai	ENA	16	19	26	36	47	55	58	56	48	34	22	18
AK	Ketchikan	KTN	22	25	30	38	46	52	55	54	47	38	28	25
AK	King Salmon	AKN	15	16	24	33	44	51	56	55	48	33	23	17
AK	Kodiak	ADQ	30	30	33	37	44	49	54	55	49	40	34	31
AK	Sitka	SIT	26	29	34	41	48	54	57	56	50	42	33	29
AK	St Paul Island	SNP	26	23	24	28	36	42	47	48	45	38	33	29
AK	Talkeetna	TKA	11	15	23	34	46	55	59	56	46	31	18	13
AK	Valdez	VWS	22	25	30	38	46	52	55	54	47	38	28	25
AK	Yakutat	YAK	26	28	32	37	44	50	54	53	48	41	32	29
AL	Birmingham	BHM	43	47	55	61	69	76	80	80	74	63	53	46
AL	Huntsville	HSV	40	44	52	60	69	76	80	79	72	61	51	43
AL	Mobile	MOB	50	54	60	66	74	79	82	81	77	68	59	52
AL	Montgomery	MGM	47	51	58	64	72	79	82	81	76	65	56	49
AL	Muscle Shoals	MSL	40	45	53	61	69	76	80	79	73	62	51	43
AL	Tuscaloosa	TCL	45	49	57	64	72	79	82	81	75	64	54	47
AR	Fayetteville	FYV	35	41	49	58	65	74	79	78	70	59	48	39
AR	Fort Smith	FSM	38	44	53	61	70	78	82	82	74	63	51	41
AR	Little Rock	LIT	40	45	53	61	70	78	82	81	74	63	52	43
AR	Texarkana	TXK	38	44	53	61	70	78	82	82	74	63	51	41
AZ	Douglas	DUG	45	49	54	59	68	76	79	77	73	63	51	45
AZ	Flagstaff	FLG	30	32	37	43	51	60	66	64	58	47	37	30

Station Location		Code	Monthly Average Outdoor Temperature											
State	City		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
AZ	Phoenix	PHX	56	60	65	71	81	90	95	93	87	75	63	56
AZ	Tucson	TUS	52	55	59	66	75	84	87	85	81	71	59	52
AZ	Winslow	INW	34	40	46	53	62	72	78	76	68	56	43	34
AZ	Yuma	NYL	58	62	67	73	80	89	94	94	88	77	65	57
CA	Bakersfield	BFL	48	53	57	63	70	78	83	82	77	67	55	47
CA	Blythe	BLH	53	58	63	70	78	86	92	91	84	72	59	52
CA	Eureka	EKA	48	49	49	51	54	56	58	59	57	55	51	48
CA	Fresno	FAT	46	51	56	61	69	76	81	80	75	65	53	45
CA	Los Angeles	LAX	57	58	58	61	63	66	69	71	70	67	62	58
CA	Mt Shasta	MHS	35	38	41	46	53	60	66	65	60	51	40	35
CA	Paso Robles	PRB	48	51	53	56	61	66	70	71	68	61	51	47
CA	Red Bluff	RBL	46	49	53	58	66	75	81	79	73	63	51	45
CA	Redding	RDD	46	49	53	58	66	75	81	79	73	63	51	45
CA	Sacramento	SAC	46	51	55	59	66	72	75	75	72	64	53	46
CA	San Diego	SAN	58	59	60	63	65	67	71	73	72	68	62	58
CA	San Francisco	SFO	49	52	54	56	59	61	63	64	64	61	55	50
CA	Stockton	SCK	46	51	55	60	67	73	77	77	73	65	53	45
CO	Alamosa	ALS	15	23	33	41	50	59	64	62	55	43	28	17
CO	Colorado Spring	COS	28	32	38	45	55	64	70	68	60	49	36	29
CO	Denver	DEN	29	33	40	48	57	68	73	72	62	51	38	30
CO	Eagle	EGE	15	23	33	41	50	59	64	62	55	43	28	17
CO	Pueblo	PUB	29	35	42	50	60	70	75	74	65	52	38	30
CO	Trinidad	TAD	33	36	42	49	58	67	71	69	62	52	40	33
CT	Bridgeport	BDR	30	32	40	49	59	68	74	73	66	55	45	35
CT	Hartford	BDL	26	29	38	49	60	69	74	72	63	52	42	31
DC	Washington	DCA	35	38	47	56	66	75	79	77	71	59	49	40
DE	Wilmington	ILG	32	34	43	52	63	72	77	75	68	56	46	36
FL	Daytona Beach	DAB	58	60	65	69	75	80	82	82	80	74	67	61
FL	Fort Myers	FMY	65	66	70	74	79	82	83	83	82	78	72	66
FL	Ft Lauderdale	FLL	67	68	71	74	78	81	82	83	82	78	74	69
FL	Gainesville	GNV	54	57	63	68	74	79	81	80	78	70	63	56
FL	Jacksonville	JAX	53	56	62	67	73	79	82	81	78	69	62	55
FL	Key West	EYW	70	71	74	77	81	83	85	84	83	80	76	72
FL	Melbourne	MLB	63	64	68	72	76	80	82	82	81	76	71	65
FL	Miami	MIA	68	69	72	76	80	82	84	84	82	79	74	70
FL	Orlando	MCO	61	63	67	72	77	81	82	83	81	75	69	63
FL	Pensacola	PNS	52	55	61	67	75	81	83	82	79	70	61	54
FL	Tallahassee	TLH	52	55	61	66	74	80	82	82	79	69	60	54
FL	Tampa	TPA	61	63	67	72	78	82	83	83	82	76	69	63
FL	Vero Beach	VRB	63	64	68	72	76	80	82	82	81	76	71	65
FL	West Palm Beach	PBI	66	67	71	74	78	81	83	83	82	78	73	68
GA	Albany	ABY	48	52	60	66	73	79	82	82	77	67	59	51
GA	Athens	AHN	42	46	54	61	69	76	80	78	73	62	53	45
GA	Atlanta	ATL	43	47	54	62	70	77	80	79	73	63	53	45
GA	Augusta	AGS	45	48	56	62	71	78	81	79	74	63	54	47
GA	Brunswick	SSI	53	56	62	67	75	80	83	82	78	70	62	55

Station Location		Code	Monthly Average Outdoor Temperature											
State	City		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
GA	Columbus	CSG	47	50	58	64	72	79	82	81	76	66	57	49
GA	Macon	MCN	46	49	56	63	71	78	81	80	75	64	55	48
GA	Savannah	SAV	49	53	59	65	73	79	82	81	77	67	59	51
GA	Waycross	AYS	50	53	60	66	73	79	82	81	77	67	60	52
HI	Hilo-Hawaii	ITO	71	72	72	73	74	75	76	76	76	76	74	72
HI	Honolulu-Oahu	HNL	73	73	74	76	77	80	81	82	82	80	78	75
HI	Kahului-Maui	OGG	72	72	73	74	76	78	79	80	79	78	76	73
HI	Lihue-Kauai	LIH	72	72	73	74	75	78	79	80	80	78	76	73
IA	Burlington	BRL	20	27	38	51	62	71	76	74	65	53	38	25
IA	Cedar Rapids	CID	16	23	35	48	60	70	74	71	63	50	35	22
IA	Des Moines	DSM	20	27	38	51	62	71	76	74	65	53	38	25
IA	Dubuque	DBQ	17	23	35	48	59	68	72	70	62	50	36	23
IA	Mason City	MCW	16	23	35	48	60	70	74	71	63	50	35	22
IA	Ottumwa	OTM	20	27	38	51	62	71	76	74	65	53	38	25
IA	Sioux City	SUX	19	25	37	50	61	71	75	72	63	51	35	22
IA	Waterloo	ALO	16	23	35	48	60	70	74	71	63	50	35	22
ID	Boise	BOI	30	37	44	51	59	67	75	74	64	53	40	31
ID	Burley	BYI	24	30	38	46	54	62	69	68	59	48	35	25
ID	Idaho Falls	IDA	24	30	38	46	54	62	69	68	59	48	35	25
ID	Lewiston	LWS	34	38	45	51	59	66	74	73	64	52	40	34
ID	Pocatello	PIH	24	30	38	46	54	62	69	68	59	48	35	25
IL	Chicago	ORD	22	27	37	48	59	68	73	72	64	52	39	27
IL	Moline	MLI	21	27	39	51	62	71	75	73	65	53	39	26
IL	Peoria	PIA	23	28	40	51	62	71	75	73	65	53	40	28
IL	Quincy	UIN	23	28	40	51	62	71	75	73	65	53	40	28
IL	Rockford	RFD	19	25	36	48	60	69	73	71	63	51	37	24
IL	Springfield	SPI	25	31	42	53	64	73	76	74	67	56	42	30
IN	Evansville	EVV	31	36	46	56	66	75	79	77	69	57	46	36
IN	Fort Wayne	FWA	24	27	38	49	60	70	73	71	64	52	41	29
IN	Indianapolis	IND	27	31	42	52	63	72	75	74	66	55	43	32
IN	South Bend	SBN	23	27	38	48	60	69	73	71	63	52	40	29
IN	West Lafayette	LAF	24	27	38	49	60	70	73	71	64	52	41	29
KS	Concordia	CNK	27	32	43	53	63	73	79	77	68	56	41	30
KS	Dodge City	DDC	30	36	44	54	64	74	80	78	69	57	42	33
KS	Garden City	GCK	30	36	44	54	64	74	80	78	69	57	42	33
KS	Goodland	GLD	28	32	40	49	59	70	75	73	64	52	37	30
KS	Russell	RSL	27	32	43	53	63	73	79	77	68	56	41	30
KS	Salina	SLN	30	36	46	55	65	76	81	80	71	59	44	34
KS	Topeka	TOP	27	33	44	55	64	74	78	77	68	57	43	31
KS	Wichita	ICT	30	36	46	55	65	76	81	80	71	59	44	34
KY	Bowling Green	BWG	34	39	48	57	66	74	79	77	70	58	48	38
KY	Jackson	JKL	34	38	47	56	64	71	75	74	68	58	48	38
KY	Lexington	LEX	32	36	46	55	64	72	76	75	68	57	46	36
KY	Louisville	SDF	33	38	47	56	66	74	78	77	70	59	48	38
KY	Paducah	PAH	33	38	48	57	66	75	78	76	69	58	47	37
LA	Baton Rouge	BTR	50	54	60	67	74	80	82	81	78	68	59	52

Station Location		Code	Monthly Average Outdoor Temperature											
State	**City**		**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
LA	Lafayette	LFT	52	55	62	68	76	81	83	82	78	69	61	54
LA	Lake Charles	LCH	51	54	61	67	75	81	83	82	78	70	60	53
LA	Monroe	MLU	46	51	59	65	73	80	83	83	77	67	56	48
LA	New Orleans	MSY	53	56	62	68	76	81	83	83	79	70	61	55
LA	Shreveport	SHV	46	51	59	65	73	80	83	83	77	67	56	48
MA	Boston	BOS	29	32	39	48	59	68	74	72	65	54	45	35
MA	Worcester	ORH	24	26	34	45	56	65	70	68	60	50	40	29
MD	Baltimore	BWI	32	36	44	53	63	72	77	75	67	55	46	37
MD	Salisbury	SBY	36	38	46	55	64	72	77	75	69	58	49	40
ME	Augusta	AUG	22	25	34	44	54	63	69	67	59	48	38	28
ME	Bangor	BGR	22	25	34	44	54	63	69	67	59	48	38	28
ME	Caribou	CAR	10	13	25	38	52	61	66	63	54	43	31	16
ME	Houlton	HUL	11	14	26	39	52	61	66	64	55	43	31	17
ME	Portland	PWM	22	25	34	44	54	63	69	67	59	48	38	28
MI	Alpena	APN	18	19	28	40	52	61	67	65	56	46	35	24
MI	Detroit	DTW	25	27	37	48	60	69	74	72	64	52	41	30
MI	Flint	FNT	21	24	34	45	57	66	71	69	61	49	38	27
MI	Grand Rapids	GRR	22	25	35	46	58	67	71	69	61	50	38	28
MI	Houghton Lake	HTL	18	20	29	42	54	62	67	65	57	46	35	24
MI	Jackson	JXN	24	25	34	45	56	65	70	69	61	50	39	29
MI	Lansing	LAN	22	24	34	46	57	66	70	68	61	49	38	27
MI	Marquette	MQT	12	15	24	36	50	59	64	62	54	43	29	17
MI	Muskegon	MKG	24	25	34	45	56	65	70	69	61	50	39	29
MI	Saginaw	MBS	24	25	34	45	56	65	70	69	61	50	39	29
MI	Sault St Marie	SSM	13	16	25	38	51	59	64	63	55	44	32	20
MI	Traverse City	TVC	24	25	34	45	56	65	70	69	61	50	39	29
MN	Alexandria	AXN	9	16	28	44	57	65	70	67	57	45	29	14
MN	Duluth	DLH	8	15	25	39	52	60	66	64	55	44	28	14
MN	Hibbing	HIB	3	11	24	39	53	62	66	64	53	42	24	9
MN	Int'l Falls	INL	3	11	24	39	53	62	66	64	53	42	24	9
MN	Minneapolis	MSP	13	20	32	47	59	68	73	71	61	49	33	19
MN	Rochester	RST	12	18	31	45	57	66	70	68	59	47	31	17
MN	Saint Cloud	STC	9	16	28	44	57	65	70	67	57	45	29	14
MO	Columbia	COU	28	34	44	54	64	73	77	76	67	56	43	32
MO	Joplin	JLN	32	37	46	56	65	73	79	78	69	58	46	36
MO	Kansas City	MCI	27	33	44	54	64	74	79	77	68	57	43	31
MO	Saint Louis	STL	30	35	46	57	67	76	80	78	70	58	45	34
MO	Springfield	SGF	32	37	46	56	65	73	79	78	69	58	46	36
MS	Greenwood	GWO	40	45	53	61	69	77	81	80	73	62	52	43
MS	McComb	MCB	45	49	57	63	72	79	81	81	76	64	55	48
MS	Tupelo	TUP	40	45	53	61	69	77	81	80	73	62	52	43
MT	Billings	BIL	24	30	37	46	56	65	72	71	60	48	34	26
MT	Butte	BTM	17	22	30	40	49	57	62	62	51	41	27	20
MT	Cut Bank	CTB	17	22	30	40	49	57	62	62	51	41	27	20
MT	Great Falls	GTF	22	26	33	43	52	60	66	66	55	46	32	24
MT	Havre	HVR	22	26	33	43	52	60	66	66	55	46	32	24

Station Location		Code	Monthly Average Outdoor Temperature											
State	City		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
MT	Helena	HLN	20	26	35	44	53	61	68	67	56	45	31	21
MT	Kalispell	FCA	21	27	35	43	51	58	64	63	53	42	31	23
MT	Lewistown	LWT	22	26	33	43	52	60	66	66	55	46	32	24
MT	Miles City	MLS	17	25	35	47	57	67	74	73	60	48	32	21
MT	Missoula	MSO	24	29	38	45	53	60	67	66	56	44	32	23
NC	Asheville	AVL	36	39	46	54	62	69	73	72	66	55	46	39
NC	Cape Hatteras	HAT	46	47	52	60	68	75	79	79	75	66	58	50
NC	Charlotte	CLT	42	45	53	61	69	77	80	79	73	62	52	44
NC	Greensboro	GSO	38	41	49	58	66	74	78	76	70	59	49	41
NC	Hickory	HKY	38	41	49	58	66	74	78	76	70	59	49	41
NC	New Bern	EWN	46	49	55	63	70	77	81	80	75	65	57	49
NC	Raleigh Durham	RDU	40	43	51	59	67	75	79	77	71	60	51	43
NC	Wilmington	ILM	46	49	55	63	70	77	81	80	75	65	57	49
ND	Bismarck	BIS	10	18	30	43	56	65	70	69	58	45	28	15
ND	Devil's Lake	P11	5	13	26	42	57	65	69	68	57	44	26	11
ND	Fargo	FAR	7	14	27	44	57	66	71	69	58	45	27	13
ND	Grand Forks	GFK	5	13	26	42	57	65	69	68	57	44	26	11
ND	Minot	MOT	8	15	28	43	57	66	71	69	58	45	26	13
ND	Williston	ISN	8	17	29	43	55	64	69	68	56	44	26	13
NE	Grand Island	GRI	22	28	38	50	61	71	76	74	64	52	36	26
NE	Lincoln	LNK	22	28	39	51	62	73	78	75	66	54	38	27
NE	Norfolk	OFK	20	26	37	49	60	70	75	73	63	51	35	24
NE	North Platte	LBF	23	29	38	48	58	68	74	73	62	50	35	26
NE	Omaha	OMA	22	28	39	51	62	72	77	75	65	53	38	26
NE	Scottsbluff	BFF	25	30	37	46	57	67	73	71	61	48	34	26
NE	Valentine	VTN	21	27	35	46	58	68	74	72	62	48	33	24
NH	Concord	CON	20	23	33	45	56	65	70	68	59	48	38	26
NH	Lebanon	LEB	20	23	33	45	56	65	70	68	59	48	38	26
NJ	Atlantic City	ACY	32	34	42	51	61	70	75	74	66	55	46	37
NJ	Newark	EWR	31	34	42	52	63	72	77	76	68	56	46	36
NM	Albuquerque	ABQ	36	41	48	56	65	75	79	76	69	57	44	36
NM	Carlsbad	CNM	43	49	56	63	72	79	82	80	73	63	51	44
NM	Clayton	CAO	34	38	44	52	61	70	74	72	65	55	42	35
NM	Gallup	GUP	34	38	44	52	61	70	74	72	65	55	42	35
NM	Roswell	ROW	40	46	53	61	70	78	81	79	72	61	49	41
NV	Elko	EKO	26	31	39	45	53	62	69	68	58	47	35	26
NV	Ely	ELY	25	30	36	42	50	60	67	66	57	45	34	26
NV	Las Vegas	LAS	47	52	58	66	75	86	91	89	81	69	55	47
NV	Lovelock	LOL	30	37	42	48	57	65	72	70	62	50	38	30
NV	Reno	RNO	34	39	43	49	56	65	71	70	62	52	41	34
NV	Tonopah	TPH	34	39	43	49	56	65	71	70	62	52	41	34
NV	Winnemucca	WMC	30	36	41	47	55	64	72	70	60	49	37	30
NY	Albany	ALB	22	25	35	47	58	66	71	69	61	49	39	28
NY	Binghamton	BGM	22	24	33	44	56	64	69	67	59	48	38	27
NY	Buffalo	BUF	25	26	34	45	57	66	71	69	62	51	40	30
NY	Glens Falls	GFL	20	22	31	44	56	65	70	68	60	48	38	26

Station Location		Code	Monthly Average Outdoor Temperature											
State	City		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
NY	Massena	MSS	20	22	31	44	56	65	70	68	60	48	38	26
NY	New York	LGA	33	35	42	52	62	72	77	76	69	58	48	38
NY	Rochester	ROC	24	25	34	45	57	66	71	69	61	50	40	29
NY	Syracuse	SYR	23	25	34	45	57	66	71	69	61	50	40	29
NY	Utica	UCA	21	23	33	45	57	66	70	68	60	49	38	27
NY	Watertown	ART	20	22	31	44	56	65	70	68	60	48	38	26
OH	Akron Canton	CAK	25	28	38	48	59	68	72	70	63	52	41	31
OH	Cincinnati	CVG	30	34	44	54	64	72	76	75	67	56	45	35
OH	Cleveland	CLE	26	28	38	48	59	68	72	70	63	52	42	31
OH	Columbus	CMH	28	32	42	52	63	71	75	74	67	55	44	34
OH	Dayton	DAY	26	30	40	51	61	70	74	72	65	54	42	31
OH	Findlay	FDY	25	28	38	49	61	70	74	71	64	53	41	30
OH	Mansfield	MFD	24	27	37	47	58	67	71	69	63	52	41	30
OH	Toledo	TOL	24	27	37	48	60	69	73	71	64	52	41	29
OH	Youngstown	YNG	25	28	37	47	58	66	70	68	62	51	41	30
OK	Hobart	HBR	36	42	50	59	68	78	83	81	73	62	48	38
OK	McAlester	MLC	37	42	51	60	68	77	82	81	73	62	49	40
OK	Oklahoma City	OKC	37	42	51	60	68	77	82	81	73	62	49	40
OK	Tulsa	TUL	36	42	51	61	69	78	84	82	74	63	50	40
OR	Astoria	AST	42	44	46	49	53	57	60	61	59	53	47	43
OR	Baker	BKE	26	32	38	45	52	59	66	65	56	46	34	26
OR	Eugene	EUG	40	43	46	50	55	60	66	66	62	53	45	40
OR	Medford	MFR	39	44	47	52	58	66	73	73	66	55	44	38
OR	Pendleton	PDT	34	39	45	51	58	65	73	72	63	52	41	34
OR	Portland	PDX	40	43	47	51	57	63	68	69	64	54	46	40
OR	Redmond	RDM	24	30	37	43	51	58	66	64	55	44	33	25
OR	Salem	SLE	40	43	47	50	56	61	67	67	62	53	45	40
PA	Allentown	ABE	27	30	39	49	60	69	73	71	63	52	42	32
PA	Altoona	AOO	26	29	38	49	60	68	72	71	63	51	41	31
PA	Bradford	BFD	26	29	38	49	60	68	72	71	63	51	41	31
PA	Du Bois	DUJ	26	29	38	49	60	68	72	71	63	51	41	31
PA	Erie	ERI	27	28	37	47	58	67	72	71	64	53	43	33
PA	Harrisburg	CXY	30	33	42	52	62	71	76	74	66	55	44	35
PA	Philadelphia	PHL	32	35	43	53	64	72	78	76	69	57	47	37
PA	Pittsburgh	PIT	28	31	40	50	60	68	73	71	64	53	42	33
PA	Williamsport	IPT	26	29	38	49	60	68	72	71	63	51	41	31
RI	Providence	PVD	29	31	39	49	59	68	73	72	64	53	44	34
SC	Charleston	CHS	48	51	58	64	72	78	82	81	76	66	58	51
SC	Columbia	CAE	45	48	55	63	72	79	82	80	75	64	55	47
SC	Florence	FLO	45	48	55	63	72	79	82	80	75	64	55	47
SC	Greenville	GSP	41	44	52	59	67	75	79	78	71	61	51	44
SD	Aberdeen	ABR	11	19	31	45	58	67	72	71	60	47	29	16
SD	Huron	HON	14	21	33	46	58	68	73	72	61	48	31	19
SD	Pierre	PIR	18	24	35	47	59	69	76	74	64	50	34	22
SD	Rapid City	RAP	22	27	35	45	55	65	72	71	61	48	33	25
SD	Sioux Falls	FSD	14	21	33	46	58	68	73	71	61	48	31	18

Station Location		Code	Monthly Average Outdoor Temperature											
State	**City**		**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
TN	Bristol	TRI	34	38	47	55	63	71	74	73	67	55	46	37
TN	Chattanooga	CHA	39	43	51	60	68	75	80	79	72	60	50	42
TN	Crossville	CSV	33	38	46	55	63	70	73	72	66	55	46	37
TN	Jackson	MKL	38	42	51	59	68	76	79	78	72	60	50	41
TN	Knoxville	TYS	38	42	50	58	66	74	78	77	71	59	49	41
TN	Memphis	MEM	40	45	54	62	71	79	83	81	75	64	52	43
TN	Nashville	BNA	37	41	50	59	67	75	79	78	71	60	49	41
TX	Abilene	ABI	44	49	56	65	73	80	84	83	76	66	54	45
TX	Alice	ALI	56	60	68	73	79	83	85	85	81	74	66	58
TX	Amarillo	AMA	36	41	48	56	65	74	78	76	69	58	45	37
TX	Austin	AUS	51	56	63	69	76	82	85	85	80	71	61	53
TX	Brownsville	BRO	60	63	69	74	79	83	84	84	81	75	68	61
TX	College Station	CLL	51	56	63	69	76	82	85	85	80	71	61	53
TX	Corpus Christi	CRP	56	60	66	72	78	82	84	84	81	74	65	58
TX	Dallas-Ft. Worth	DFW	44	49	57	65	73	81	85	84	78	67	55	47
TX	Del Rio	DRT	51	56	64	71	78	83	85	85	80	71	60	52
TX	El Paso	ELP	45	51	57	65	74	82	83	81	75	65	53	45
TX	Galveston	GLS	56	58	64	70	77	82	84	84	81	74	65	58
TX	Houston	IAH	52	55	62	69	76	81	84	83	79	70	61	54
TX	Laredo	LRD	60	63	69	74	79	83	84	84	81	75	68	61
TX	Lubbock	LBB	38	43	51	60	69	77	80	78	71	61	48	40
TX	Lufkin	LFK	51	56	63	69	76	82	85	85	80	71	61	53
TX	McAllen	MFE	60	63	69	74	79	83	84	84	81	75	68	61
TX	Midland Odessa	MAF	43	49	56	64	73	80	82	80	74	64	52	45
TX	San Angelo	SJT	45	50	57	65	73	79	82	81	75	65	54	46
TX	San Antonio	SAT	50	55	62	69	76	82	84	84	79	71	60	52
TX	Victoria	VCT	53	57	64	70	77	82	84	84	80	72	63	55
TX	Waco	ACT	46	51	59	66	74	81	85	85	79	69	57	48
TX	Wichita Falls	SPS	41	46	54	62	71	80	85	84	76	65	52	43
UT	Cedar City	CDC	29	35	43	50	59	69	77	76	65	53	40	30
UT	Salt Lake City	SLC	29	35	43	50	59	69	77	76	65	53	40	30
VA	Lynchburg	LYH	35	38	46	55	63	71	75	74	67	56	47	38
VA	Norfolk	ORF	40	42	49	57	66	75	79	77	72	61	52	44
VA	Richmond	RIC	36	40	48	57	65	74	78	76	70	58	49	40
VA	Roanoke	ROA	36	39	47	56	64	72	76	75	68	57	47	39
VT	Burlington	BTV	18	20	31	44	57	66	71	68	59	48	37	25
VT	Montpelier	MPV	18	20	31	44	57	66	71	68	59	48	37	25
WA	Bellingham	BLI	39	42	45	49	55	59	63	63	59	51	44	40
WA	Olympia	OLM	38	41	44	47	53	58	63	63	58	50	42	38
WA	Quillayute	UIL	41	42	44	47	51	55	59	59	57	50	44	41
WA	Seattle Tacoma	SEA	41	43	46	50	56	61	65	66	61	53	45	41
WA	Spokane	GEG	27	33	40	47	54	62	69	69	59	47	35	27
WA	Walla Walla	ALW	35	40	47	53	60	67	75	75	66	55	43	35
WA	Yakima	YKM	29	35	43	49	56	63	69	68	60	49	37	29
WI	Eau Claire	EAU	16	21	31	44	56	65	70	68	59	47	34	21
WI	Green Bay	GRB	16	21	31	44	56	65	70	68	59	47	34	21

Station Location		Code	Monthly Average Outdoor Temperature											
State	City		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
WI	Lacrosse	LSE	16	23	35	48	61	70	74	72	63	51	36	22
WI	Madison	MSN	17	23	34	46	58	67	72	69	61	49	36	23
WI	Milwaukee	MKE	21	25	35	45	56	66	72	71	63	51	38	26
WI	Wausau	AUW	16	21	31	44	56	65	70	68	59	47	34	21
WV	Beckley	BKW	30	34	42	52	60	67	71	69	63	53	43	35
WV	Charleston	CRW	33	37	45	54	62	70	74	73	66	55	46	38
WV	Elkins	EKN	29	32	40	49	58	66	70	69	62	51	41	33
WV	Huntington	HTS	33	37	46	55	64	71	75	74	67	56	46	37
WV	Martinsburg	MRB	31	35	43	53	63	71	76	74	67	55	45	36
WV	Morgantown	MGW	31	35	43	53	63	71	76	74	67	55	45	36
WV	Parkersburg	PKB	31	35	43	53	63	71	76	74	67	55	45	36
WY	Casper	CPR	22	27	35	43	52	63	70	69	58	46	32	24
WY	Cheyenne	CYS	26	29	34	42	51	62	68	66	57	45	33	27
WY	Cody	COD	22	27	35	43	52	63	70	69	58	46	32	24
WY	Lander	LND	20	26	36	44	53	64	71	69	59	46	30	21
WY	Rock Springs	RKS	21	24	32	41	51	61	68	66	56	44	30	22
WY	Sheridan	SHR	21	27	35	44	53	62	69	68	57	45	31	22
WY	Worland	WRL	16	25	37	46	57	66	72	70	59	47	31	19

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APPENDIX 7D. REDUCED SET OF RESIDENTIAL FURNACE MODELS AND CHARACTERISTICS

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APPENDIX 7D. REDUCED SET OF RESIDENTIAL FURNACE MODELS AND CHARACTERISTICS

7D.1 INTRODUCTION

This appendix presents the approach for developing a reduced set of non-weatherized gas furnace (NWGF) and mobile home gas furnace (MHGF) models and the resulting furnace characteristics.

7D.2 REDUCED SET OF FURNACE MODELS DATABASE

7D.2.1 Purpose

The reduced set of furnace models was developed to identify actual unique NWGF and MHGF models that represent units with different design characteristics and to expand the AHRI directory data for each unique furnace model by adding information provided in the manufacturers' product literature.

The February 2013 Air-Conditioning, Heating, and Refrigeration Institute (AHRI) Directory[1] list more than 6,000 models. The database of NWGF and MHGF models described here (referred to as the reduced set of NWGF and MHGF models or simply the reduced set) represents non-repetitive NWGF and MHGF models only. After examining the AHRI Directory database, the Department determined that about 1,019 models (396 non-condensing NWGFs, 553 condensing NWGFs, 17 non-condensing MHGFs, and 53 condensing MHGFs) may be considered sufficiently different to be listed as unique models. See the LCC Input spreadsheet ("Models Directory" worksheet) for a complete listing of models used for each furnace product class.

Once the reduced set was identified, DOE examined the manufacturer's product literature and added additional data, including power for the blower, blower motor type, low fire heating input and output capacity for two-stage and modulating furnaces, and delay times. DOE identified the main residential furnace manufacturers, shown in Table 7D.2.1, and the trade names of their residential furnace lines.

Table 7D.2.1 Residential Furnace Manufacturers

Manufacturer	Trade/Brand Name
Allied Air Enterprises, LLC	Advance Comfort System
	Aire Command
	Airease
	Aire-Flo
	Allied
	Armstrong Air
	Concord
	Ducane
	Great Lakes

Manufacturer	Trade/Brand Name
	Kerr Smart Energy
American Standard Heating & Air Conditioning	American Standard Ameristar Freedom 90 High Efficiency Gold SM, SV, XI, XM, ZM Platinum SV, XV, ZV Silver SI, XI, ZI
Bryant Heating & Cooling Systems	Bryant Bryant Plus 80, 80X, 80T
Carrier Corporation	Airquest Arcoaire Bryant Carrier Comfort 80 Comfortmaker Day & Night Heil Icp Commercial Infinity 80 Keeprite Kenmore Performance 80 Tempstar
Coleman By Johnson Controls	Coleman Coleman-Evcon Crown Red T Revolv
Dettson Industries, Inc.	Dettson
ECR International	Airco Olsen
Evcon By Johnson Controls	Evcon
Fraser-Johnston By Johnson Controls	Fraser - Johnston
Goodman Manufacturing Co., Lp.	Amana Energiair Everrest Goodman Janitrol One Hour A/C And Heating
International Comfort Products	Airquest Arcoaire Comfortmaker Day & Night Heil ICP Commercial Keeprite Kenmore

Manufacturer	**Trade/Brand Name**
	Maratherm MSH Legacy Tempstar Grandaire Ecotemp V-Aire
Lennox Industries, Inc.	Dave Lennox Signature Elite 80, 90 Merit 80, 90
Luxaire By Johnson Controls	Luxaire
Nordyne, Llc.	Aabel AC Pro Airtemp Answer Aire Blue Dot Broan Brothers Select Century Comfort Plus Climate Star Columbus Worthington Air Cool Solutions Cowboys Ecologic Air Elect-Aire Evans Mechanical Fire & Ice Frigidaire Garrison Gibson Golden Rule Groggs Heating & Ac Intertherm James River Kelvinator Lifestyle Maximum Air Maytag Mccown Miller Nutone Oliver Peaden Philco Settle-Comfort Tappan Westinghouse
Payne Heating & Cooling	Payne

Manufacturer	Trade/Brand Name
Rheem Sales Company, Inc.	Duroguard Rheem Rudd Sure Weatherking
Trane	Trane XB, XC, XL, XP, XR, XT, XV
Williamson-Thermoflo	Williamson-Thermoflo
York By Johnson Controls	Coleman York

7D.2.2 Data Set Development Background

In 2002, DOE began to develop a database of product specifications (such as different design characteristics) for residential furnaces currently sold in the United States. A preliminary version of the reduced set database was completed at the end of 2004 and released with the 2004 ANOPR.[2] In 2005, during the NOPR phase of the 2007 rulemaking, an update version of the database was published and a final version was published in 2007.[3, 4] This current version updates the past version of the data for NWGFs and MHGFs.

7D.3 DECODING OF MANUFACTURER MODEL NUMBERS

The Department used manufacturer model numbers to determine furnace characteristics not listed in the AHRI database. Manufacturers often code furnace specifications into their model numbers. This appendix illuminates the coding of different manufacturer model numbers.

An Amana model number is shown as an example of how manufacturers code furnace characteristics. Table 7D.3.1 shows the Amana model number “GUID045CA30.” The first row of the table shows the model number broken into eight cells. The fifth, sixth, and seventh characters of the model number are grouped together. The tenth and eleventh characters are grouped together. The second row gives an explanation for each character or group of characters. Row three deciphers the character or group. Deciphering the model number shows that this Amana furnace model is an upflow gas furnace with induced draft, a nominal output of 45 kBtu/h, that it is not NO_X certified, and has a nominal airflow capability appropriate for a three-ton air conditioner.

Table 7D.3.1 Example Furnace Model Number Description

G	**U**	**I**	**D**	**045**	**C**	**A**	**30**
Product Type	Supply Type	Furnace Type	Model Features	Nominal Input (kBtu/h)	Design Series	Additional Features	Nominal AC Size
G: Gas Furnace	U: Upflow	I: Induced Draft (80%)	D: Air Command 80 SV (Category I Venting)	045	C: Third Series	A: Standard Unit (not NOx certified)	30: 3 Tons

All manufacturers have similar coding schemes for their furnace model numbers. Table 7D.3.2 to Table 7D.3.16 show model numbers from the major manufacturers and an explanation of their conventions.

Table 7D.3.2 Amana Model Number Description

A	**M**	**S**	**8**	**070**	**3**	**A**	**N**	**A**
Brand	Air Flow Direction	Description	AFUE	Nominal Input (kBtu/h)	Max CFM @0.5" ESP	Cabinet Width	NOx	Revision
A = Amana B = Distinctions G = Goodman	M: Upflow/ Horizontal D: Dedicated Downflow C: Downflow/ Horizontal H: Hi Air Flow	S: Single-Stage/ Multi-Speed V:Two-Stage/ Variable-Speed	8: 80% 9: 90%	045 070 090 115 140	3:1,200 4:1,600 5:2,000	A:14" B:17.5" C:21" D:24.5"	N:Natural Gas X:Low NOx	A: Initial Revision B: First Revision C: Second Revision

Table 7D.3.3 Armstrong Model Number Description

G	**1N**	**80**	**A**	**H**	**100**	**D**	**20**	**B**		**1A**
Product Family	Furnace Type	Nominal AFUE	Series	Configuration	Heating Input x 1000 (btu/h)	Motor Type	Nominal Maximum CFM x 100	Cabinet Width	Low NOx Model	Revision
G=Gas Furnace	1N = Single-Stage Heat, Non-Direct Vent 1D = Single-Stage Heat, Direct Vent 2D = Two-Stage Heat, Direct Vent	80 AFUE 93 AFUE 95 AFUE	A Series B Series	H = Horizontal U = Upflow T = Upflow/ Horizontal R = Downflow/ Horizontal	50 75 100 125 150	D = Direct Drive	12=1200 14=1400 16=1600 20=2000	A = 13-1/2 B = 17 C = 20-1/2	L = Low NOx Model	1A

Table 7D.3.4 Carrier Model Number Description

58DLA	045	100	08
Furnace Series Configuration/Type	Input Capacity (kBtu/h)	Series Number	Nominal Cooling Size (Airflow) (400 CFM per 12,000 btu/h)
58DLA = Deluxe 4-Way Multipoise 58DLX = Low NOx version 58CVA = Variable Speed 4-Way Multipoise 58CVX = Low NOx version 58CTA = Two-Stage 4-Way Multipoise 58CTX = Low NOx version	045 = 44,000 070 = 66,000 090 = 88,000 110 = 110,000 135 = 132,000 155 = 154,000	100 Series	08 = 800 CFM 12 = 1200 CFM 14 = 1400 CFM 16 = 1600 CFM 20 = 2000 CFM 22 = 2200 CFM

Table 7D.3.5 Ducane Model Number Description

MGPA	075	B	4	B
Furnace Family	Input Capacity (kBtu/h)	Series	Nominal Cooling Capacity (tons)	Revision
MGPA = Fits-All 80 AFUE FPBB = Horizontal 80 AFUE DPGB = Downflow 80 AFUE CMPB = Fits-All 92 AFUE (Downflow) CMPU = Fits-All 92 AFUE (Upflow) CMPV = Fits-All 92 AFUE variable speed	050 075 100 125	A B C U	3 4 5	B

Table 7D.3.6 ECR International (Olsen) Model Number Description

GTM	50
Furnace Family	Input Capacity (kBtu/h)
GTM = Med Efficiency Gas Furnace (80% AFUE) GTH = High Efficiency Gas Furnace (95% AFUE)	50 70 85 100

Table 7D.3.7 Goodman Model Number Description

GMNT	040	3
Unit Type	Input Capacity (Btu/h)	Nominal Cooling Capacity (tons)
GMNT = Multi-position gas furnace	040 = 40,000 Btu/h 060 = 60,000 Btu/h 080 = 80,000 Btu/h 100 = 100,000 Btu/h 120 = 120,000 Btu/h	3 = 3 tons 4 = 4 tons 5 = 5 tons

Table 7D.3.8 ICP Model Number Description

N	9	MP	2	075	F	12	A	#
Brand Identifier	Model Identifier	Installation Configuration	Major Design Feature	Heating Input (btu/h)	Cabinet Width (inches)	Cooling Airflow	Marketing Digit	Engineering Rev.
N = Non-Brand Specific (Generic) T = Tempstar	8 = Non-Condensing 9 = Condensing	MP = Multiposition UP = Upflow DN = Downflow UH = Uplfow/ Horizontal HZ = Horizontal DH = Downflow/ Horizontal	1 = One pipe 2 = Two pipe D = 1 or 1 pipe L = Low Nox N = Single-Stage P = PVC Vent T = Two-Stage V = Variable Speed	050 075 080 100 125	B = 15.5" J = 22.8" F = 19.1" L = 24.5"	08 = 800 12 = 1200 14 = 1400 16 = 1600 20 = 2000	Denotes minor change	Denotes minor change

Table 7D.3.9 Lennox Model Number Description

G	40	UH	24	A	045	X
Unit Type	Series	Configuration	Nominal Add-On Cooling Capacity	Cabinet Width	Heating Input (btu/h)	CA emission requirements
G = Gas Furnace	40 = Merit Series 80% 50 = Elite 80% 60 = Two-Stage 80%	UH = Upflow/Horizontal DF = Downflow/Horizontal	24 = 2 Tons 36 = 3 Tons 48 = 4 Tons 60 = 5 Tons	A = 14-1/2 B = 17-1/2 C = 21 D = 24-1/2	045 = 44,000 070 = 66,000 090 = 88,000 110 = 110,000 135 = 132,000 155 = 154,000	X = meets California NOx standards

Table 7D.3.10 Nordyne Model Number Description

G	6	R	A	144	C	20	C
Furnace Fuel Type	Design Series	Furnace Type	Furnace Configuration	Heating Input (btu/h)	Certification Type	Nominal CFM	Cabinet Width
G, FG, KG, L = Gas	6 or 1	R = Residential T = Residential, Two-Stage	A = Upflow C = Upflow, Condensing K = Downflow L = Downflow, condensing	045 = 45,000 060 = 60,000 072 = 72,000 096 = 96,000 120 = 120,000 144 = 144,000	C = US/Canada N = NOx US	08 = 800 CFM 12 = 1200 CFM V = Variable Speed	A = 14-1/4 B = 19-3/4 C = 22-1/2

Table 7D.3.11 Rheem Non-Condensing Model Number Description

R	G	P	J	07	E	A	U	E	R
Brand Identifier	Fuel Type	Non-Condensing Furnace Type	Design Series	Heating Input (kbtu/h)	Ignition Type	Variations	Blower Size	Cooling Designation (CFM)	Natural Gas Fuel Code
R = Rheem U = Ruud W = Weatherking	G = Natural Gas	D = Upflow L = Downflow P = Upflow/ Horizontal	J = Acclaim A = Acclaim II K = Criterion II Plus 2 N = Classic Series L = Criterion II Plus 2 LXE	04 = 45 05 = 50 06 = 67.5 07 = 75 10 = 100 12 = 125 15 = 150	E = Electric Ignition N = Electric Ignition - NOx Model	A = Standard B= Wide Cabinet	U = 11x6 M = 11x7 R = 11x10	S = 500-1200 E = 1100-1300 G = 1450-1750 J = 1900-2075	R = US A = Canada

Table 7D.3.12 Rheem Condensing Model Number Description

R	**G**	**T**	**J**	**07**	**E**	**M**	**A**	**E**	**S**
Brand Identifier	Fuel Type	Condensing Furnace Type	Design Series	Heating Input (kbtu/h)	Ignition Type	Blower Size	Variations	Cooling Designation (CFM)	Natural Gas Fuel Code
R = Rheem U = Ruud W = Weatherking	G = Natural Gas	T = Downflow/ Horizontal R = Upflow M = Upflow Modulating	J = Classic 90 A = Classic 90 Plus D = Classic 90 Plus Modulating	04 = 45 06 = 60 07 = 75 09 = 90 10 = 105 12 = 120	E = Electric Ignition N = Electric Ignition - (Low NOx)	M = 11x7 R = 11x10 Z = 12x11 Y = 12x7	A = Standard B= Wide Cabinet C = Single/Multi Zone	E = 1100-1300 G = 1500-1700 J = 1900-2100 K = 600-1200 M = 1200-2000	S = US B = Canada

Table 7D.3.13 Texas Furnace Model Number Description

ABA	**040**	**NH**	**3**	**R**
Furnace Family	Heating Input (kbtu/h)	Series	Nominal Cooling Capacity (tons)	Version
ABA = 80 Plus CSA = 90 Plus (Downflow) VSA = 90 Plus (Upflow)	040 060 080 100 120 140	NH	2 3 4 5 6	R = Standard RX = Low Nox RH = High Altitude

Table 7D.3.14 Thermo-Pride Furnace Model Number Description

MHA	**50**	**N**
Furnace Family	Heating Input (kbtu/h)	Furnace Fuel Type
MHA1 = Comfort 80+% Mid-Efficiency Gas Fired Furnace MHA = Comfort 80+% Mid-Efficiency Gas Fired Furnace CHX1 or CDX1 = Premiere Series Two-Stage Gas Fired Furnace CHB1 or CDB1 = 90+% High-Efficiency Gas Fired Furnace	50 75 100 125	N = Natural Gas P = Propane

Table 7D.3.15 Trane/American Standard Model Number Description

T	**U**	**Y**	**080**	**R**	**9**	**V3**	**V**	**0**
Brand Identifier	Furnace Configuration	Type	Heating Input (Kbtu/h)	Major Design Change	Power Supply and Fuel	Airflow Capacity for Cooling (400 CFM/Ton)	Minor Design Change or	Service Digit
T = Trane A = American Standard	U = Upflow/ Horizontal D = Downflow/ Horizontal	C = Condensing D = Induced Draft E = Electronic Ignition X = Direct Vent Condensing Y = Direct Vent Condensing Variable Speed	040 060 080 100 120 140	C = Single-Stage R = Two-Stage All other = Standard system	115 Volt/ Natural Gas	3 = 3 Tons V3 = 1½-3 Tons, Variable Speed Motor (ICM) V4 = 2 - 4 Tons, Variable Speed Motor (ICM) V5 = 3 - 5 Tons, Variable Speed Motor (ICM)	H = Upflow/ Horizontal V = Variable Speed Motor	0

Table 7D.3.16 York Furnace Model Number Description

P4	HU	A	12	N	032	01
Series	Furnace Configuration	Cabinet Size Width	Design Series		Output Capacity (kbtu/h)	Revision
P4	HU = Upflow Horizontal	A = 14-1/2 B = 17-1/2 C = 21 D = 24-1/2	12 = 1200 CFM 16 = 1600 CFM 20 = 2000 CFM	N L = Low NOx	032 048 064 080 100 115 130	01 = first revision 02 = second revision

7D.4 REDUCED FURNACE MODEL CHARACTERISTICS

Input capacity and AFUE distributions for residential furnaces are an essential component in the LCC analysis. Figure 7D.4.1 and Figure 7D.4.2 show the input capacity distribution for each furnace product class. Figure 7D.4.3 and Figure 7D.4.4 show the AFUE distribution for each residential furnace product class.

7D.4.1 Residential Furnace Input Capacity by Product Class

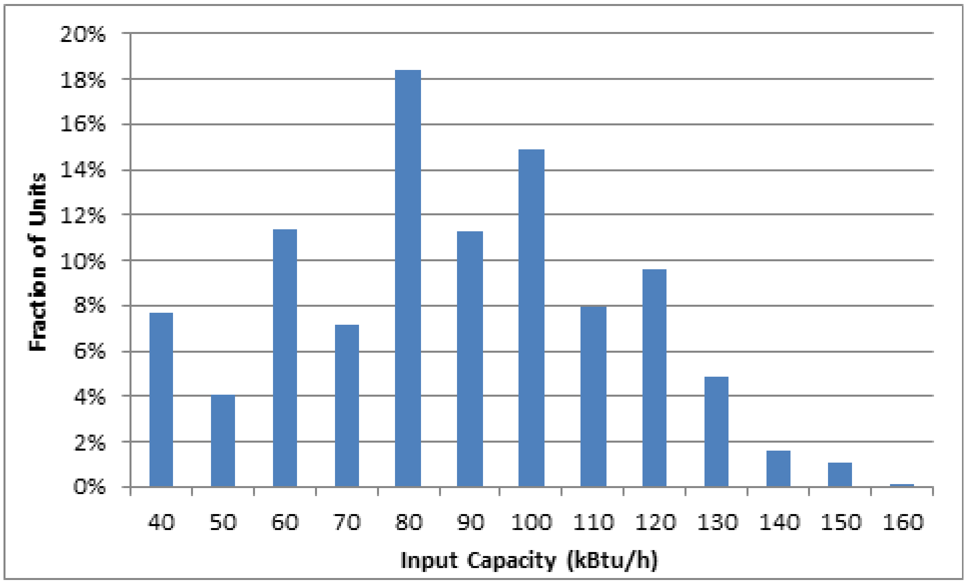

Figure 7D.4.1 Fraction of Non-Weatherized Gas Furnace Models by Input Capacity

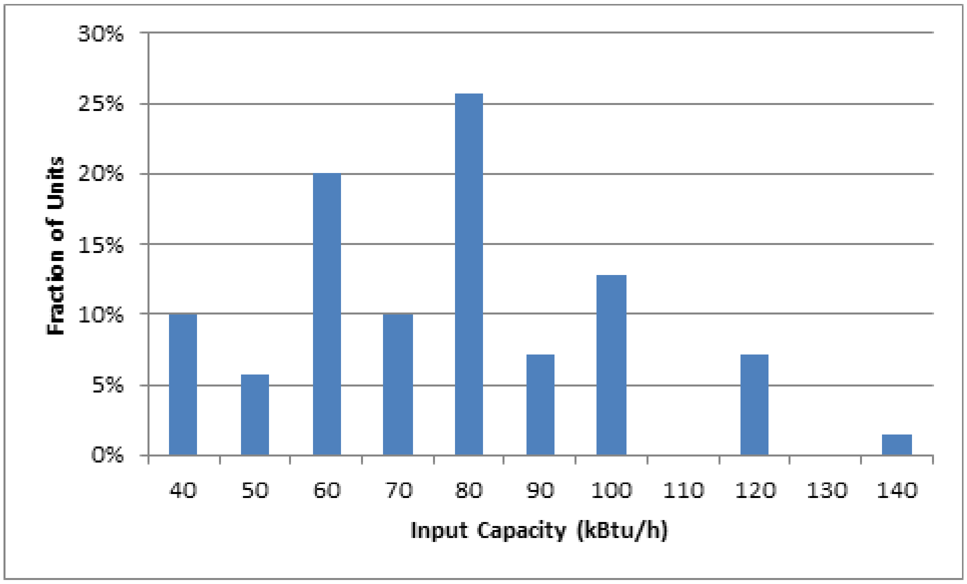

Figure 7D.4.2 **Fraction of Mobile Home Gas Furnace Models by Input Capacity**

7D.4.2 Residential Furnace AFUE by Product Class

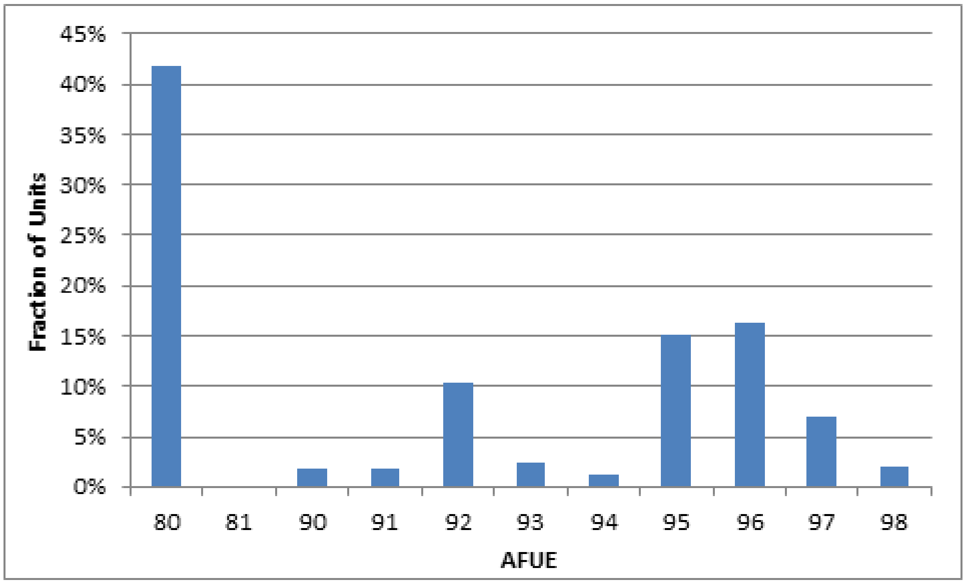

Figure 7D.4.3 **Fraction of Non-Weatherized Gas Furnace Models by AFUE**

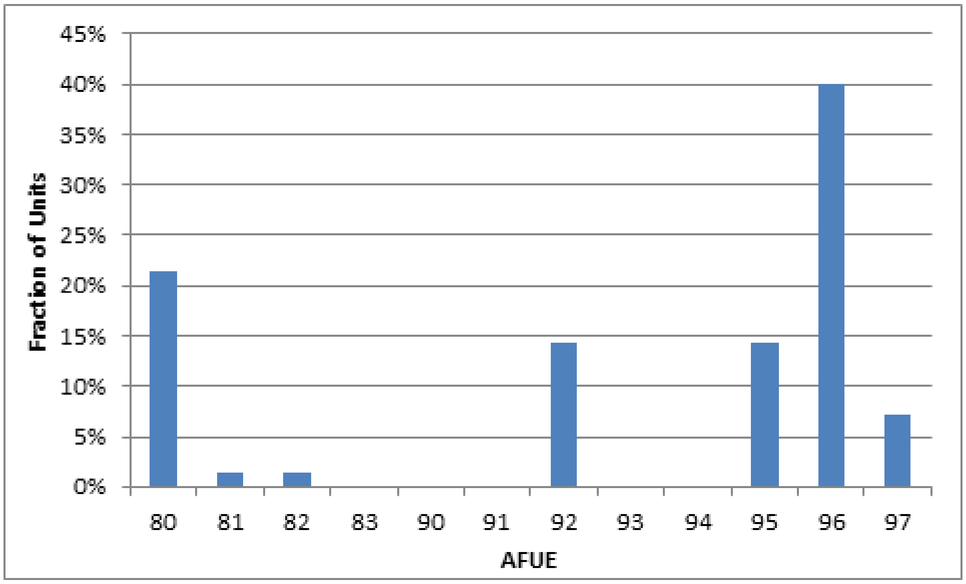

Figure 7D.4.4 Fraction of Mobile Home Gas Furnace Models by AFUE

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CHAPTER 8. LIFE-CYCLE COST AND PAYPACK 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 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 consumers.

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

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 certain of the key parameters as discussed further in section 8.1.1.

Inputs to the LCC and PBP analysis of non-weatherized gas furnace (NWGF) and mobile home gas furnace (MHGF) products are discussed in sections 8.2 and 8.3, respectively. Results for each metric are presented in section 8.5. 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 (www1.eere.energy.gov/buildings/appliance_standards/product.aspx/productid/72).

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

In recognition of the fact that each residential building using furnaces is unique, variability and uncertainty are analyzed by performing the LCC and PBP calculations detailed here for a representative sample of individual households and commercial buildings. 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 NWGF or MHGF unit as described in the energy use analysis in chapter 7. Energy use of NWGFs and MHGFs 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, product distribution markups, and sales taxes.

A certain fraction of NWGFs are used for commercial applications. This fraction determines the frequency at which the model's sampling process will select an item from the commercial category.

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 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 results are displayed as distributions of impacts compared to a base case. The base case efficiency is for 2021 and reflects the expected distribution of efficiency levels by product class. The PBP results are displayed compared to the baseline efficiency level for each product class.

Because consumers are sensitive to the cost of heating products, a standard level that significantly increases the purchase price of NWGFs may induce some consumers to switch to a different heating system rather than purchase a new NWGF. For NWGFs, DOE developed a consumer choice model to estimate the response of builders and home owners to potential amended furnace standards.[a] The model considers the options available to each sample household, which are to purchase and install: (1) a furnace that meets a particular standard level, (2) a heat pump, or (3) an electric furnace.

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

The LCC is the total consumer cost over the life of the product, including purchase price (including retail markups, sales taxes, and installation costs) and operating cost (including repair costs, maintenance costs, and energy cost). Future operating costs are discounted to the time of purchase and summed over the lifetime of the product. The PBP is the increase in purchase cost of a higher efficiency product divided by the change in annual operating cost of the product. It represents the number of years that it will take the consumer to recover the increased purchase cost through decreased operating costs. In the PBP calculation, future costs are not discounted.

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[a] DOE did not analyze switching for MHGFs because the installation cost differential is small between condensing and non-condensing equipment, so the incentive for switching is fairly small.

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:

- *Baseline manufacturer selling price*: The baseline manufacturer selling price (MSP) is the price charged by the manufacturer to a wholesaler for product meeting existing minimum efficiency (or baseline) standards. The MSP includes a markup that converts the cost of production (*i.e.*, the manufacturer cost) to a MSP.
- *Standard-level manufacturer selling price increase*: The standard-level MSP is the incremental change in MSP associated with producing product 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 consumer price.
- *Installation cost*: Installation cost is the cost to the consumer of installing the product. The installation cost represents all costs required to install the product but does not include the marked-up consumer product price. The installation cost includes labor, overhead, and any miscellaneous materials and parts.

The primary inputs for calculating the operating cost are:

- *Product energy consumption*: The product energy consumption is the site energy use associated with the use of the furnace to provide space heating to the building.
- *Energy Prices*: Electricity, natural gas, and liquid petroleum gas (LPG) 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 2014* (*AEO 2014*)[1] is used to forecast energy prices into the future. For the results presented in this chapter, DOE used the *AEO 2014* Reference case to forecast future energy prices.
- *Maintenance costs*: The labor and material costs associated with maintaining the operation of the product.
- *Repair costs*: The labor and material costs associated with repairing or replacing components that have failed.
- *Lifetime*: The age at which the furnace is retired from service.
- *Discount rate*: The rate at which future costs and savings are discounted to establish their present value.

Figure 8.1.1 graphically depicts the relationships between the installed cost and operating cost inputs for the calculation of the LCC and PBP.

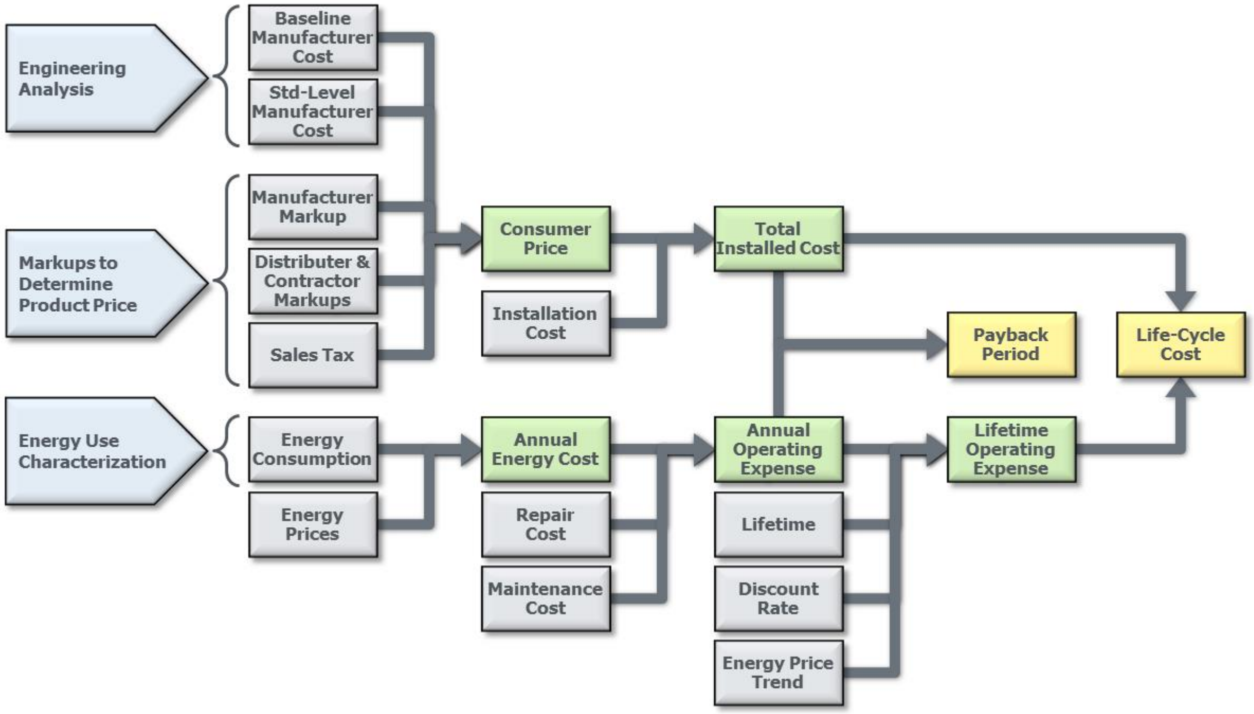

Figure 8.1.1 Flow Diagram of Inputs for the Determination of LCC and PBP

Table 8.1.1 provides descriptions of the various inputs to the calculation of the LCC and PBP. As noted earlier, most of the inputs are characterized by probability distributions that capture variability in the input variables.

Table 8.1.1 Summary of Inputs and Key Assumptions Used in the LCC and PBP Analysis

Inputs	Description
Affecting Installed Costs	
Product Price	Derived from the manufacturer selling price (MSP) for NWGF and MHGF units at different input capacities (from the engineering analysis) multiplied by wholesaler markups and contractor markups plus sales tax (from markups analysis). Used the probability distribution for the different markups to describe the variability.
Installation Cost	Includes installation labor derived from *RS Means Residential Cost Data 2013*.[2] Overhead and materials costs and profits are assumed to be included in the contractor's markup. Thus, the total installed cost equals the consumer product price (manufacturer cost multiplied by the various markups plus sales tax) plus the installation cost.
Affecting Operating Costs	

Annual Energy Use	See chapter 7.
Energy Efficiency	The Annual Fuel Utilization Efficiency (AFUE) is the efficiency descriptor for residential furnaces. Residential furnace test procedure calculation methodologies are used to determine the annual energy consumption associated with the considered standard levels.
Energy Prices	Calculated for RECS 2009 households from monthly marginal average electricity and natural gas or LPG prices in each of the 30 states and groups of states in RECS 2009.[b] Residential prices were escalated by the *AEO 2014* forecasts to estimate future electricity prices. Escalation was performed at the census division level and aggregated to the regions used in the study. Costs were calculated for CBECS 2003 buildings from monthly marginal average electricity and natural gas or LPG prices in each of the 9 divisions in CBECS 2003. Commercial prices were escalated by the *AEO 2014* forecasts to estimate future electricity prices. Escalation was performed at the census division level.
Maintenance Cost	The cost associated with maintaining the operation of the product (*e.g.*, checking blower). Estimated the annualized maintenance cost for baseline efficiency product based on data from a variety of published sources. It is assumed that maintenance costs would vary for higher efficiency levels.
Repair Cost	Estimated the annualized repair cost for baseline efficiency product, based on costs of major repair (such as motor 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	
Product Lifetime	Used the probability distribution of lifetimes developed for furnaces.
Discount Rate	Mean real discount rates ranging from 3.57 percent to 5.12 percent for various classes of residential consumers based on Federal Reserve Board's *Survey of Consumer Finances*. Probability distributions are used for the discount rates. Mean real discount rates ranging from 3.51 percent to 5.96 percent for various classes of commercial consumers based on Federal Reserve Board's *Federal Reserve Statistical Releases – Selected Interest Rates*.[c] Probability distributions are used for the discount rates.
Compliance Date	2021 (5 years after expected publication of the final rule)

All of the inputs depicted in Figure 8.1.1 and summarized in Table 8.1.1 are discussed in section 8.2.

8.1.3 Sample of Furnace Users

The LCC and PBP calculations detailed here are for a representative sample of individual furnace users. NWGFs are assumed to be installed both in residential and commercial buildings, while MHGFs are assumed to be installed in only residential buildings.

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

[c] The *Federal Reserve Statistical Release* reference includes historical data sets for state and local bonds, CDs, and corporate bonds.

As explained in chapter 7, the Energy Information Administration (EIA)'s 2009 Residential Energy Consumption Survey (RECS 2009)[3] serves as the basis for determining the representative residential sample, while EIA's 2003 Commercial Building Energy Consumption Survey (CBECS 2003)[4] serves as the basis for determining the representative commercial sample. RECS collects energy-related data for occupied primary housing units in the United States. RECS 2009 included data from 12,083 housing units that represent almost 113.6 million households. CBECS collects energy-related data for commercial buildings in the United States. CBECS 2003 included data from 5,215 buildings representing 4.9 million buildings.

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

DOE developed a consumer choice model to estimate the response of builders and home owners to potential amended furnace standards. The model considers the options available to each sample household, which are to purchase and install: (1) the furnace that meets a particular standard level, (2) a heat pump, or (3) an electric furnace. In addition, DOE allowed for the possibility that households for which installation of a condensing furnace would leave an "orphaned" gas water heater that would require expensive re-sizing of the vent system might choose instead to purchase an electric water heater when they choose any of the above three options. For option 2, purchase a heat pump, DOE took into consideration the age of the existing central air conditioner, if one exists, because if the air conditioner is not very old, it is unlikely that the consumer would opt to install a heat pump to provide both heating and cooling.

8.2 LIFE-CYCLE COST ANALYSIS INPUTS

Life-cycle cost is the total consumer cost over the life of a product, including purchase cost and operating costs (which are composed of energy costs, maintenance costs, and repair costs). Future operating costs are discounted to the time of purchase and summed over the lifetime of the product. Life-cycle cost 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 over the lifetime, from year 1 to year N,
where N = lifetime of product (years),
OC = operating cost ($),
r = discount rate, and
t = year for which operating cost is being determined.

DOE expresses all costs in 2013$. Total installed cost, operating cost, lifetime, and discount rate are discussed in the following sections. In the LCC analysis, the year of product purchase is assumed to be 2021, the assumed effective date of energy conservation standards for NWGFs and MHGFs.

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 = product price ($) (*i.e.*, consumer price for the product only), and
$INST$ = installation cost ($) (*i.e.*, the cost for labor and materials).

The product price is based on the distribution channel through which the consumer purchases the product. As discussed in chapter 6, DOE defined two major distribution channels for NWGF and MHGF units installed in new construction to describe how the product passes from the manufacturer to the consumer. For NWGFs, the manufacturer sells the product to a wholesaler or distributor, who sells to a mechanical contractor hired by a general contractor. The general contractor purchases and installs the product on behalf of the consumer and adds its markup to the mechanical contractor's price. Because MHGFs are sold installed in mobile homes, these furnaces have a specific distribution chain when purchased in the new construction market. The furnace manufacturer sells MHGFs to the maker of the mobile home, who installs the equipment in the home. The mobile home manufacturer then sells the home to a mobile home dealer, who in turns sells it to a homebuyer and provides installation services. Replacement NWGF and MHGF products follow the same distribution channel as NWGFs in the new construction market, except that there is no general contractor. Instead, the mechanical contractor takes on the general contractor's function. For NWGFs installed in small to mid-sized commercial buildings, the manufacturer sells the product to the wholesaler and then to the consumer through a national account under both replacement and new construction markets.

The remainder of this section provides information about the variables DOE used to calculate the total installed cost for NWGF and MHGF products.

8.2.1.1 Manufacturer Costs

DOE developed manufacturer production costs (MPC) for furnaces as described in chapter 5, Engineering Analysis. The MPCs developed in chapter 5 are by input capacity. The MPCs at each efficiency level averaged over all input capacities are shown in Table 8.2.1.

Table 8.2.1 Manufacturer Production Cost for Residential Furnaces by Efficiency

Product Class	AFUE	Manufacturer Production Cost 2013$	Incremental Cost 2013$
Non-Weatherized Gas Furnace	80%	$379.30	-
	90%	$465.57	$86.26
	92%	$474.06	$94.75
	95%	$545.04	$165.73
	98%	$646.65	$267.35
Mobile Home Gas Furnace	80%	$322.77	-
	92%	$420.41	$97.64
	95%	$502.26	$179.48
	97%	$567.98	$245.20

To capture variations in MPCs, DOE derived manufactured cost adders for different furnace input capacities and design options, including motor type, staging controls (single-stage, two-stage, or modulating), and the use of a low NO_X burner. Chapter 5 contains additional details about DOE's cost assumptions and estimates.

8.2.1.2 Shipping Costs

The MPC of NWGF and MHGF products derived above is considered to be a price that does not include the cost of shipping the product to the distributor (wholesaler for all NWGFs and MHGFs in the replacement distribution channel, and mobile home manufacturer for MHGFs in the new construction distribution channel). Based on the physical attributes of the furnace products (product dimensions and shipping) and the requirements for maximum weight and dimensions of a standard 53-ft trailer, DOE determined that manufacturers were likely to run out of volume inside the shipping trailer before reaching the maximum weight for a truckload. The cost of transporting a furnace unit to the local distribution point depends mainly on its volume, which was calculated for each product class at each efficiency level. Shipping cost was calculated as a function of size and weight, which vary by input capacity, for both product classes. Furnace dimensions typically do not change as a result of increases in efficiency, and DOE's shipping costs show no change across efficiency levels, except for MHGFs. For those products, DOE found that legacy designs, which are shipped with an evaporator coil cabinet on top of the unit, are the most common design at the baseline, while at the condensing efficiency levels the size and design of the units were more in line with NWGFs at the condensing level. Due to the increased size of the baseline unit (to include the coil cabinet), the shipping cost at the baseline is higher for mobile home furnaces. Chapter 5 contains additional details about DOE's shipping cost assumptions and estimates, which are developed by input capacity.

Table 8.2.2 shows the estimated transportation costs of standard-compliant products averaged over all input capacities for each product class. Shipping costs do not vary by furnace fan motor type.

Table 8.2.2 Shipping Costs for Furnaces

Product Class	EL	Shipping Cost Estimate *2013$*
Non-Weatherized Gas Furnace	80%	$11.79
	90%	$11.79
	92%	$11.79
	95%	$11.79
	98%	$11.79
Mobile Home Gas Furnace	80%	$19.67
	92%	$10.59
	95%	$10.59
	97%	$10.59

8.2.1.3 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 by the baseline or standard-compliant manufacturer cost to arrive at the price paid by the 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 consumer price) and an incremental markup (*i.e.*, a markup used to convert a standard-compliant manufacturer cost increase due to an efficiency increase into an incremental consumer price). Markups can differ depending on whether the product is being purchased for a new construction installation or is being purchased to replace an existing product. DOE developed 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 8.2.3 and Table 8.2.4 display the weighted-average overall markups and their associated components for the baseline and incremental markups for NWGFs in residential and commercial applications, respectively. Table 8.2.5 display the weighted-average overall markups and their associated components for the baseline and incremental markups for MHGFs.

Table 8.2.3 Summary of Overall Markups for Non-Weatherized Gas Furnaces in Residential Application

	Replacement		New Construction	
	Baseline Markup	**Incremental Markup**	**Baseline Markup**	**Incremental Markup**
Manufacturer	1.34		1.34	
Wholesaler	1.36	1.10	1.36	1.10
Mechanical Contractor	1.53	1.23	1.43	1.14
General Contractor	-		1.46	1.33
Sales Tax	1.07		-	
Overall Markup	3.00	1.95	3.80	2.24

Table 8.2.4 Summary of Overall Markups for Non-Weatherized Gas Furnaces in Commercial Application

	Replacement			New Construction		
	Baseline Markup	**Incremental Markup**	**National Account: Baseline/ Incr. MU**	**Baseline Markup**	**Incremental Markup**	**National Account: Baseline/ Incr. MU**
Manufacturer	1.34			1.34		
Wholesaler	1.36	1.10	1.36/1.10	1.36	1.10	1.36/1.10
Mechanical Contractor	1.53	1.23	-	1.43	1.14	-
General Contractor	-			1.46	1.33	-
Sales Tax	1.07					
Overall Markup	3.00	1.95	1.96/1.59	3.80	2.24	1.83/1.48

Table 8.2.5 Summary of Overall Markups on Mobile Home Gas Furnaces in Residential Application

	Replacement		New Construction	
	Baseline Markup	**Incremental Markup**	**Baseline Markup**	**Incremental Markup**
Manufacturer	1.27		1.27	
Wholesaler (replacement only)	1.36	1.10	-	-
Mechanical Contractor (replacement only)	1.53	1.23	-	-
Mobile Home Manufacturer (new construction only)	-	-	1.41	1.28
Mobile Home Dealer (new construction only)	-	-	1.30	1.17
Sales Tax (replacement only)	1.07	1.07	-	-
Overall Markup	2.84	1.84	2.32	1.90

Because the relative importance of new construction and replacements in total shipments varies among the product classes, the total markup varies as well (Table 8.2.6).

Table 8.2.6 Summary of Total Markup by Non-Weatherized Gas Furnaces and Mobile Home Gas Furnaces Product Class

Product Class	Baseline Markup	Incremental Markup
Non-Weatherized Gas Furnace	3.20	2.02
Mobile Home Gas Furnace	2.57	1.87

8.2.1.4 Future Product Prices

Examination of historical price data for certain appliances and equipment that have been subject to energy conservation standards indicates that the assumption of constant real prices and costs may, in many cases, overestimate long-term trends in appliance and equipment prices. Economic literature and historical data suggest that the real costs of these products may in fact trend downward over time according to "learning" or "experience" curves. Desroches et al. (2013) summarizes the data and literature currently available that is relevant to price projections for selected appliances and equipment.[5]

In light of these data and DOE's aim to improve the accuracy and robustness of its analyses, DOE decided to assess future costs by incorporating price trend over time, consistent with the analysis in the available literature. DOE used this approach to project future prices of NWGFs and MHGFs at the considered efficiency levels.

An extensive body of literature discusses the "learning" or "experience" curve phenomenon, typically based on observations in the manufacturing sector.[d] In the experience curve method, the real cost of production is related to the cumulative production or "experience" with a product. To explain the empirical relationship, the theory of technology learning is used to substantiate a decline in the cost of producing a given product as firms accumulate experience with the technology. A common functional relationship used to model the evolution of production costs is:

$$Y = aX^{-b}$$

Eq. 8.3

Where:

a = an initial price (or cost),
b = a positive constant known as the learning rate parameter,
X = cumulative production, and
Y = the price as a function of cumulative production.

Thus, as experience (production) accumulates, the cost of producing the next unit decreases. The percentage reduction in cost that occurs with each doubling of cumulative production is known as the learning rate (LR), and is given by:

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

Eq. 8.4

In typical experience curve formulations, the learning rate parameter is derived using two historical data series: price (or cost) and cumulative production, which is a function of shipments during a long time span.

The learning rate factor applied to the total consumer price in 2021 is 0.937. DOE's derivation of learning rates for NWGFs and MHGFs, and their application in the LCC and PBP analysis, are described in appendix 8C. DOE did not conduct a product price trend analysis for standby and off mode standards due to the lack of data indicating a price trend for the components involved in standby and off mode

8.2.1.5 Total Consumer Price

DOE derived the consumer product price for the baseline product by taking the product of the baseline manufacturer cost and the baseline overall markup (including the sales tax) as well as the learning rate in 2021. For each efficiency level above the baseline, DOE derived the consumer product price by taking baseline product consumer price and adding to it the product of the incremental manufacturer cost and the incremental overall markup (including the sales

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

tax). Markups and sales tax can all 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.

Table 8.2.7 presents the average consumer product price for each furnace product class at each efficiency level examined in 2021.

Table 8.2.7 Average Consumer Price for Residential Furnaces (2013$) in 2021

Product Class	AFUE	Average Consumer Price 2013$	Incremental Cost 2013$
Non-Weatherized Gas Furnace	80%	$1,163.42	-
	90%	$1,326.58	$163.16
	92%	$1,342.61	$179.19
	95%	$1,476.87	$313.45
	98%	$1,669.18	$505.76
Mobile Home Gas Furnace	80%	$816.32	-
	92%	$974.68	$158.37
	95%	$1,117.93	$301.62
	97%	$1,232.96	$416.64

8.2.1.6 Installation Cost

The installation cost is the cost to the consumer of installing the furnace. The cost of installation covers all labor and material costs associated with the replacement of an existing furnace or the installation of a furnace in a new home, as well as delivery of the new furnace, removal of the existing furnace, and any applicable permit fees. Higher-efficiency furnaces may require additional installation costs. DOE's analysis of installation costs estimated specific installation costs for each sample household based on building characteristics given in RECS 2009.

DOE estimated the installation costs at each considered efficiency level using a variety of sources, including RS Means 2013 *Residential Cost Data*,[2] manufacturer literature, and information from expert consultants. DOE's analysis of installation costs accounted for regional differences in labor costs. For a detailed discussion of the development of installation costs, see appendix 8D.

DOE gave separate consideration to the cost of installing condensing furnaces in replacement cases, for new owners, and in new buildings.[e] DOE conducted a detailed analysis of

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[e] For NWGFs, DOE assumed that 75 percent are replacements or new owners and 25 percent are new construction. Of the 75 percent replacements, 10 percent are new owners (in other words, 7.5 percent are new owners and 67.5 percent are replacements). For MHGFs, 50 percent are replacements and 50 percent are new construction. DOE assumed that there are no new owners in the MHGF market.

installation costs when a non-condensing furnace is replaced with a condensing furnace, with particular attention to venting issues in replacement applications. The installation cost depends on the furnace installation location, which DOE determined using information from RECS 2009 and CBECS 2003.

For NWGFs, DOE estimated basic installation costs that are applicable to both replacement and new home installations. These costs, which apply to all furnaces, include putting in place and setting up the furnace, gas piping, ductwork, electrical hookup for the thermostat, permit, removal or disposal fees, and, when applicable, additional labor hours for an attic installation.

For NWGF *replacement* installations, DOE included a number of additional costs ("adders") for a fraction of the sample households. For non-condensing furnaces, these additional costs included updating flue vent connectors, vent resizing, and chimney relining. For condensing furnaces, these additional costs included adding a new flue vent (PVC), combustion air vent for direct vent installations (PVC), concealing vent pipes for indoor installations, addressing an orphaned water heater (by updating flue vent connectors, vent resizing, or chimney relining), and condensate removal. Freeze protection (heat tape) is accounted for in the cost of condensate removal for a fraction of NWGFs installed in attics.

DOE also included installation adders for NWGF *new owner* and *new construction* installations. For non-condensing furnaces, a new flue vent (metal) is the only adder. For condensing gas furnaces, the adders include new flue vent (PVC), combustion air vent for direct vent installations (PVC), accounting for a commonly vented water heater, and condensate removal. Table 8.2.8 includes the average cost of installation components for NWGFs in replacement installations. Table 8.2.9 presents the average cost of installation components for NWGFs in new owner and new construction installations. These cost components were included in the overall installation cost as applicable for each installation.

Table 8.2.8 Additional Installation Costs for Non-Weatherized Gas Furnaces in Replacement Applications

Installation Cost Adder	Replacement Installations Impacted	Average Cost (2013$)
Non-Condensing Furnaces		
Updating Flue Vent*	2%	$555.95
Condensing Furnaces		
New Flue Venting (PVC)	100%	$296.12
Combustion Air Venting (PVC)	59%	$295.36
Concealing Vent Pipes	9%	$360.25
Orphaned Water Heater	19%	$672.09
Condensate Removal	100%	$70.06

* For a fraction of installation, this cost includes the commonly vented water heater vent connector, relining chimney, and vent resizing.

Table 8.2.9 Additional Installation Costs for Non-Weatherized Gas Furnaces in New Owner and New Construction Applications

Installation Cost Adder	New Construction Installations Impacted	Average Cost (2013$)
Non-Condensing Furnaces		
New Flue Vent (Metal)*	100%	$1,273.78
Condensing Furnaces		
New Flue Venting (PVC)	100%	$207.83
Combustion Air Venting (PVC)	60%	$205.77
Concealing Vent Pipes	6%	$125.28
Orphaned Water Heater	45%	$987.60
Condensate Removal	100%	$47.46

* For a fraction of installation, this cost includes the commonly vented water heater vent connector.

For MHGFs DOE included similar basic installation costs as described above for NWGFs. DOE also included costs for venting and, for replacement installations, condensate removal.

Table 8.2.10 presents the average installation cost by efficiency level for each product class. For further details on installation costs for NWGFs and MHGFs, see appendix 8D.

Table 8.2.10 Average Installation Cost for Residential Furnaces (2013$)

Product Class	AFUE	Average Installation Cost 2013$	Incremental Cost 2013$
Non-Weatherized Gas Furnace	80%	$1,054.93	-
	90%	$1,369.70	$314.77
	92%	$1,369.70	$314.77
	95%	$1,369.70	$314.77
	98%	$1,369.70	$314.77
Mobile Home Gas Furnace	80%	$734.84	-
	92%	$745.91	$11.08
	95%	$745.91	$11.08
	97%	$745.91	$11.08

8.2.1.7 Total Installed Cost

The total installed cost is the sum of the product 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 8.2.11 presents the average total installed cost for each residential furnace product class at each efficiency level examined.

Table 8.2.11 Average Total Installed Cost for Residential Furnaces (2013$)

Product Class	AFUE	Average Total Installed Cost 2013$	Incremental Cost 2013$
Non-Weatherized Gas Furnace	80%	$2,218.35	-
	90%	$2,696.28	$477.93
	92%	$2,712.31	$493.96
	95%	$2,846.57	$628.22
	98%	$3,038.88	$820.53
Mobile Home Gas Furnace	80%	$1,551.15	-
	92%	$1,720.59	$169.44
	95%	$1,863.84	$312.69
	97%	$1,978.87	$427.72

8.2.2 Operating Cost Inputs

DOE defined the operating cost by the following equation:

$$OC = EC + RC + MC \qquad \textbf{Eq. 8.5}$$

Where:

OC = operating cost ($),
EC = energy cost associated with operating the product ($),
RC = repair cost associated with component failure ($), and
MC = annual maintenance cost for maintaining product operation ($).

The remainder of this section provides information about the variables that DOE used to calculate the operating cost for NWGFs and MHGFs. The annual energy costs of the product are computed from energy consumption per unit for the baseline (efficiency level 0) and standard-compliant cases (efficiency level 1, 2, 3, and so on), combined with the energy prices. Product 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 product class, DOE calculated the annual energy use savings for each sample household at each efficiency level as described in chapter 7.

DOE considered the possibility that some consumers may use a higher-efficiency furnace more than a baseline one, thereby negating some or all of the energy savings from the more-efficient product. Such change in behavior when operating costs decline is known as a (direct) rebound effect. However, the increased furnace usage associated with the rebound effect provides consumers with increased value (*e.g.,* more comfortable indoor temperature). DOE believes that, if it were able to monetize the increased value to consumers of the rebound effect, this value would be similar in monetary value to the foregone energy savings. Therefore, the economic impacts on consumers, with or without including the rebound effect in the analysis, are the same.

8.2.2.2 Energy Prices

DOE derived 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 developed. The process then assigns an appropriate energy price to each household and commercial building in the sample, depending on its type (residential or commercial) and its location.

Derivation of Average and Marginal Monthly Prices

EIA Data – Derivation of Average Annual Energy Prices. DOE derived 2012 annual electricity prices from EIA Form 826 data.[6] The EIA Form 826 data include energy prices by State. DOE calculated annual electricity prices for each RECS region or CBECS region by averaging monthly energy prices by State to get State electricity prices.

DOE obtained the data for natural gas prices from EIA's Natural Gas Navigator,[7] which includes monthly natural gas prices by State for residential, commercial, and industrial consumers.

DOE collected 2012 average LPG prices from EIA's 2012 State Energy Consumption, Price, and Expenditures Estimates (SEDS).[8] SEDS includes annual LPG prices for residential, commercial, industrial, and transportation consumers by state.

For areas with more than one State, DOE weighted each State's average energy price by its number of households in 2021. See appendix 8E for the calculated annual energy prices in 2012.

EIA Data – Derivation of Average Monthly Energy Factors. To determine monthly prices for use in the analysis, DOE developed monthly energy price factors for each fuel based on long-term price data. See appendix 8E for a description of the method. DOE multiplied the average 2012 annual prices by the monthly price factors for each fuel to derive prices for each month.

EIA Data – Seasonal Electricity and Natural Gas Marginal Price Factors. Monthly electricity and natural gas prices were adjusted using seasonal marginal price factors to determine monthly marginal electricity and natural gas prices. These marginal energy prices were used to determine the cost to the consumer of the change in energy consumed. Because marginal price data is only available for residential electricity and natural gas, DOE only developed marginal monthly prices for these fuels. For LPG, DOE used average monthly prices. For a detailed discussion of the development of marginal energy price factors and for a comparison to other data and methods, see appendix 8E.

Table 8.2.12 and Table 8.2.13 show residential marginal monthly natural gas and electricity prices. Average residential LPG prices and commercial prices are shown in appendix 8E.

Table 8.2.12 Residential Marginal Monthly Natural Gas Prices for 2012 Using Marginal Price Factors (2013$/MMBtu)

Geographical Area	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Connecticut, Maine, New Hampshire, Rhode Island, Vermont	12.8	12.9	13.0	11.8	12.4	13.5	14.9	15.2	14.7	13.1	13.9	13.4
Massachusetts	13.3	13.3	13.2	11.7	11.0	11.3	12.5	13.1	12.7	11.0	13.7	13.6
New York	11.4	11.2	11.4	10.0	11.1	12.7	13.4	12.6	12.4	10.8	11.5	10.8
New Jersey	10.3	10.2	10.2	9.2	9.8	10.8	11.2	11.2	11.0	10.1	10.9	10.6
Pennsylvania	10.6	10.7	10.9	8.9	10.0	11.5	12.8	13.1	12.4	10.2	11.5	10.9
Illinois	7.9	8.0	8.0	5.9	7.2	8.3	8.9	9.0	8.3	6.6	8.4	7.9
Indiana, Ohio	10.4	10.5	10.8	9.2	10.2	11.8	12.8	12.9	12.0	9.6	10.8	10.6
Michigan	9.4	9.4	9.5	8.4	9.3	10.7	11.8	12.2	11.3	9.4	10.2	9.8
Wisconsin	9.4	9.2	9.3	7.7	7.7	8.8	9.1	9.3	8.5	7.0	9.6	9.4
Iowa, Minnesota, North Dakota, South Dakota	8.1	7.9	8.1	6.1	6.9	8.0	8.7	9.0	8.3	6.6	8.4	8.1
Kansas, Nebraska	8.6	8.6	8.6	7.0	7.8	9.2	9.9	10.4	10.1	8.6	9.5	8.9
Missouri	10.0	10.0	10.1	8.2	9.5	11.6	13.3	14.0	13.1	11.1	12.0	10.7
Virginia	11.2	10.8	10.7	8.6	10.2	12.0	12.8	12.6	12.6	10.2	11.5	11.2
Delaware, District of Columbia, Maryland	10.7	10.6	10.9	8.9	10.2	11.6	12.4	12.4	11.9	9.8	11.5	10.9
Georgia	11.6	12.3	12.9	9.2	11.4	12.7	13.4	13.3	12.9	11.1	13.2	12.4
North Carolina, South Carolina	11.1	11.1	11.4	9.1	10.5	12.4	13.2	13.7	13.1	10.9	12.2	11.8
Florida	12.7	12.9	13.8	11.4	12.4	13.2	13.6	13.9	13.7	13.5	15.8	14.0
Alabama, Kentucky, Mississippi	10.2	10.1	10.5	9.9	11.3	12.6	13.0	13.3	12.9	11.7	11.6	10.8
Tennessee	9.3	9.4	9.4	8.0	8.8	10.1	10.8	11.1	10.6	9.6	10.4	9.8
Arkansas, Louisiana, Oklahoma	9.0	9.0	9.2	7.9	9.4	10.4	11.1	11.5	11.1	10.2	11.0	9.5
Texas	8.0	8.1	8.3	6.7	7.7	8.5	8.8	9.0	9.0	8.1	9.5	8.4
Colorado	7.1	7.2	7.4	5.8	6.4	8.1	8.2	8.7	8.0	6.4	7.7	7.3
Idaho, Montana, Utah, Wyoming	8.0	8.0	8.2	6.9	7.2	7.8	8.3	8.7	8.2	7.3	8.3	8.2
Arizona	11.5	11.9	12.3	10.0	11.3	12.5	13.6	14.1	13.6	12.7	14.3	12.4
Nevada, New Mexico	7.8	8.0	8.2	7.3	8.2	9.3	9.3	9.7	9.4	8.4	8.7	7.9
California	9.9	9.8	9.5	7.4	7.8	8.2	8.2	8.1	7.9	8.0	9.7	9.8
Oregon, Washington	10.2	10.2	10.3	9.5	9.8	10.4	11.5	11.9	11.6	10.5	10.8	10.5
Alaska	7.8	7.9	8.0	7.2	7.6	7.8	8.4	8.2	7.6	7.2	7.9	8.1
Hawaii	45.4	46.3	46.4	39.5	40.1	40.5	41.4	42.5	42.4	42.2	49.1	48.1
West Virginia	10.3	10.3	10.4	9.0	10.0	12.1	13.4	13.3	12.2	9.9	10.9	10.6
United States	9.8	9.9	10.0	8.3	9.1	10.2	10.9	11.1	10.6	9.1	10.5	10.0

Table 8.2.13 Residential Marginal Monthly Electricity Prices for 2012 Using Marginal Price Factors (2013$/kWh)

Geographical Area	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Connecticut, Maine, New Hampshire, Rhode Island, Vermont	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.17	0.17
Massachusetts	0.15	0.16	0.16	0.14	0.15	0.15	0.14	0.15	0.15	0.15	0.16	0.16
New York	0.15	0.15	0.15	0.20	0.20	0.21	0.21	0.21	0.21	0.20	0.15	0.15
New Jersey	0.15	0.15	0.15	0.19	0.19	0.20	0.21	0.21	0.21	0.19	0.15	0.15
Pennsylvania	0.10	0.10	0.10	0.14	0.14	0.15	0.15	0.15	0.15	0.14	0.11	0.10
Illinois	0.07	0.08	0.08	0.11	0.12	0.12	0.12	0.12	0.12	0.12	0.08	0.08
Indiana, Ohio	0.08	0.08	0.08	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.09	0.08
Michigan	0.13	0.14	0.13	0.16	0.16	0.17	0.17	0.17	0.17	0.16	0.14	0.14
Wisconsin	0.11	0.12	0.12	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.12	0.12
Iowa, Minnesota, North Dakota, South Dakota	0.09	0.09	0.09	0.12	0.12	0.13	0.13	0.13	0.13	0.12	0.09	0.09
Kansas, Nebraska	0.07	0.07	0.07	0.12	0.13	0.14	0.14	0.14	0.14	0.13	0.07	0.07
Missouri	0.07	0.07	0.07	0.12	0.13	0.15	0.14	0.14	0.13	0.12	0.07	0.07
Virginia	0.09	0.09	0.09	0.12	0.13	0.13	0.13	0.13	0.13	0.12	0.09	0.09
Delaware, District of Columbia, Maryland	0.11	0.11	0.11	0.14	0.16	0.17	0.17	0.17	0.17	0.15	0.11	0.11
Georgia	0.09	0.09	0.09	0.13	0.13	0.14	0.14	0.15	0.14	0.13	0.09	0.09
North Carolina, South Carolina	0.09	0.09	0.09	0.11	0.11	0.11	0.11	0.11	0.11	0.12	0.09	0.09
Florida	0.11	0.11	0.11	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.11	0.11
Alabama, Kentucky, Mississippi	0.08	0.08	0.08	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.09	0.08
Tennessee	0.08	0.08	0.08	0.10	0.10	0.10	0.10	0.09	0.10	0.10	0.09	0.09
Arkansas, Louisiana, Oklahoma	0.06	0.06	0.07	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.07	0.06
Texas	0.09	0.09	0.10	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.10	0.10
Colorado	0.09	0.09	0.09	0.12	0.13	0.13	0.13	0.13	0.13	0.13	0.09	0.09
Idaho, Montana, Utah, Wyoming	0.09	0.09	0.09	0.11	0.11	0.11	0.12	0.12	0.11	0.11	0.09	0.09
Arizona	0.08	0.09	0.09	0.12	0.13	0.13	0.13	0.13	0.13	0.12	0.09	0.09
Nevada, New Mexico	0.10	0.10	0.10	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.11	0.10
California	0.17	0.17	0.17	0.18	0.19	0.19	0.20	0.20	0.19	0.18	0.18	0.18
Oregon, Washington	0.09	0.09	0.09	0.08	0.08	0.08	0.09	0.09	0.09	0.09	0.09	0.09
Alaska	0.16	0.16	0.16	0.15	0.16	0.16	0.16	0.16	0.16	0.16	0.17	0.16
Hawaii	0.33	0.33	0.33	0.54	0.55	0.55	0.56	0.56	0.56	0.57	0.35	0.35
West Virginia	0.08	0.08	0.08	0.09	0.10	0.09	0.09	0.09	0.09	0.10	0.09	0.08
United States	0.09	0.09	0.09	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.10	0.09

Household Energy Price Adjustment Factor

RECS 2009 and CBECS 2003 report the total annual consumption and expenditure of each fuel type. To take into account that household energy prices vary inside a geographical area, DOE developed an adjustment factor based on the reported average energy price in RECS 2009 and CBECS 2003 for each building divided by the average energy price in the geographical region in RECS 2009 and CBECS 2003. The monthly price was then multiplied by this adjustment factor to determine the household energy price. Appendix 8E includes more details.

__Energy Price Trends by Census Division__

To arrive at prices in future years, DOE multiplied the prices described in the preceding section by annual energy price factors derived from the forecasts of annual average price changes in EIA's *AEO 2014.* DOE applied the projected energy price trends from 2012 to 2060 for each of the nine census divisions to each building in the sample based on the building's location. Figure 8.2.1 shows the national residential energy price factors. To estimate the trend after 2040, DOE used the average rate of change during 2030–2040. For more details, including commercial energy price factors, see appendix 8E.

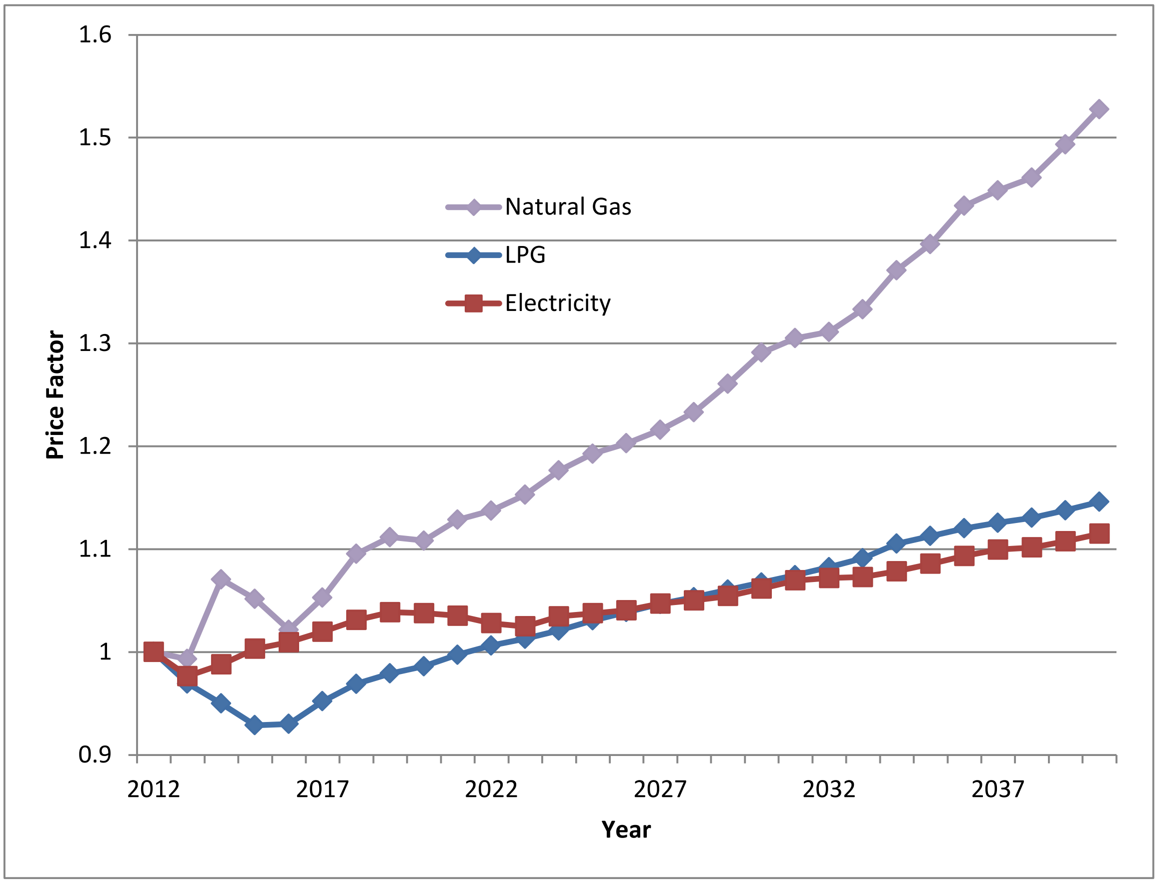

Figure 8.2.1 Projected National Residential Energy Price Factors

__Overall Summary Results by Region__

Table 8.2.14 presents the resulting average and marginal energy prices in 2021 by region. The average price is applied to the base case energy use. The marginal price is applied to the energy savings when comparing each efficiency level to the base case.

Table 8.2.14 Summary of Non-Weatherized Gas Furnaces Average and Marginal Prices in 2021

Energy Price	Unit	Energy Prices (2013$)		Fraction of Affected Shipments
		Average	Marginal	
National				
Natural Gas	2013$/MMbtu	11.2	10.0	90%
LPG	2013$/MMbtu	26.0	26.0	10%
Electricity	2013$/kWh	0.123	0.115	100%
North				
Natural Gas	2013$/MMbtu	10.8	9.7	87%
LPG	2013$/MMbtu	26.0	26.0	13%
Electricity	2013$/kWh	0.126	0.114	100%
Rest of Country				
Natural Gas	2013$/MMbtu	11.65	10.24	94%
LPG	2013$/MMbtu	26.0	26.0	6%
Electricity	2013$/kWh	0.119	0.117	100%

8.2.2.3 Repair Cost

The repair cost is the cost to the consumer for replacing or repairing components in the NWGF or MHGF that have failed (such as the blower or inducer motor). The repair costs at each considered efficiency level were based on *2013 RS Means Facilities Maintenance and Repair Data*,[9] manufacturer literature, and a consultant input. DOE accounted for regional differences in labor costs.

For a detailed discussion of the development of repair costs, see appendix 8F, Maintenance and Repair Cost Determination.

Table 8.2.15 shows the annualized repair cost estimates for each product class.

Table 8.2.15 Annualized Repair Cost for Residential Furnaces (2013$)

Product Class	AFUE	Average Repair Cost 2013$	Incremental Cost 2013$
Non-Weatherized Gas Furnace	80%	$19.80	-
	90%	$22.52	$2.72
	92%	$22.52	$2.72
	95%	$22.52	$2.72
	98%	$22.52	$2.72
Mobile Home Gas Furnace	80%	$8.84	-
	92%	$9.90	$1.05
	95%	$9.90	$1.05
	97%	$9.90	$1.05

8.2.2.4 Maintenance Cost

The maintenance cost is the routine cost to the consumer of maintaining product operation. DOE assumes that condensing furnaces have a higher maintenance cost than non-condensing furnaces, but that this maintenance cost is the same at all non-condensing or condensing efficiency levels within each product class.

Labor hours and costs for annual maintenance were estimated using RS Means data. The frequency with which maintenance occurs was derived using RECS 2009 data and a consumer survey[10] on the frequency with which owners of different types of furnaces perform maintenance. For more details on the development of maintenance costs, see appendix 8F.

Table 8.2.16 shows the annualized maintenance cost estimates for each product class.

Table 8.2.16 Annualized Maintenance Cost for Residential Furnaces (2013$)

Product Class	AFUE	Annualized Maintenance Cost 2013$	Incremental Cost 2013$
Non-Weatherized Gas Furnace	80%	$38.20	-
	90%	$40.06	$1.86
	92%	$40.06	$1.86
	95%	$40.06	$1.86
	98%	$40.06	$1.86
Mobile Home Gas Furnace	80%	$37.79	-
	92%	$39.62	$1.84
	95%	$39.62	$1.84
	97%	$39.62	$1.84

8.2.2.5 Lifetime

DOE defines lifetime as the age when a product is retired from service. DOE used national survey data, along with manufacturer shipment data, to calculate the distribution of NWGF and MHGF lifetimes. For a detailed discussion of the development of furnace lifetime, see appendix 8G.

Table 8.2.17 shows the Weibull distribution parameters alpha, beta and the location. DOE assumed that the lifetime of a NWGF or MHGF is the same across the different product classes and efficiency levels.

Table 8.2.17 Lifetime Parameters for Non-Weatherized Gas Furnaces and Mobile Home Gas Furnaces

Product Class	Weibull Parameters			Mean Lifetime
	Alpha (scale)	Beta (shape)	Location (delay)	
All Furnaces	22.9	3.37	1	21.5

8.2.2.6 Discount Rates

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

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 life-cycle cost and life-cycle cost savings. DOE notes that the discount rate used in the LCC analysis is distinct from an implicit discount rate, as it is not used to model consumer purchase decisions. The opportunity cost of funds in this case may include interest payments on debt and interest returns on assets.

DOE estimates separate discount rate distributions for six income groups, divided based on income percentile as reported in the SCF.[11] 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 involved identifying all relevant household debt or asset classes in order to approximate a consumer's opportunity cost of funds related to appliance energy cost savings and maintenance costs. The approach assumes that in the long term, consumers are likely to draw from or add to their collection of debt and asset holdings approximately in proportion to their current holdings when future expenditures are required or future savings accumulate. DOE has included several previously excluded debt types (*i.e.,* vehicle and education loans, mortgages, all forms of home equity loan) in order to better account for all of the options available to consumers.

The average share of total debt plus equity and the associated rate of each asset and debt type are used to calculate a weighted average discount rate for each SCF household (Table 8.2.19). 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 estimated the average percentage shares of the various types of debt and equity using data from the SCF for 1995, 1998, 2001, 2004, 2007, and 2010.[f] DOE derived the household-weighted mean percentages of each source of financing throughout the 5 years surveyed. DOE posits that these long-term averages are most appropriate to use in its analysis.

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[f] Note that two older versions of the SCF are also available (1989 and 1992); these surveys are not used in this analysis because they do not provide all of the necessary types of data (*e.g.*, credit card interest rates, etc). DOE feels that the 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 estimated interest rates associated with each type of debt. The source for interest rates for mortgages, loans, credit cards, and lines of credit was the SCF for 1995, 1998, 2001, 2004, 2007, 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).[g] For example, a 6 percent nominal mortgage rate has an effective nominal rate of 5.5 percent for a household at the 25 percent marginal tax rate. When adjusted for an inflation rate of 2 percent, the effective real rate becomes 2.45 percent.

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[g] 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**[12]	**Applicable Marginal Tax Rate**[13]	**Average Real Effective Interest Rate**
1995	8.2	2.83	24.2	3.3
1998	7.9	1.56	25.0	4.3
2001	7.6	2.85	24.2	2.8
2004	6.2	2.66	20.9	2.2
2007	6.3	2.85	20.6	2.1
2010	5.7	1.64	20.0	2.9

Table 8.2.21 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 2021.

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 derived asset interest rates from various sources of national historical data (1983-2013). The interest rates associated with certificates of deposit,[14] savings bonds,[15] and bonds (AAA corporate bonds)[16] were collected from Federal Reserve Board time-series data. Rates on money market accounts came from Cost of Savings Index data.[17] Rates on savings accounts were estimated as one half of the rate for money market accounts, based on recent differentials between the return to each of these assets. The rates for stocks are the annual returns on the Standard and Poor's.[18] Rates for mutual funds are a weighted average of the stock rates (two-thirds weight) and the bond rates (one-third weight) in each year. DOE assumed rates on checking accounts to be zero.

DOE adjusted the nominal rates to real rates using the annual inflation rate for each year. Average nominal and real interest rates for the classes of household assets are listed in Table 8.2.22. 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 2021. For each type, DOE developed a distribution of rates, as shown in appendix 8H.

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 calculated discount rate distributions for each income group as follows. First, DOE calculated the discount rate for each consumer in each of the six versions of the *SCF*, using the following formula:

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

Eq. 8.6

Where:

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

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

Once the real discount rate was estimated for each consumer, DOE compiled the distribution of discount rates in each survey by income group by calculating the proportion of consumers with discount rates in bins of 1 percent increments, ranging from 0-1 percent to greater than 30 percent. Giving equal weight to each survey, DOE compiled 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 sampled a rate for each RECS household from the distributions for the appropriate income group. (RECS provides household income data.) Appendix 8H presents the full probability distributions for each income group that DOE used 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

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 future year energy costs and non-energy operations and maintenance costs to calculate the estimated net life-cycle cost of products of various efficiency levels and life-cycle cost savings as compared to the baseline for a representative sample of commercial end users.

DOE's method views the purchase of a higher efficiency appliance as an investment that yields a stream of energy cost savings. DOE derived the discount rates for the LCC analysis by estimating the cost of capital for companies that purchase NWGFs. The weighted average cost of capital (WACC) is commonly used to estimate the present value of cash flows to be derived from a typical company project or investment. Most companies use both debt and equity capital to fund investments, so their cost of capital is the weighted average of the cost to the firm of equity and debt financing, as estimated from financial data for publicly traded firms in the sectors that purchase NWGFs.[19]

Damodaran Online, a widely used source of information about company debt and equity financing, was used as the primary source of data for this analysis.[20] Companies included in the Damondaran Online database were assigned to the aggregate categories listed below:

- Retail
- Property Owners
- Medical Services
- Industrial
- Lodging

- Food Service
- Offices
- State and Local Government, Education
- Federal Government
- Other

DOE estimated the cost of equity using the CAPM.[21] 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. 8.7

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; therefore, the estimates can vary with the time period over which data is 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 used Federal Reserve methodologies for calculating these parameters. In its use of the CAPM, the Federal Reserve uses a forty-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."[22]

By taking a forty-year geometric average of Federal Reserve data on annual nominal returns for 10-year Treasury bills, DOE found for this analysis the following risk-free rates for 2011-2013 (Table 8.2.24).[23] DOE also estimated the ERP by calculating the difference between risk-free rates and stock market return for the same time period.[24]

Table 8.2.24 Risk-Free Rate and Equity Risk Premium, 2010-2012

Year	Risk-free rate (%)	ERP (%)
2011	6.61%	2.94%
2012	6.41%	3.99%
2013	6.24%	5.30%

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

$$\boldsymbol{k_{di} = R_f + R_{ai}} \qquad \textbf{Eq. 8.8}$$

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:

$$WACC = k_e \times w_e + k_d \times w_d \qquad \textbf{Eq. 8.9}$$

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 WACC, or discount rate, for each company. DOE then aggregates the company real WACC to estimate the discount rate for each of the ownership types in the analysis. These values are presented in Table 8.2.25. Table 8.2.25 provides results for average- to large-sized companies. Discount rates for small companies are estimated using a modification of the CAPM model, discussed in the Life-Cycle Cost Subgroup Analysis (chapter 11). While WACC values for any category may trend higher or lower over substantial periods of time, these values represent a private sector cost of capital that is averaged over major business cycles.

Table 8.2.25 Weighted Average Cost of Capital for Sectors that Purchase Residential Furnaces

Sector	Mean Discount Rate (%)	Standard Deviation (%)
Retail	5.00	1.07
Property owners	5.12	0.90
Medical services	4.97	0.92
Industrial	5.23	1.18
Lodging	5.96	1.65
Food Service	4.90	0.95
Offices	5.08	1.28
State/Local Government/Education	3.51	1.20
Federal Government	3.55	1.45
Other	5.04	1.07

Source: Damodaran Online *Data Page: Costs of Capital by Industry Sector,* 2011, 2012, 2013.

8.2.2.7 Compliance Date of Standard

Pursuant to 42 U.S.C. 6295(m), the compliance date of any new energy efficiency standard for residential furnaces is 5 years after the final rule is published. Consistent with its published regulatory agenda, DOE assumed that the final rule would be issued by the end of 2015 and that, therefore, the new standards would require compliance beginning in 2021. DOE calculated the LCC and PBP for all consumers as if they each would purchase a new furnace in 2021.

8.2.2.8 Base Case Distribution of Efficiency Levels

To estimate the share of consumers affected by a potential standard at a particular efficiency level, DOE considered the projected distribution (*i.e.*, market shares) of product efficiencies that consumers will purchase in the first compliance year, without amended energy conservation standards (base case).

DOE estimated the market shares of the different efficiency levels in each residential furnace product class in 2021. DOE used data on the distribution of models in AHRI's Directory of Certified Product Performance[25] to disaggregate the condensing-level shipments among condensing efficiency levels. Based on stakeholder input, DOE assumed that for furnace replacements, the fraction of 95 percent AFUE and above shipments in the replacement market would be double the fraction in the new construction market. DOE also assumed that the fraction of 95 percent AFUE and above shipments would be higher in the North compared to the Rest of Country, because the ENERGY STAR® level in the North is 95 percent AFUE compared to 90 percent in the Rest of Country.

DOE considered incentives and other market forces that have increased the sales of high-efficiency furnaces to estimate base-case efficiency distributions for the considered products. DOE started with data provided by AHRI on historical shipments for each product class. For NWGFs, DOE reviewed AHRI data from 1992 to 2009, detailing the market shares of non-condensing (80-percent AFUE) and condensing (90-percent AFUE and greater) furnaces by region.[h] DOE also compiled data on the national market shares of non-condensing and condensing gas furnaces from 2010 to 2012 from the ENERGY STAR program.[26] With these data, DOE derived historic trends for the North and Rest of Country regions.

To project trends from 2011 to 2021, DOE only used the trends from 1993 to 2004 because from 2005 to 2011, there was a sharp increase in the share of condensing furnaces primarily due to Federal tax credits, which was followed by a sharp decrease in 2012. DOE determined that excluding these years provides a more reasonable projection. The maximum share of condensing shipments for each region is assumed to be 95 percent. In other words, at least five percent of NWGF and MHGF shipments will be non-condensing.

Table 8.2.26 and Table 8.2.27 show the estimated AFUE base-case efficiency distributions in 2021 for NWGFs and MHGFs by region (National, North, and Rest of Country) and market (replacement and new construction).

Table 8.2.26 Base-Case AFUE Distribution for Non-Weatherized Gas Furnaces in 2021

Efficiency, AFUE	**2021 Market share in percent**				
	National	**North, Repl**	**North, New**	**Rest of Country, Repl**	**Rest of Country, New**
80%	53.4%	33.0%	34.7%	77.6%	70.4%
90%	5.2%	5.5%	8.8%	3.4%	5.5%
92%	17.9%	15.8%	32.4%	13.9%	20.2%
95%	23.0%	44.9%	23.6%	4.9%	3.8%
98%	0.5%	0.8%	0.6%	0.1%	0.2%

Table 8.2.27 Base-Case AFUE Distribution for Mobile Home Gas Furnaces in 2021

Efficiency, AFUE	**2021 Market share in percent**				
	National	**North, Repl**	**North, New**	**Rest of Country, Repl**	**Rest of Country, New**
80%	73.9%	65.8%	64.3%	87.2%	89.2%
92%	12.1%	6.1%	21.2%	9.6%	9.6%
95%	13.8%	27.7%	14.3%	3.2%	1.2%
98%	0.2%	0.4%	0.2%	0.0%	0.0%

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[h] The market share of furnaces with AFUE between 80 and 90 percent is well below 1 percent due to the very high installed cost of 81-percent AFUE furnaces, compared with condensing designs, and concerns about safety of operation.

DOE also estimated base-case efficiency distributions for furnace standby mode and off mode power. As shown in Table 8.2.29, DOE estimated that 61 percent of the affected market would be at the baseline level in 2021 based on data from 18 furnace models from field study conducted in Wisconsin[27] and data from DOE laboratory tests. In addition, for MHGFs, DOE assumed that all PSC furnace fan motor models would have lower standby power than the max tech efficiency level.

Table 8.2.28 Standby Mode and Off Mode Base-Case Efficiency Distribution in 2021 for Non-Weatherized Gas Furnaces and Mobile Home Gas Furnaces

Efficiency Level	Standby/Off Mode *Watts*	NWGF Market Share in percent	MHGF Market Share in percent
Baseline	11.0	61	5
1	9.5	0	0
2	9.2	17	1
3	8.5	22	94

For a detailed discussion of the development of base case distributions, see appendix 8I.

8.3 PAYBACK PERIOD INPUTS

The PBP is the amount of time it takes the consumer to recover the assumed higher purchase cost of more energy-efficient product 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:

$$PBP = \Delta IC / \Delta OC \qquad \text{Eq. 8.10}$$

Where:

PBP = payback period in years,
Δ IC = difference in the total installed cost between the more efficient standard-level product (efficiency levels 1, 2, 3, etc.) and the baseline efficiency product (efficiency level 0), 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 product if the increased total installed cost of the more-efficient product is not recovered fast enough in reduced operating costs.

DOE also calculates a rebuttable PBP, which is the time it takes the consumer to recover the assumed higher purchase cost of more energy-efficient product 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 product to the 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 product 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 energy price trends are not required. Because the PBP is a "simple" payback, the required energy cost is only for the year in which a new standard is to take effect—in this case, 2021.

8.4 PRODUCT SWITCHING

Because consumers are sensitive to the cost of heating products, a standard level that significantly increases the purchase price of NWGFs may induce some consumers to switch to a different heating system rather than purchase a new NWGF. The decision to switch is affected by the prices of the energy sources for competing products, as well as other factors.

For NWGFs, DOE developed a consumer choice model to estimate the response of builders and home owners to potential amended furnace standards.[i] The model considers the options available to each sample household, which are to purchase and install: (1) a furnace that meets a particular standard level, (2) a heat pump, or (3) an electric furnace. In addition, DOE allowed for the possibility that households for which installation of a condensing furnace would leave an "orphaned" gas water heater that would require expensive re-sizing of the vent system might choose instead to purchase an electric water heater when they choose any of the above three options. For option 2, purchase a heat pump, DOE took into consideration the age of the existing central air conditioner (CAC), if one exists, because if the air conditioner is not very old, it is unlikely that the consumer would opt to install a heat pump to provide both heating and cooling.

The consumer choice model uses the installed cost of each option and the operating costs, taking into account the space heating and water heating loads for each household and the cost of energy over the lifetime of the available product options. DOE also accounted for the cooling load of each household that might switch from a NWGF and CAC to a heat pump.

For heat pumps, DOE used the efficiency and consumer prices for models that meet the energy conservation standards due to take effect on January 1, 2015 (10 CFR 430.32(c)(3)) For water heaters, DOE used the efficiency and consumer prices for models that meet the standards due to take effect on April 16, 2015. (10 CFR 430.32(d)) For electric furnaces, DOE used an efficiency of 98-percent AFUE and a consumer price based on RS Means. For situations where a

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[i] DOE did not analyze switching for MHGFs because the difference in installation cost is small between condensing and non-condensing products, so the incentive for switching is fairly small.

household with a NWGF might switch to electric space heating, DOE used the installed cost of the electric heating options, including a separate circuit up to 100 amps that would need to be installed to power the electric resistance heater within an electric furnace or heat pump, as well as the cost of upgrading the electrical service panel for a fraction of households. For all installations, DOE used regional labor rates from RS Means.

Electric furnaces are estimated to have the same lifetime as NWGFs, but heat pumps have an estimated average lifetime of 19 years, which is 2.5 years less than the estimated average lifetime of NWGFs (21.5 years). To ensure comparable accounting, DOE annualized the installed cost of a second heat pump and multiplied the annualized cost by the difference in years between the heat pump and the NWGF in each heat pump switching situation.

The decision criteria in the model are based on proprietary data from Decision Analysts, which identified the willingness of a representative sample of consumers to purchase more-efficient space-conditioning systems.[28, 29, 30, 31] From these data, DOE deduced that consumers would expect a payback period of 3.6 years or less for a more-expensive but more-efficient product (see appendix 8J for further discussion). This reflects that in general, consumers place a relatively high importance on first cost differences. For each household, the model calculates the PBP for each option relative to a NWGF that meets each particular efficiency level. The model rejects any option that has a PBP greater than 3.6 years, and selects the option with the lowest PBP.

For a detailed discussion of the development of the product switching methodology and inputs, see appendix 8J.

For NWGFs, the LCC and PBP results at each efficiency level include consumers that would purchase and install a NWGF at that level, and also consumers that would choose to switch to alternative heating equipment rather than pay the cost of installing a furnace at that level.[j] The impacts for consumers that switch depend on the product that they choose (heat pump or electric furnace) and the NWGF that they would purchase in the base case. The extent of projected product switching (in 2021) is shown in Table 8.4.1 for each efficiency level for NWGFs. As expected, the degree of switching increases at higher-efficiency ELs where the installed cost of a NWGF is very high for some consumers. A comparison of these results to a GTI survey of home builders and consultants conducted in 2014 is presented in appendix 8J.[32]

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[j] DOE did not analyze switching for MHGFs because the installation cost differential is small enough between condensing and non-condensing equipment that the incentive for switching is fairly small.

Table 8.4.1 Results of Consumer Choice Model for Non-Weatherized Gas Furnaces

	National Standard at:			
Consumer Option	**90% AFUE**	**92% AFUE**	**95% AFUE**	**98% AFUE**
Purchase NWGF at Standard Level	90.6%	90.6%	88.6%	84.7%
Switch to Heat Pump*	6.8%	6.8%	8.6%	12.0%
Switch to Electric Furnace*	2.6%	2.5%	2.8%	3.3%
Total	100%	100%	100%	100%

*Includes households that also switch from a gas water heater to an electric water heater.

8.5 LIFE-CYCLE COST AND PAYBACK PERIOD RESULTS

DOE's approach for conducting the LCC and PBP analysis relied on developing samples of households that use each of the considered products. DOE also used 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 households in the sample. LCC and PBP calculations were performed 10,000 times on the sample of households established for each residential product. Each LCC and PBP calculation was performed on a single household that was selected from the sample of the residential users. The selection of a household was based on its sample weight (*i.e.*, how representative a particular household is of other households in the distribution—either regionally or nationally). Each LCC and PBP calculation also sampled from the probability distributions that DOE developed to characterize many of the inputs to the analysis.

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

National and regional LCC and PBP results are presented below. For results disaggregated by sector (residential and commercial), and installation type (replacement and new construction), see the Summary worksheet in the LCC spreadsheet tool.

8.5.1 Non-Weatherized Gas Furnaces

Table 8.5.1 and Table 8.5.2 show the LCC and PBP results by EL and region for NWGFs. The average operating cost is the discounted sum. The results include consumers that switch to electric heating systems. In these cases, the installed cost and operating costs of the electric heating system are compared to the gas furnace that would have been installed in the base case. Cases with switching only include consumers that would buy an 80-percent AFUE furnace in the base case – in these cases, a standard requiring a condensing furnace causes them to switch. The LCC savings are positive in the majority of switching cases.

Table 8.5.1 Average LCC and PBP Results by AFUE Standard Efficiency Level for Non-Weatherized Gas Furnaces

Efficiency Level	AFUE	Average Costs *2013$*				Simple Payback *years*
		Installed Cost	First Year's Operating Cost	Lifetime Operating Cost	LCC	
National						
0	80%	$2,218	$642	$10,314	$12,533	--
1	90%	$2,654	$589	$9,388	$12,042	8.2
2	92%	$2,669	$579	$9,228	$11,897	7.2
3	95%	$2,788	$565	$8,985	$11,773	7.4
4	98%	$2,948	$554	$8,771	$11,718	8.3
North						
0	80%	$2,410	$807	$12,923	$15,333	--
1	90%	$2,985	$737	$11,761	$14,746	8.3
2	92%	$3,000	$724	$11,555	$14,556	7.2
3	95%	$3,133	$706	$11,251	$14,385	7.2
4	98%	$3,311	$690	$10,979	$14,290	7.7
Rest of Country						
0	80%	$2,003	$456	$7,374	$9,376	--
1	90%	$2,280	$422	$6,714	$8,994	8.1
2	92%	$2,295	$415	$6,606	$8,901	7.1
3	95%	$2,398	$406	$6,430	$8,828	7.9
4	98%	$2,539	$401	$6,281	$8,820	9.6

Note: The results for each EL are calculated assuming that all consumers use products with that efficiency level. The PBP is measured relative to the baseline product.

Table 8.5.2 LCC Savings Relative to the Base Case Efficiency Distribution for Non-Weatherized Gas Furnaces AFUE Standards

Efficiency Level	AFUE	Life-Cycle Cost Savings	
		% of Consumers that Experience Net Cost	Average Savings* *2013$*
National			
0	80%	0%	--
1	90%	22%	$236
2	92%	20%	$305
3	95%	24%	$388
4	98%	40%	$441
North			
0	80%	0%	--
1	90%	11%	$208
2	92%	10%	$277
3	95%	14%	$374
4	98%	37%	$467
Rest of Country			
0	80%	0%	--
1	90%	33%	$267
2	92%	31%	$336
3	95%	35%	$404
4	98%	43%	$412

* The calculation includes buildings with zero LCC savings (no impact).

Figure 8.5.1 shows the range of LCC savings for the efficiency levels considered for NWGFs. 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 percent of the households have lifecycle cost 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.

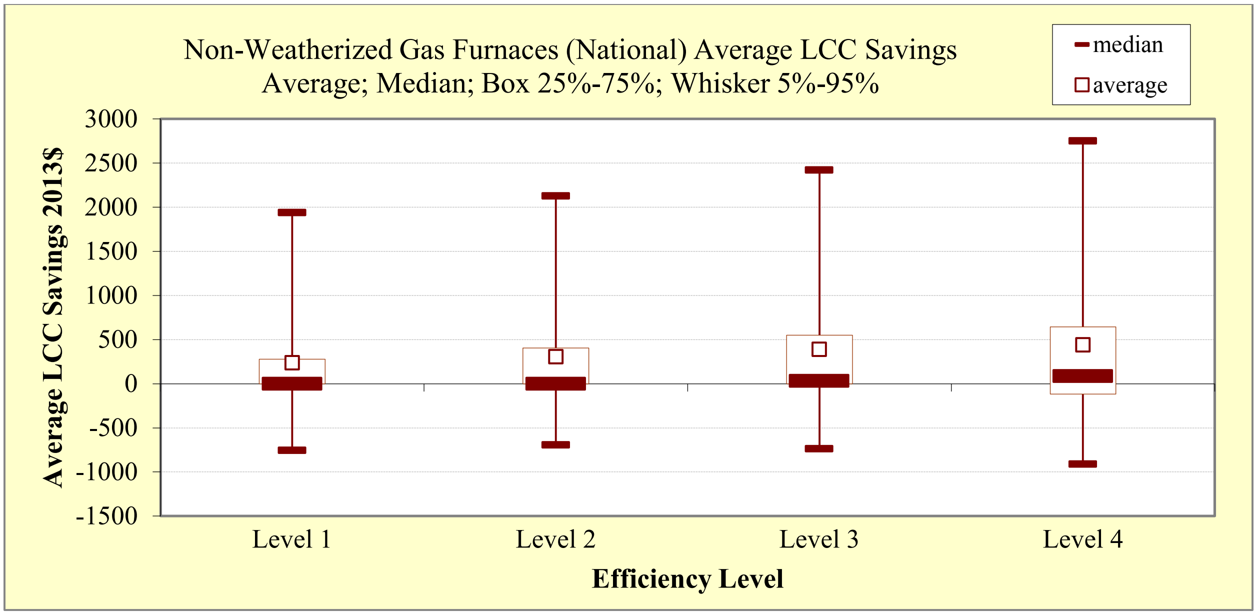

Figure 8.5.1 **Distribution of LCC Savings for Non-Weatherized Gas Furnaces, AFUE Standards**

8.5.2 Mobile Home Gas Furnaces

Table 8.5.3 and Table 8.5.4 show the LCC and PBP results by EL and region for MHGFs.

Table 8.5.3 Average LCC and PBP Results by AFUE Standards Efficiency Level for Mobile Home Gas Furnaces

Efficiency Level	AFUE	Average Costs *2013$* Installed Cost	 First Year's Operating Cost	 Lifetime Operating Cost	 LCC	Simple Payback *years*
National						
0	80%	$1,551	$700	$10,887	$12,438	--
1	92%	$1,721	$623	$9,694	$11,415	2.2
2	95%	$1,864	$607	$9,440	$11,304	3.3
3	97%	$1,979	$599	$9,319	$11,298	4.2
North						
0	80%	$1,590	$832	$12,829	$14,418	--
1	92%	$1,760	$740	$11,415	$13,175	1.8
2	95%	$1,902	$719	$11,103	$13,005	2.8
3	97%	$2,017	$709	$10,949	$12,966	3.5
Rest of Country						
0	80%	$1,489	$489	$7,762	$9,251	--
1	92%	$1,658	$436	$6,926	$8,584	3.2
2	95%	$1,802	$426	$6,766	$8,568	5.0
3	97%	$1,918	$422	$6,696	$8,614	6.4

Note: The results for each EL are calculated assuming that all consumers use products with that efficiency level. The PBP is measured relative to the baseline product.

Table 8.5.4 LCC Savings Relative to the Base Case Efficiency Distribution for Mobile Home Gas Furnaces AFUE Standards

Efficiency Level	AFUE	Life-Cycle Cost Savings	
		% of Consumers that Experience Net Cost	Average Savings* *2013$*
National			
0	80%	0%	--
1	92%	7%	$691
2	95%	13%	$778
3	97%	25%	$784
North			
0	80%	0%	--
1	92%	4%	$770
2	95%	8%	$902
3	97%	22%	$941
Rest of Country			
0	80%	0%	--
1	92%	13%	$565
2	95%	22%	$579
3	97%	30%	$533

* The calculation includes buildings with zero LCC savings (no impact).

Figure 8.5.2 shows the range of LCC savings for the efficiency levels considered for MHGFs. 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 percent of the households have life-cycle cost 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.

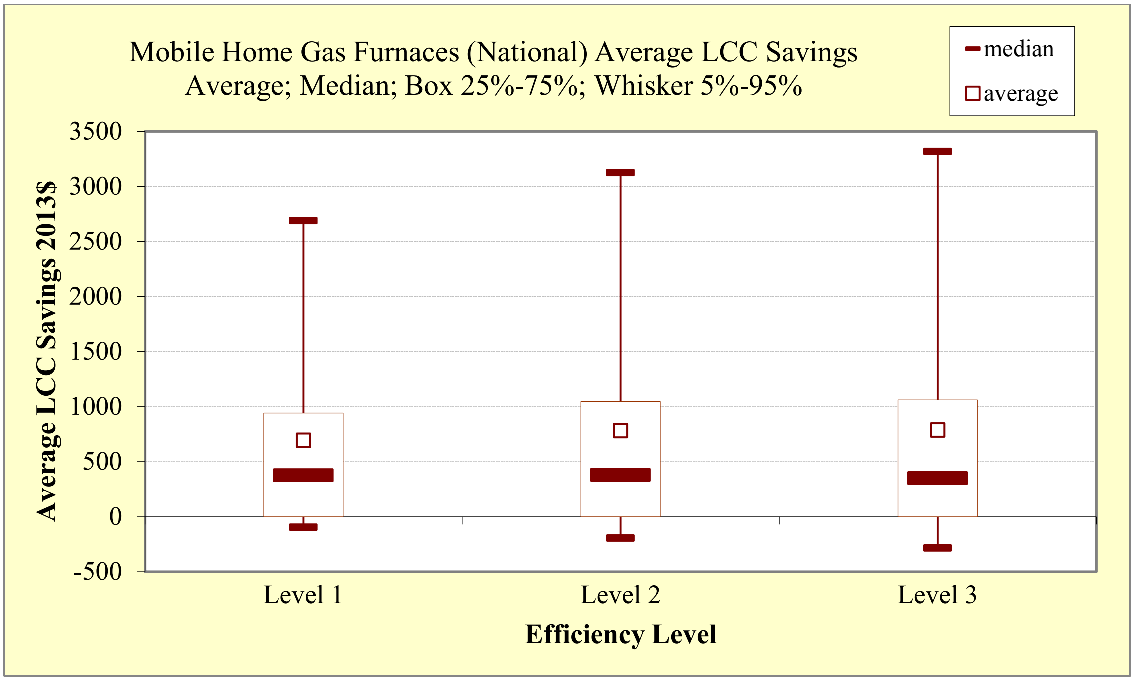

Figure 8.5.2 Distribution of LCC Savings for Mobile Home Gas Furnaces, AFUE Standards

8.5.3 Standby Mode and Off Mode Power Results

8.5.3.1 Non-Weatherized Gas Furnaces

Table 8.5.5 and Table 8.5.6 show the standby mode and off mode power LCC and PBP results by EL for NWGFs.

Table 8.5.5 Average Standby Mode and Off Mode LCC and PBP Results by Efficiency Level for Non-Weatherized Gas Furnaces

Efficiency Level	Average Costs *2013$*				Simple Payback *years*	Average Lifetime
	Installed Cost	First Year's Operating Cost	Lifetime Operating Cost	LCC		
0	$0	$11	$159	$159	NA	21.5
1	$2	$9	$137	$139	1.3	21.5
2	$17	$9	$133	$150	9.7	21.5
3	$18	$8	$123	$141	7.5	21.5

Note: The results for each EL are calculated assuming that all consumers use products with that efficiency level. The PBP is measured relative to the baseline product.

Table 8.5.6 Standby Mode and Off Mode LCC Savings Relative to the Base Case Efficiency Distribution for Non-Weatherized Gas Furnaces

Efficiency Level	Life-Cycle Cost Savings	
	% of Consumers that Experience Net Cost	Average Savings* *2013$*
0	0%	NA
1	2%	$12
2	15%	$6
3	9%	$13

* The calculation includes buildings with zero LCC savings (no impact).

Figure 8.5.3 show the range of LCC savings for the efficiency levels considered for NWGFs. 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 percent of the households have life-cycle cost 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.

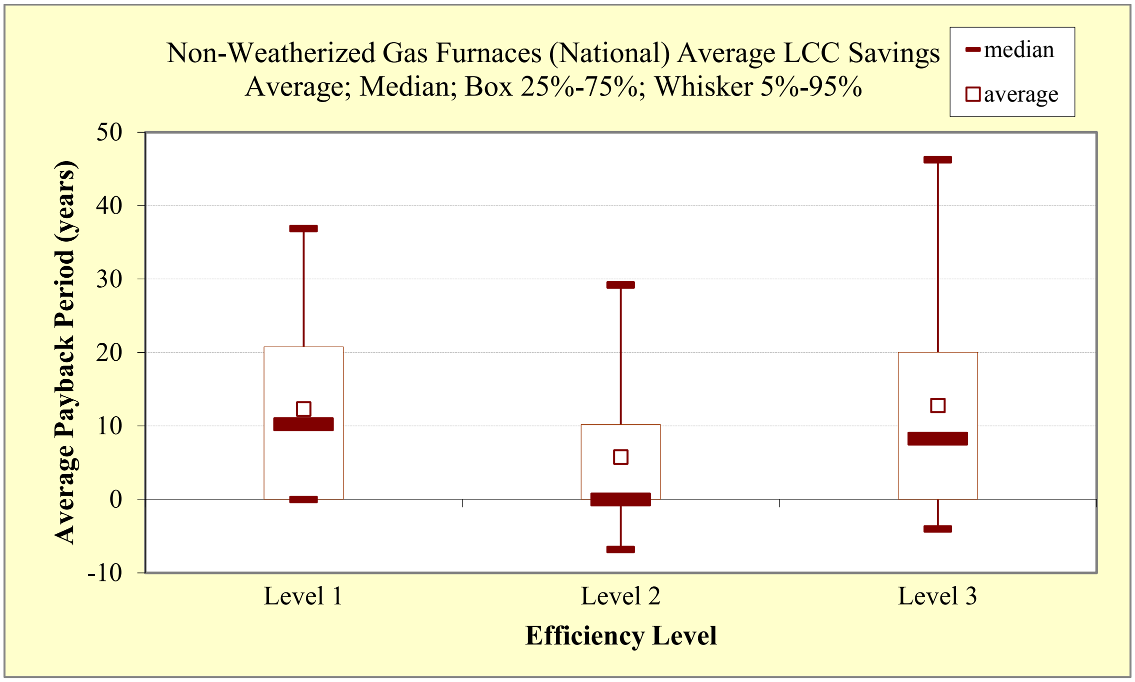

Figure 8.5.3 Distribution of LCC Savings for Non-Weatherized Gas Furnaces, Standby Mode and Off Mode

8.5.3.2 Mobile Home Gas Furnaces

Table 8.5.7 and Table 8.5.8 show the standby mode and off mode power LCC and PBP results by EL for MHGFs.

Table 8.5.7 Average Standby Mode and Off Mode LCC and PBP Results by Efficiency Level for Mobile Home Gas Furnaces

Efficiency Level	Average Costs *2013$*				Simple Payback *years*	Average Lifetime
	Installed Cost	First Year's Operating Cost	Lifetime Operating Cost	LCC		
0	$0	$10	$155	$155	NA	21.5
1	$2	$9	$134	$136	1.2	21.5
2	$16	$9	$130	$145	9.2	21.5
3	$17	$8	$120	$137	7.1	21.5

Note: The results for each EL are calculated assuming that all consumers use products with that efficiency level. The PBP is measured relative to the baseline product.

Table 8.5.8 Standby Mode and Off Mode LCC Savings Relative to the Base Case Efficiency Distribution for Mobile Home Gas Furnaces

Efficiency Level	Life-Cycle Cost Savings	
	% of Consumers that Experience Net Cost	Average Savings* *2013$*
0	0%	NA
1	0%	$1
2	1%	$0
3	1%	$1

* The calculation includes buildings with zero LCC savings (no impact).

Figure 8.5.4 shows the range of LCC savings for the efficiency levels considered for MHGFs. 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 percent of the households have life-cycle cost 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.

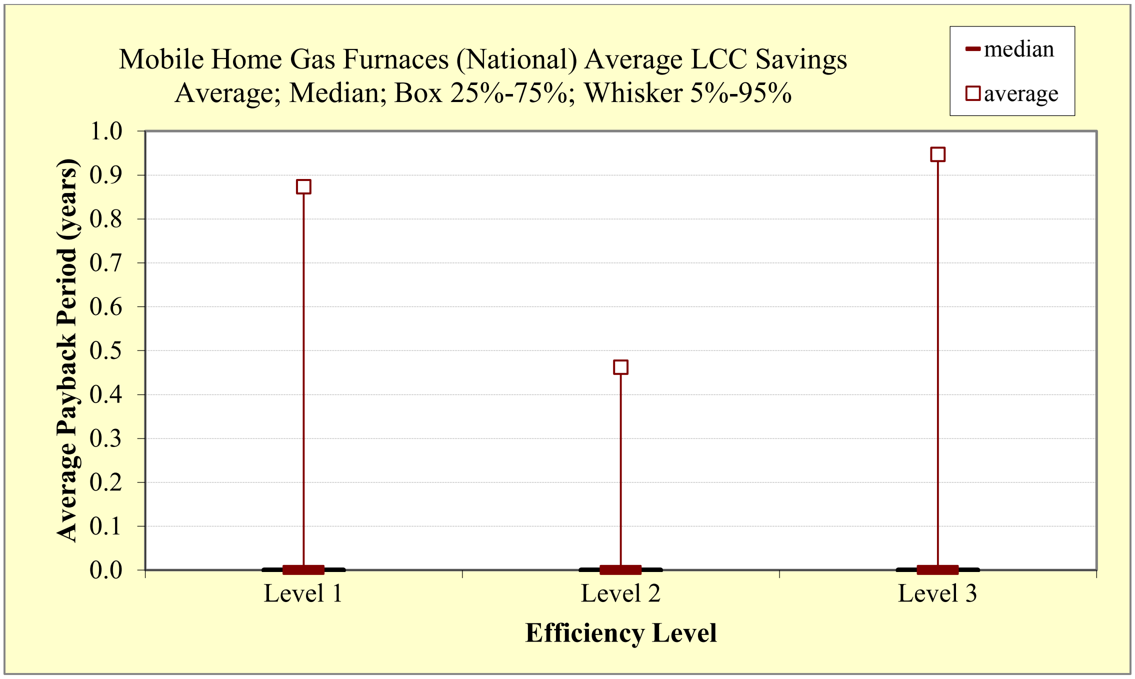

Figure 8.5.4 Distribution of LCC Savings for Mobile Home Gas Furnaces, Standby Mode and Off Mode

8.6 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 product costs attributed to the standard are less than three times the value of the first-year energy cost savings. (42 U.S.C. §6295 (o)(2)(B)(iii))

The basic equation for rebuttable PBP is the same as that shown for the PBP in section 8.3. Unlike the analysis described in section 8.3, however, the rebuttable PBP is not based on the use of household samples and probability distributions, but on discrete single-point values. For example, whereas DOE uses a probability distribution of energy prices in the distributional PBP analysis, it uses only the national average energy price to determine the rebuttable PBP.

Other than the use of single-point values, the most notable difference between the distribution PBP and the rebuttable PBP is the latter's reliance on the DOE test procedure to determine a product's annual energy consumption.

8.6.1 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 2021.

8.6.2 Results

DOE calculated rebuttable PBPs for each standard level relative to the distribution of product energy efficiencies estimated for the base case. Table 8.6.1 and Table 8.6.2 present the rebuttable PBPs for NWGFs and MHGFs AFUE standards. Table 8.6.3 and Table 8.6.4 present the rebuttable PBPs for standby mode and off mode.

Table 8.6.1 Rebuttable Payback Period for Non-Weatherized Gas Furnaces, AFUE Standards

EL	AFUE	Rebuttable Payback Period *years*
National		
1	90%	4.4
2	92%	3.9
3	95%	3.9
4	98%	4.8
North		
1	90%	4.2
2	92%	3.6
3	95%	3.5
4	98%	4.2
Rest of Country		
1	90%	5.7
2	92%	5.1
3	95%	5.4
4	98%	7.4

Table 8.6.2 Rebuttable Payback Period for Mobile Home Gas Furnaces, AFUE Standards

EL	AFUE	Rebuttable Payback Period *years*
National		
1	92%	1.1
2	95%	1.4
3	97%	1.8
North		
1	92%	0.9
2	95%	1.1
3	97%	1.4
Rest of Country		
1	92%	2.0
2	95%	2.5
3	97%	3.2

Table 8.6.3 Rebuttable Payback Period for Non-Weatherized Gas Furnaces, Standby Mode and Off Mode

Efficiency Level	Technology Option	Rebuttable Payback Period *years*
1	Linear Power Supply with LLTX	1.5
2	Switching Mode Power Supply	11.1
3	Switching Mode Power Supply with LLTX	8.6

Table 8.6.4 Rebuttable Payback Period for Mobile Home Gas Furnaces, Standby Mode and Off Mode

Efficiency Level	Technology Option	Rebuttable Payback Period *years*
1	Linear Power Supply with LLTX	1.3
2	Switching Mode Power Supply	9.8
3	Switching Mode Power Supply with LLTX	7.5

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APPENDIX 8A. USER INSTRUCTIONS FOR THE LIFE-CYCLE COST ANALYSIS SPREADSHEET FOR RESIDENTIAL FURNACES

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APPENDIX 8A. USER INSTRUCTIONS FOR THE LIFE-CYCLE COST ANALYSIS SPREADSHEET FOR RESIDENTIAL FURNACES

8A.1 USER INSTRUCTIONS

The results obtained in this analysis can be examined and reproduced using the Microsoft Excel spreadsheets available on the Department of Energy's (DOE's) furnace rulemaking website: www1.eere.energy.gov/buildings/appliance_standards/product.aspx/productid/72. From that page, follow the links to the notice of proposed rulemaking phase and then to Analytical Tools.

8A.2 STARTUP

DOE's spreadsheets enables users to perform life-cycle cost (LCC) and payback period (PBP) analyses for each product class. Two spreadsheets exist for both furnace product classes: a spreadsheet labeled "LCC" and another labeled "analysis input". The analysis input spreadsheet contains the raw data used for the analysis as well the formulas that led to the processed data that are used in the LCC. The analysis input spreadsheet serves the purpose of delivering the raw input used in the analysis as well as of informing the public on how the processed data in the main LCC is derived, for complete transparency.

The two spreadsheets are independent. The main LCC spreadsheet can be downloaded and run separately. In order to change the input of the main LCC based or updated data from the analysis input spreadsheet, the user will need to manually copy/paste the data that was modified in the analysis input spreadsheet into the main LCC spreadsheet.

To examine the spreadsheets, DOE assumes that the user has access to a personal computer with hardware capable of running Windows XP or later. All spreadsheets require Microsoft Excel 2003 or later installed under the Windows operating system. Crystal Ball[a] (a commercially available Excel add-on program) is also needed to regenerate the LCC results and to view the statistical distributions that are used to define certain variables inside the spreadsheets.

8A.3 DESCRIPTION OF LIFE-CYCLE COST WORKSHEETS

8A.3.1 Main LCC worksheet

For both of the furnace product classes, DOE created 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 are related, each worksheet contains an area on the extreme left showing variables imported to and exported from the current worksheet. The LCC spreadsheet contains the following worksheets:

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[a] See www.oracle.com/us/products/applications/crystalball/overview/index.html

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 households or 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.
Summary Switching	The *Summary Switching* worksheet contains summary results by region for NWGFs, including impacts of consumers switching to other space and water heating products. Also contains results comparisons between DOE's LCC analysis and GTI's product switching survey.[b]
NWGF Switching*	The *NWGF Switching* worksheet contains the LCC calculation results that are used to determine whether the single Residential Energy Consumption Survey (RECS) 2009[1] household or Commercial Building Energy Consumption Survey (CBECS) 2003[2] building will switch to other space and/or water heating products under the standards cases.
LCC&PB Calcs*	The *LCC&PB Calcs* worksheet shows LCC calculation results for different efficiency levels for a single RECS 2009 household or CBECS 2003 building. During a Crystal Ball simulation, the spreadsheet records the LCC and PBP values for every sampled household or building.
LCC&PB by Category*	The *LCC&PB Calcs* worksheet shows LCC calculation results from LCC&PB Calcs disaggregated by different markets (all combinations of: residential and commercial; replacement and new construction; and National, North, or South regions).
Rebuttable Payback	The *Rebuttable Payback* 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. DOE's residential furnace and furnace test procedure is used to calculate parameters used in energy use calculations.
Prod Price*	The *Prod 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 *Prod Price* worksheet. DOE applied baseline and incremental markups to calculate final retail prices. DOE calculated the markups differently for replacement units and new units.

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[b] Available at: www.aga.org/gas-technology-institute-%E2%80%93-fuel-switching-study

Price Trend	The *Price Trend* worksheet calculates projected product price trend scenarios used to adjust the manufacturer's cost over the entire analysis period as inputs in the *Prod Price* worksheet.
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.
Installation Cost Data	The *Installation Cost Data* worksheet provides the data inputs to the installation cost calculations.
Maintenance 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 Costs*	The *Labor Cost* worksheet provides the labor cost by region as used to determine the installation and repair/maintenance costs.
Building Sample*	The *Building Sample* worksheet contains the RECS 2009 and CBECS 2003 data for each product class. During a Crystal Ball simulation, DOE uses these characteristics to determine the analysis parameters.
Base Case AFUE*	The *Base Case AFUE* worksheet includes the furnace efficiency distribution for 2021.
AFUE (Existing)*	The *Existing AFUE (existing)* worksheet includes the furnace efficiency for all years during the period 1966-2009, as well as central air conditioner (CAC) efficiency for all years during the period 1976-2009.
Energy Use*	The *Energy Use* worksheet calculates annual energy use by fuel type, depending on product 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 product class.
Energy Use (Prod Switch)*	The *Energy Use (Prod Switch)* worksheet calculates annual energy use by fuel type for households and buildings that switch to a different product type under standards cases. 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 under the switching scenario.
Furnace & AC Sizing*	The *Furnace & AC Sizing* worksheet determines the specifications of the air handler or AC size for the LCC calculations under the product switching scenario.
Energy Price*	The *Energy Price* worksheet shows the estimated monthly natural gas, electricity, and oil 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 2014 for the period until 40 and extrapolated beyond 2040.[3]
Discount Rate*	The *Discount Rate* worksheet contains the distributions of discount rates for replacement and new units.
Lifetime*	The *Lifetime* worksheet contains the distribution of lifetimes for products of that product class.
Energy Use Adjustment Factors*	The *Energy Use Adjustment 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.
Labels	The *Labels* worksheet contains labels used in graphical user interface.
Forecast Cells	The *Forecast Cells* worksheet contains the outcome of the Monte Carlo simulations for the sample of 10,000 households and commercial buildings for many parameters used in the analysis and the documentation.
LCC Outputs	The *LCC Outputs* worksheet contains intermediate inputs used for DOE's National Impact Analysis. These inputs include fuel and electricity use, total installed price, operating cost, and base case distributions for each product class and efficiency level. The inputs are presented for replacement and new construction housing markets.

* Results displayed in worksheet are for only one sampled household or building, not the entire population.

Figure 8A.3.1 depicts how these various inputs are used in order to generate the LCC and PBP outputs.

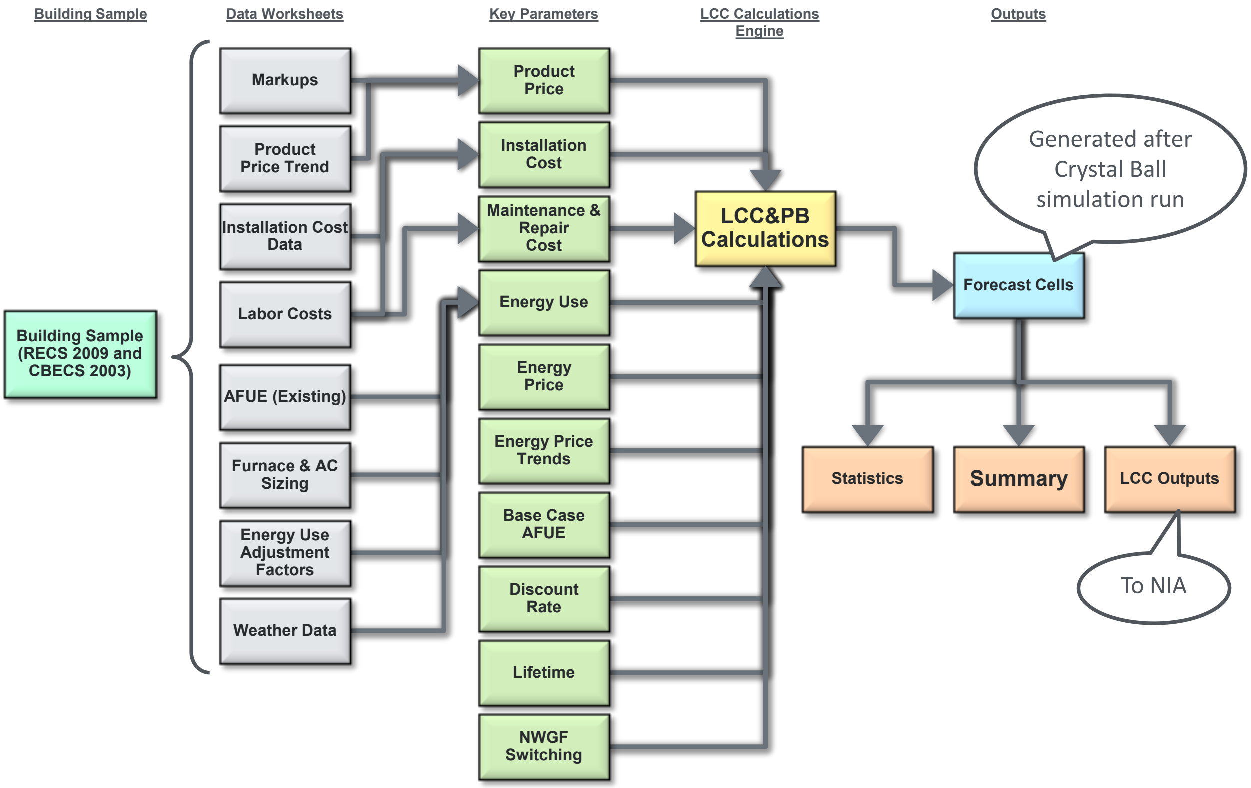

Figure 8A.3.1 LCC and Payback Calculation Process

8A.3.2 Analysis Input Spreadsheet

The analysis input spreadsheet contains the following worksheets:

- Markup Input
- Labor Cost Data
- RECS Sample
- RECS Codebook
- CBECS Sample
- Saturations
- Energy Price Trends (to LCC)
- Energy Price Trends (to NIA)
- Energy Use Trends (for NIA)
- Shipment Data
- Lifetime
- Efficiency
- Efficiency Data
- Furnace & AC Spec
- Furnace Fan Motor Types
- Furnace Spec Charts
- Models Directory

- Energy Use Adjustment Factors
- Weather Data
- Res Energy Price Input
- Res Energy Price Proc
- Res Energy Price Data
- Res Energy Price (Other)
- Com Energy Price Input
- Com Energy Price Proc
- Com Energy Price Data
- Com Energy Price (Other)
- Weighting
- Census Pop. Data
- Definitions

Each of those worksheets is designed to calculate the input that will be used in the corresponding worksheet in the main LCC.

8A.4 BASIC INSTRUCTIONS FOR OPERATING THE LIFE-CYCLE COST SPREADSHEET

Basic instructions for operating the LCC spreadsheet are as follows:

1. Once the LCC spreadsheet has been downloaded, open the file using Excel. Click “Enable Macro” when prompted and then click on the tab for the *Summary* worksheet.
2. Use Excel's View/Zoom commands at the top menu bar to change the size of the display to fit your monitor.
3. The Analysis User Variables listed on the *Summary* worksheet are:
    a. Start Year: Default is “2021.” Changing the start year does not update the inputs, and thus only gives an approximation of the results for a different start year. To change the value, type in the desired year.
    b. # of Trials: Default is “10,000.” To change the value, type in the desired number of trials for Crystal Ball to run. Decreasing the number of runs will increase the speed of the simulation but decrease the representativeness of the results.
4. The user can change the parameters listed under Scenarios in the *Summary* worksheet. There are three drop-down boxes and one command button. The default parameters are:
    a. Energy Price Trend: set to “AEO 2014 - Reference Case.” To change the input, use the drop-down menu and select the desired trend (Reference, Low, or High).
    b. Product Price Trend: set to “Decreasing.” To change the value, use the drop-down menu and select the desired product price trend (“Decreasing (Default),” “No Learning (Constant)”, or “High Decreasing”).
    c. Switching: set to “Yes.” To change the value, use the drop-down menu and select the desired product switching scenario (“Yes” or “No”).

    d. Switching Scenario: set to “Reference Switching”. To change value, click on the drop-down menu next to cell B25 “Product Switching Scenario” and change to desired scenario.

5. To run the Crystal Ball simulation, click the “Run” button (you must re-run after changing any parameters). The spreadsheet will then be minimized. You can monitor the progress of the simulation by watching the count of iterations at the left bottom corner. When the simulation is finished, the worksheet named *Summary* will reappear with the results.

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3. U.S. Department of Energy-Energy Information Administration, *Annual Energy Outlook 2014 with Projections to 2040*, 2014. Washington, DC. <www.eia.gov/forecasts/aeo/>

APPENDIX 8B. UNCERTAINTY AND VARIABILITY IN THE LCC ANALYSIS

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APPENDIX 8B. UNCERTAINTY AND VARIABILITY IN THE LCC ANALYSIS

8B.1 INTRODUCTION

Analysis of energy conservation standards involves calculations of impacts, for example, the impact of a standard on consumer life-cycle cost (LCC). In order to perform the calculation, the analyst must: 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, and
- probability analysis.

Scenario analysis uses a single numerical value for each quantity in a calculation, then changes one (or more) of the numerical values and repeats the calculation. A number of calculations are done, which provide some indication of the extent to which the result depends upon the assumptions. For example, the life-cycle cost of an appliance could be calculated for energy rates of 2, 8, and 14¢ per kWh.

The advantages of scenario analysis are that each calculation is simple; a range of estimates is used and crossover points can be identified. (An example of a crossover point is the energy rate above which the life-cycle cost is reduced, holding all other inputs constant. That is, the crossover point is the energy rate at which the consumer achieves savings in operating expense that more than compensate for the increased purchase expense.) The disadvantage of scenario analysis is that there is no information about the likelihood of each scenario.

Probability analysis considers the probabilities within a range of values. For quantities with variability (e.g., electricity rates in different households), surveys can be used to generate a frequency distribution of numerical values (e.g., the number of households with electricity rates at particular levels) to estimate the probability of each value. For quantities with uncertainty, statistical or subjective measures can be used to provide probabilities (e.g., manufacturing cost to improve energy efficiency to some level may be estimated to be $10 ± $3).

The major disadvantage of the probability approach is that it requires more information, namely information about the shapes and magnitudes of the variability and uncertainty of each quantity. The advantage of the probability approach is that it provides greater information about the outcome of the calculations; that is, it provides the probability that the outcome will be in a particular range.

Scenario and probability analysis provide some indication of the robustness of the policy given the uncertainties and variability. A policy is robust when the impacts are acceptable over a wide range of possible conditions.

8B.5 PROBABILITY ANALYSIS AND THE USE OF CRYSTAL BALL

To quantify the uncertainty and variability that exist in inputs to the engineering, LCC, and payback period (PBP) analyses, DOE used Microsoft Excel spreadsheets combined with Crystal Ball, a commercially available add-in, to conduct probability analyses. The probability analyses used Monte Carlo simulation and probability distributions.

Simulation refers to any analytical method meant to imitate a real-life system, especially when other analyses are too mathematically complex or too difficult to reproduce. Without the aid of simulation, a spreadsheet model will only reveal a single outcome, generally the most likely or average scenario. Spreadsheet risk analysis uses both a spreadsheet model and simulation to automatically analyze the effect of varying inputs on outputs of the modeled system. One type of spreadsheet simulation is Monte Carlo simulation, which randomly generates values for uncertain variables again and again to simulate a model. Monte Carlo simulation was named for Monte Carlo, Monaco, where the primary attractions are casinos containing games of chance. Games of chance, such as roulette wheels, dice, and slot machines, exhibit random behavior. The random behavior in games of chance is similar to how Monte Carlo simulation selects variable values at random to simulate a model. When you roll a die, you know that a 1, 2, 3, 4, 5, or 6 will come up, but you do not know which for any particular roll. The same applies to the variables that have a known range of values but an uncertain value for any particular time or event (e.g., equipment lifetime, discount rate, and installation cost).

For each uncertain variable (one that has a range of possible values), possible values are defined with a probability distribution. The type of distribution selected is based on the conditions surrounding that variable. Probability distribution types include:

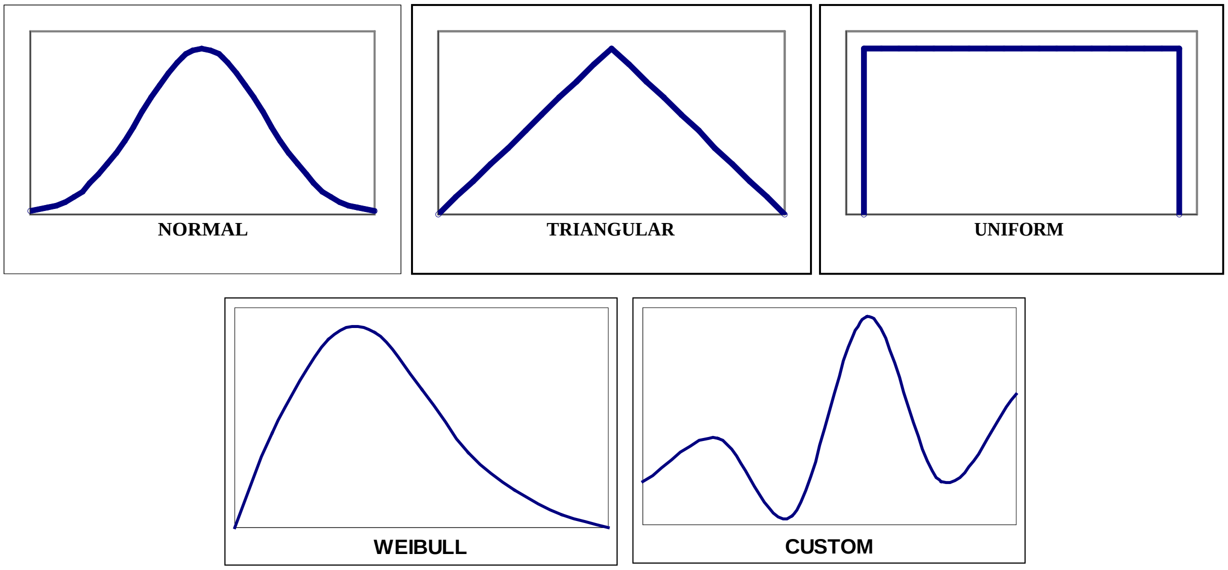

Figure 8B.5.1 Normal, Triangular, Uniform, Weibull, and Custom Probability Distributions

During a simulation, multiple scenarios of a model are calculated by repeatedly sampling values from the probability distributions for the uncertain variables and using those values for the cell. 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. FORECAST OF PRODUCT PRICE TRENDS FOR RESIDENTIAL FURNACES

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APPENDIX 8C. FORECAST OF PRODUCT PRICE TRENDS FOR RESIDENTIAL FURNACES

8C.1 INTRODUCTION

DOE examined historical producer price indices (PPI) for warm air furnaces to study the historical price trend for non-weatherized gas furnaces (NWGFs) and mobile home gas furnaces (MHGFs). For this product, DOE found consistent negative real price trends. Therefore, DOE concluded that the real prices of NWGFs and MHGFs have a different long term trend than prices in the economy as a whole. In the analysis for this NOPR, DOE concluded that the manufacturer selling prices of products meeting various efficiency levels may not remain fixed, in real terms, after 2013 (the year for which the engineering analysis estimated costs). DOE maintained the constant real price trend as a sensitivity analysis to evaluate how the impact of potential standards might change under this scenario.

Examination of historical price data for certain appliances and equipment that have been subject to energy conservation standards indicates that the assumption of constant real prices and costs may, in many cases, over-estimate long-term appliance and equipment price trends. Economic literature and historical data suggest that the real costs of these products may in fact trend downward over time according to "learning" or "experience" curves, or alternatively that the price trends for certain sectors of the US economy may be different than the price trends for the economy as a whole. Desroches et al. (2013) summarizes the data and literature currently available that is relevant to price projections for selected appliances and equipment.[1]

The extensive literature on the "learning" or "experience" curve phenomenon is typically based on observations in the manufacturing sector.[a] In the experience curve method, the real cost of production is related to the cumulative production or "experience" with a manufactured product. This experience is usually measured in terms of cumulative production. A common functional relationship used to model the evolution of production costs in this case is:

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

Eq. 8C.1

Where:

a = an initial price (or cost),
b = a positive constant known as the learning rate parameter,
X = cumulative production, and
Y = the price as a function of cumulative production.

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

Thus, as experience (production) accumulates, the cost of producing the next unit decreases. The percentage reduction in cost that occurs with each doubling of cumulative production is known as the learning rate (LR), given by:

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

Eq. 8C.2

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

8C.2 PRICE, COST AND MARKET STRUCTURE

DOE uses a cost-based analysis in estimating equipment prices. To estimate equipment prices in both the standards and the baseline or no-standards case, DOE develops engineering cost estimates that DOE then uses to estimate manufacturer selling price. The manufacturer selling price includes direct manufacturing production costs (labor, material, and overhead estimated in DOE's manufacturer production costs) and all non-production costs (SG&A, R&D, and interest), along with profit. The process of the cost-based method for developing the manufacturer selling prices is described in the engineering analysis described in chapter 5 of this TSD. To convert the manufacturer selling price to an equipment price for the consumer, DOE performs an analysis of distribution chain markups and estimates markups on both the baseline and incremental manufacture selling prices to determine equipment prices after distribution to the consumer.

In analyzing experience curves to estimate price trends, DOE uses producer price indices as a key data input and analyzes this data to estimate the experience curve exponent. This approach has only one model parameter to describe the price trend and assumes a simple relationship between producer price and retail equipment price. Specifically, the approach assumes that producer prices, distribution chain markups and equipment prices all scale proportionally over time for the same product.

DOE could have developed a more complex price trend forecasting model with more parameters that could explain different trends in different equipment price and cost components over time. But the relatively few available data points present a risk that a fit with multiple parameters would "overfit" the data. Overfitting occurs when there are too many degrees of freedom in a statistical model compared to the data and the fits are sensitive to random noise unrelated to long term trends. Due to the risk of overfitting the available data, DOE has decided to not develop a more complex multi-parameter price trend estimation model at this time.

Due to the simple nature of the price trend estimation model, there are several well-known economic and market phenomenon that will not be captured in detail by the price trend forecast. Some effects might lead to an overestimate of the long term price trend and other effects may lead to an underestimate. For example, if there has been increasing market concentration historically on the part of manufacturers, this may have resulted in increasing manufacturer and wholesale markups over time. This would result in an observed historical producer price trend that did not decrease as fast as the underlying industrial learning rate. Depending on if market concentration accelerated or decelerated into the future this could lead to an over- or under-estimation of future price trends.

Similarly, if there are cost components that have relatively slow long term price trends that have an increasing impact on price over time, the decreasing share of costs that are declining rapidly can result in a change in the empirically estimated experience curve exponent over time.

8C.3 DERIVATION OF LEARNING RATES

To develop price trends for NWGFs and MHGFs, DOE obtained historical Producer Price Index (PPI) data for warm air furnaces from the Bureau of Labor Statistics' (BLS) spanning the time period 1990-2013.[b] This is the most disaggregated price index including NWGFs and MHGFs. Inflation-adjusted price index for warm air furnaces was calculated by dividing the PPI series by the gross domestic product-chained price index for the same years. These inflation-adjusted price index (shown in Figure 8C.3.1) was used in subsequent analysis steps.

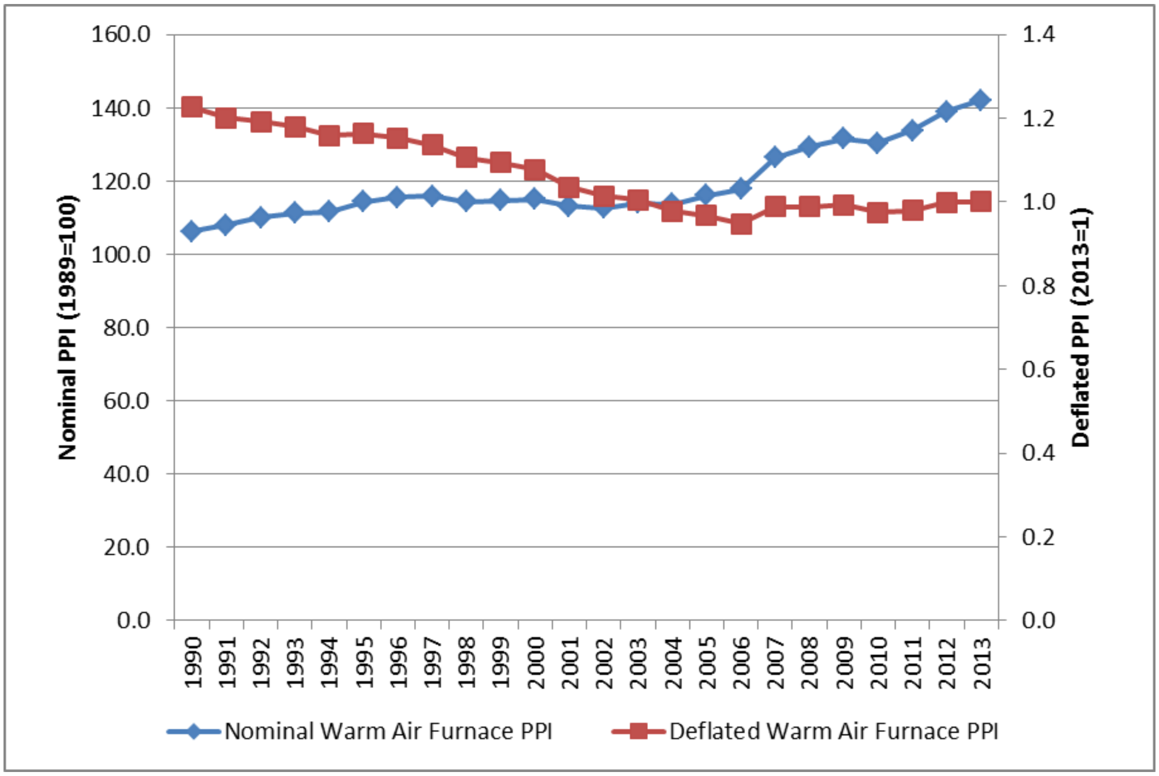

Figure 8C.3.1 Nominal and Deflated Warm Air Furnaces PPI from 1990 to 2013

DOE assembled a time-series of annual shipments for 1951-2013 for furnaces using data from the Air-Conditioning, Heating, and Refrigeration Institute (AHRI), previously Gas

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[b] Product series ID: PCU333415333415C. Available at: www.bls.gov/ppi/.

Appliance Manufacturers Association (GAMA).[2, 3] (Chapter 9 in the final rule TSD describes the data sources for 1972-2013. For shipments before 1972, DOE used earlier data from the same sources.) Furnace shipments prior to 1951 were extrapolated backward based on a linear trend to the historical shipments. The annual shipments data were used to estimate cumulative shipments (production). Projected shipments after 2013 were obtained from the base case projections made for the NIA (see chapter 9 of this TSD). Figure 8C.3.2 shows the shipments time series used in the analysis.

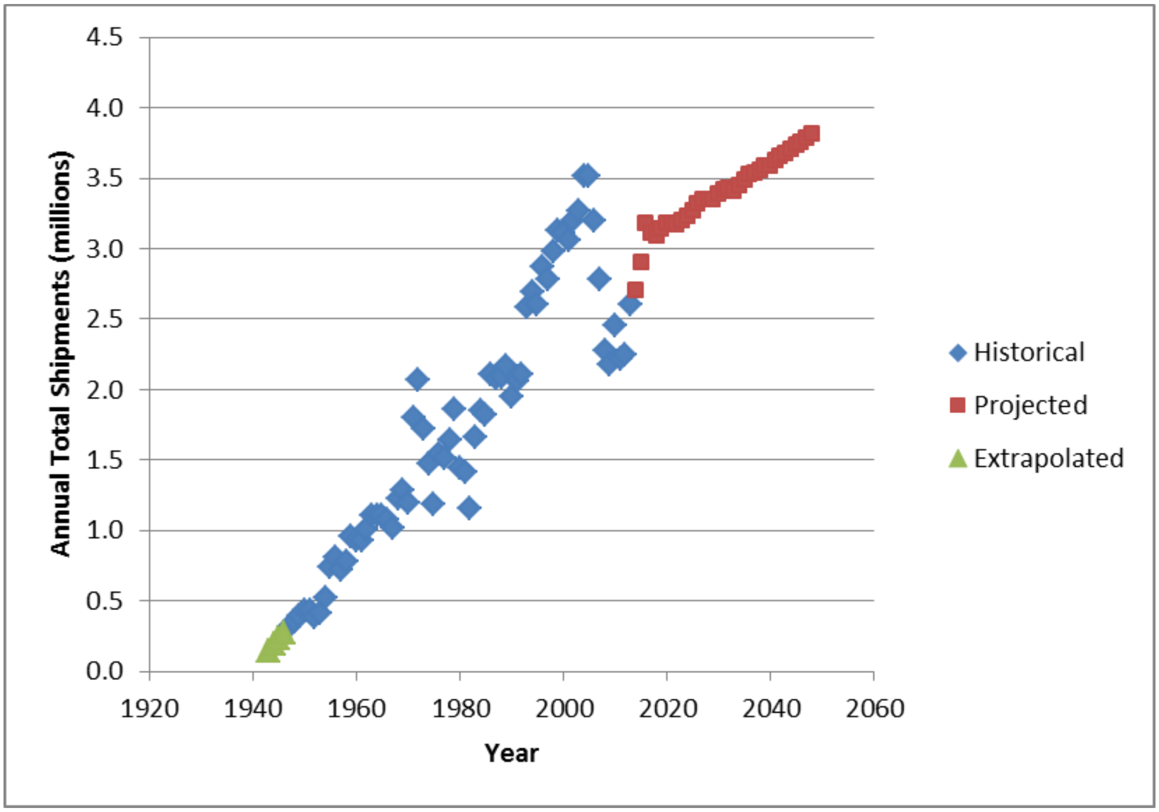

Figure 8C.3.2 Extrapolated, Historical and Projected Shipments of Warm Air Furnaces

To estimate a learning rate parameter, a least-squares power-law fit was performed on the unified price index versus cumulative shipments. See Figure 8C.3.3.

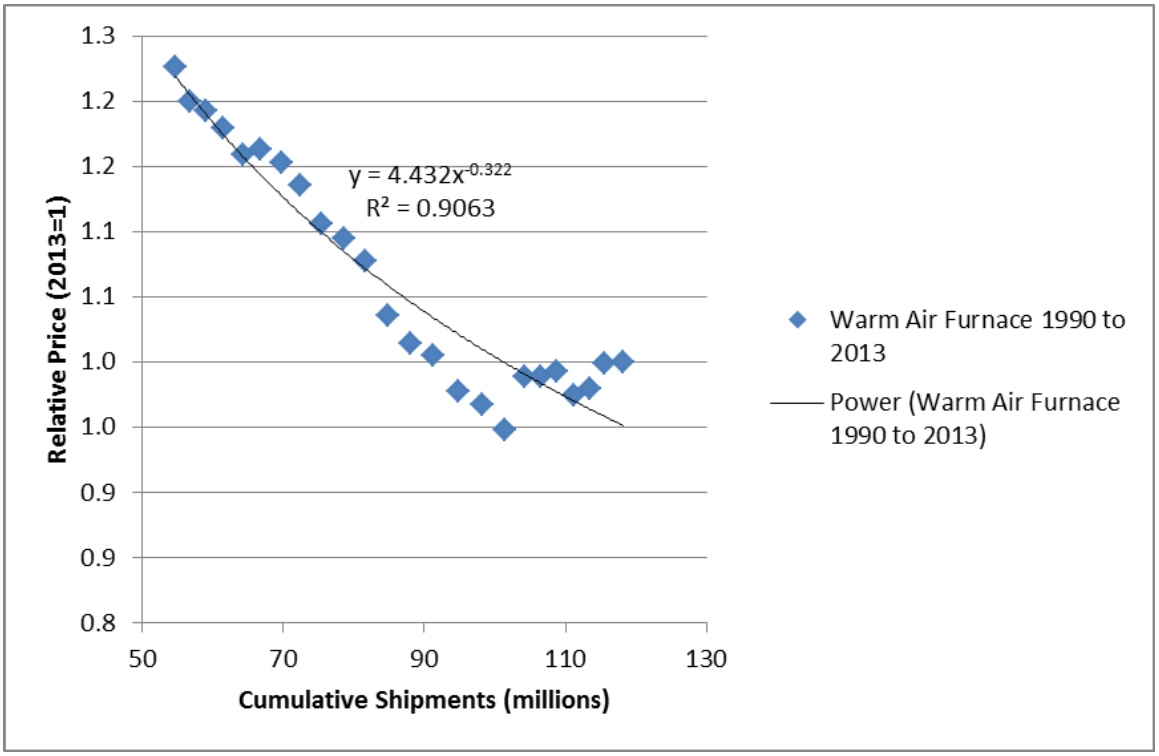

Figure 8C.3.3 **Relative Price versus Cumulative Shipments of Warm Air Furnaces from 1990 to 2013, with Power Law Fit**

The form of the fitting equation is:

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

where the two parameters, *b* (the learning rate parameter) and P_o (the price or cost of the first unit of production), are obtained by fitting the model to the data. DOE notes that the cumulative shipments on the right hand side of the equation can have a dependence on price, so there is an issue with simultaneity where the independent variable is not truly independent. DOE's use of a simple least squares fit is equivalent to an assumption of no significant first price elasticity effects in the cumulative shipments variable.

The parameter values obtained are:

$P_o = 4.432^{+1.56}_{-1.23}$ (95% confidence), and
b = 0.322±0.050 (95% confidence).

For NWGFs and MHGFs, the estimated learning rate (defined as the fractional reduction in price expected from each doubling of cumulative production) is $20.0^{+2.7}_{-2.8}$% (95% confidence).

8C.4 PRODUCT PRICE TRENDS FORECAST

DOE derived a price factor index, with 2013 equal to 1, to project prices in each future year in the analysis period. The index value in a given year is a function of the LR and the cumulative production forecast through that year. DOE applied the same value to project prices for both NWGFs and MHGFs at each considered efficiency level. The estimated price forecast index is shown in Figure 8C.4.1.

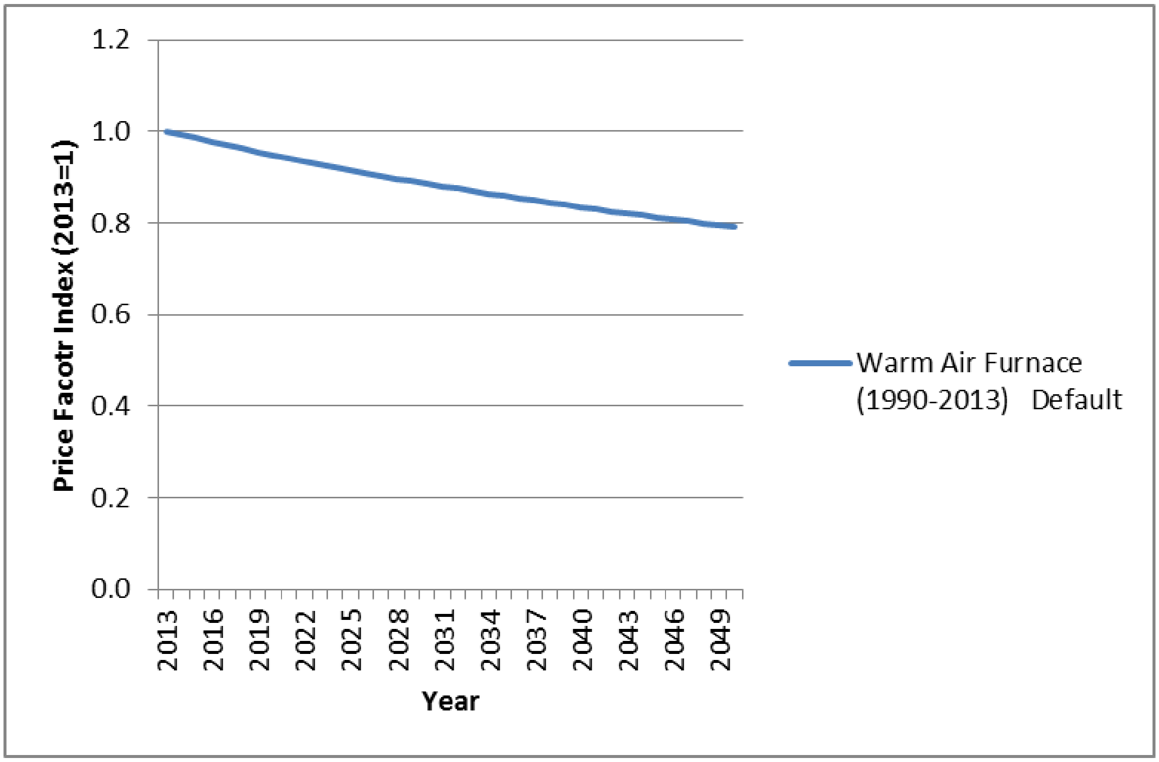

Figure 8C.4.1 Non-Weatherized Gas Furnace and Mobile Home Gas Furnace Price Forecast Index

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APPENDIX 8D. INSTALLATION COST DETERMINATION FOR RESIDENTIAL FURNACES

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8D.1 INTRODUCTION

This appendix provides details about the derivation of installation costs for non-weatherized gas furnaces (NWGFs) and mobile home gas furnaces (MHGFs). The installation cost is the price to the consumer of labor and materials (other than the cost of the actual product) needed to install a furnace product.

The Department of Energy (DOE) estimated installation costs for NWGFs and MHGFs based on RS Means, a well-known and respected construction cost estimation method, as well as manufacturer literature and information from expert consultants. Table 8D.1.1 offers an example of the installation cost calculation. All labor costs are derived using the latest residential 2013 RS Means labor costs by crew type.[1] Replacement installation cost tables include a trip charge, which is often charged by contractors and estimated to be equal to one half hour of labor per crew member. Labor hours (or person-hours) are based on RS Means data, expert data, or engineering judgment. Bare costs are all the costs without any markups. Material costs are based on RS Means data, expert data, or internet sources. The total includes overhead and profit (O&P), which is calculated using labor and material markups from RS Means. Values reported in this appendix are based on national average labor costs. In its analysis, DOE used regional labor costs to more accurately estimate installation costs by region. Section 8D.4 describes the derivation of regional labor costs. DOE then applied the appropriate regional labor cost to each RECS sample household.

Table 8D.1.1 Example Installation Cost Table

Description	Crew	Labor Hours	Unit	Bare Costs *(2013$)*			Quantity	Total incl. O&P
				Material	Labor	Total		
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								**86.50**

The installation cost calculations for NWGFs and MHGFs encompass:

- new construction, new owner, and replacement markets;
- residential and commercial markets;
- single-family (detached), single-family (attached), multi-family, and mobile home dwellings as well as commercial building types;
- basement (conditioned and unconditioned), crawlspace, garage, attic, and indoor furnace installation locations;
- Category I (non-condensing), and Category IV (condensing) venting systems;

- various vents, such as masonry chimneys, type B metal, or plastic (polyvinylchloride (PVC));
- single-wall or double-wall vent connectors;
- gas water heaters that are vented in common with a furnace or isolated;
- special situations, such as the need to reline a chimney or vent an orphaned water heater; and
- condensate withdrawal piping and drainage, including adding a condensate pump, drip pan, freeze protection (heat tape), condensate neutralizers, and an electrical connection for a condensate pump or heat tape.

Applying the RS Means installation costs to a furnace installation requires knowledge of its physical parameters, including the vent length, venting material, vent type, diameter, number of elbows, *etc*. DOE reviewed relevant literature, data, and installation manuals to estimate these quantities as a distribution of values. A Crystal Ball Monte Carlo simulation[a] was used to model the resultant costs for each individual household or building.

8D.2 NON-WEATHERIZED GAS FURNACES INSTALLATION COST METHODOLOGY

8D.2.1 Overview

DOE developed installation costs for NWGFs using RS Means cost data,[1, 2] DOE 2007 and 2011 residential furnace technical support documents,[3, 4] 2010 heating products technical support document,[5] and consultant reports.[6] The installation cost was divided into the following three components:

- basic installation,
- venting, and
- condensate removal.

Figure 8D.2.1 shows the overall NWGF installation cost inputs and components for different installation situations.

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[a] See chapter 8 for a description of the Monte Carlo simulation methodology.

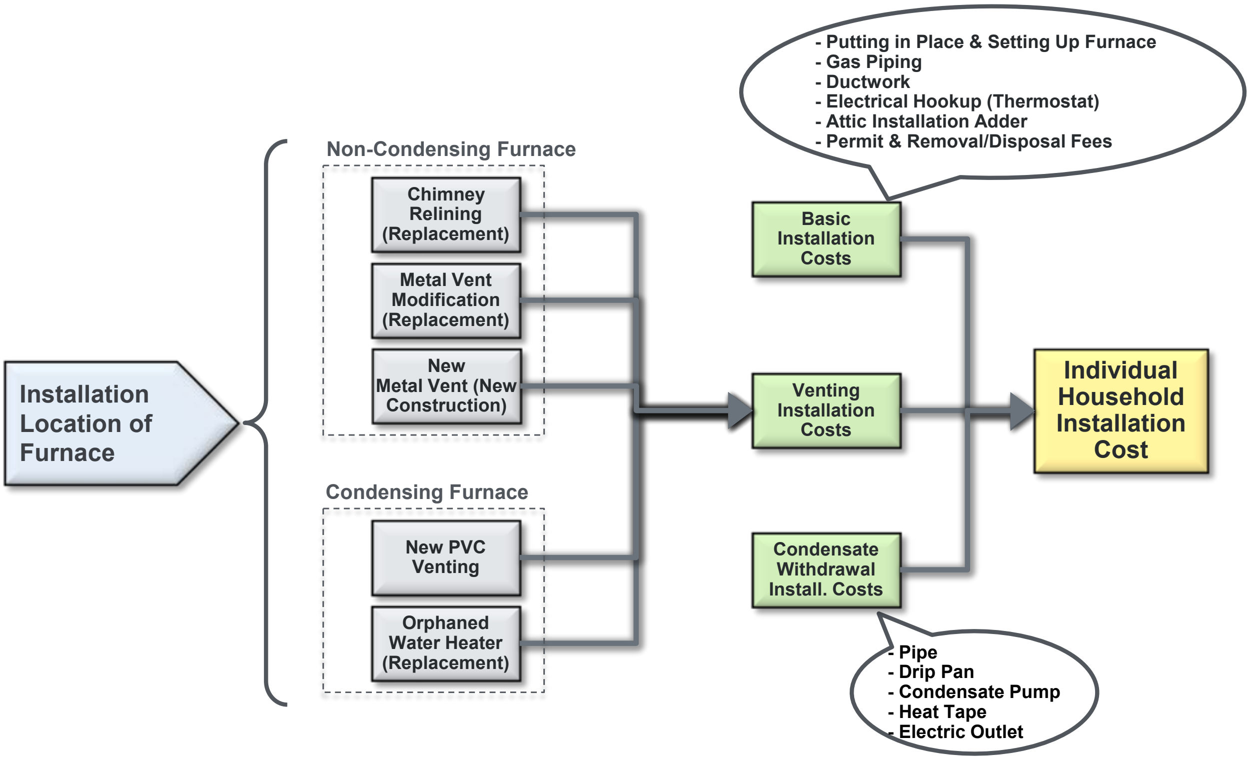

Figure 8D.2.1 NWGF Installation Cost Component Methodology Flowchart

8D.2.2 Installation Inputs

The following information about market shares, technologies, and installation location helped to shape the installation cost calculations.

New Construction, New Owner, and Replacement Market Shares. As determined in the shipment analysis (see chapter 9), for NWGFs, approximately 25 percent of the market will be new construction and 75 percent will be replacements in 2021. Of the replacement market, 10 percent are assumed to be new owners (*i.e.*, 7.5 percent new owners and 67.5 percent replacements).[b]

Residential and Commercial Market Shares. As determined in the shipment analysis (see chapter 9), for NWGFs, approximately 97 percent of the market will be residential and 3 percent will be commercial in 2021.

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[b] New owner includes many types of situations including product switching (*e.g.*, switching to an electric furnace, heat pump, oil furnace, hydronic system, etc.) or adding a new centralized heating system to an existing home for households that did not previously have centralized heating or heating of any kind. For this analysis, DOE assumed that a new owner installation would be a part of a major remodel work and therefore require similar installation costs as a new construction installation.

Non-Weatherized Gas Furnace Technologies. There are two main NWGF designs: non-condensing and condensing. Almost all of the non-condensing NWGFs have an annual fuel utilization efficiency (AFUE) of 80 percent, which represents the analysis baseline. Condensing NWGFs have an AFUE of 90 percent or greater. Non-condensing NWGFs usually use Category I venting systems, while condensing NWGFs are vented using Category IV venting systems. A Category I venting system relies on negative pressure and uses either a masonry chimney or a metal vent. A Category IV venting system uses positive pressure and a plastic (PVC) vent.

Installation Locations. Figure 8D.2.2 shows the determination of installation location using RECS 2009 variables for residential NWGF installations. All NWGF installations in commercial buildings are assumed to be in indoor locations. The installation fractions were derived using RECS 2009 household characteristics together with the following assumptions:[7]

1) If a household has a *basement*, then the furnace is installed in the basement.
2) If a household has an *attic* and built after 1980, then the furnace is installed in the attic 75 percent of the time.
3) If the household has a *crawl space*, then the furnace is installed in the crawl space 75 percent of the time.
4) If the household has a *garage*, then the furnace is installed in the garage 75 percent of the time.
5) For all other cases, the furnace is assumed to be installed in an indoor location (such as an indoor closet or utility room).

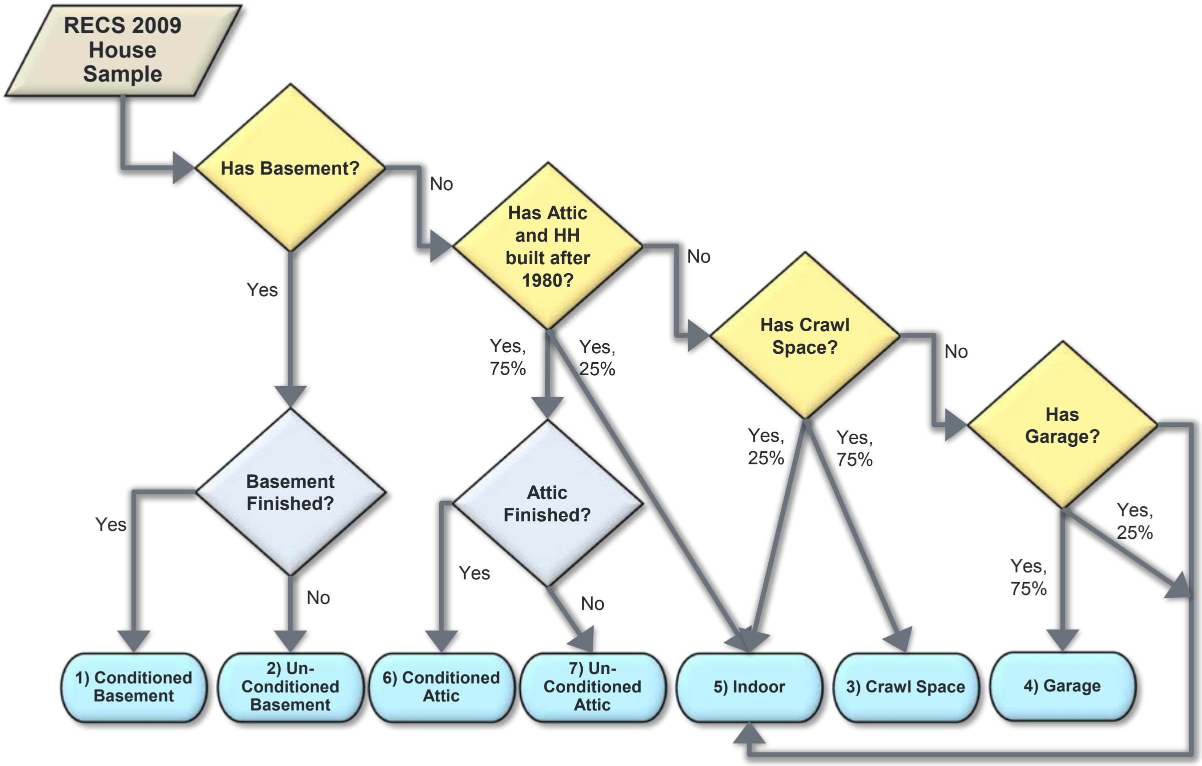

Figure 8D.2.2 Derivation of Furnace Installation Location Using RECS 2009 Variables

Figure 8D.2.3 shows the fraction of installations by installation location nationally and in the North and Rest of Country (shown as South in the figure) regions.

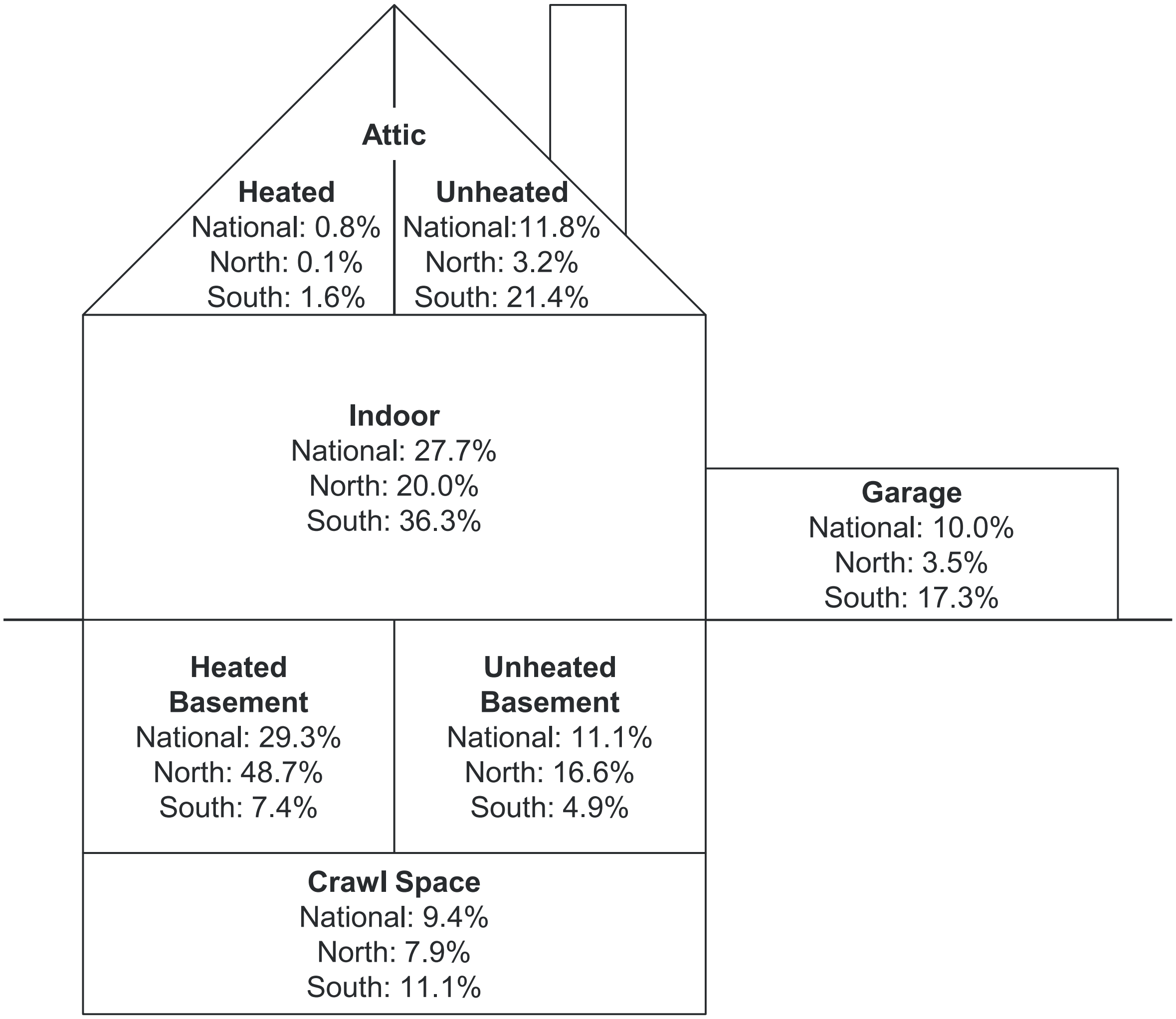

Figure 8D.2.3 Furnace Installation Location Fractions

For comparison, DOE reviewed other references that examined NWGF installation locations. Table 8D.2.1 shows data from a 2011 Decision Analysts, Inc. survey based on a representative sample.[8] Table 8D.2.2 shows a summary of the results of a 1992 GRI study, which are based on unweighted regional field data.[7] Directly comparing the data from these two references and DOE's analysis is difficult. For example, the two surveys primarily include single-family furnace installations, while DOE's analysis included single family, multi-family, and commercial NWGF installations. Nonetheless, the overall national results for the surveys and DOE's analysis appear to be similar, as shown in Table 8D.2.3. Table 8D.2.3 also includes numbers provided by a consultant report.[9]

Table 8D.2.1 Furnace Installation Location Data (2011 Decision Analysts, Inc. Survey)

ID*	Furnace Location	Northeast (n = 169)	Midwest (n = 250)	South (n = 316)	West (n = 175)	National (n=910)
1,2	Basement	76%	72%	15%	19%	43%
3	Crawl Space	-	-	-	-	-
4	Garage	2%	3%	11%	23%	9%
5	Inside closet	5%	14%	28%	22%	19%
6,7	Attic	7%	2%	30%	19%	16%
-	Outside closet	2%	1%	3%	2%	2%
-	Other location**	8%	7%	14%	14%	11%

* ID from Figure 8D.2.2.
** Includes crawl space and utility room.

Table 8D.2.2 Furnace Installation Location Data (GRI 1992 Study)

ID	Furnace Location	Northeast (n = 734)	Midwest (n = 60)	South (n = 114)	Northwest (n = 219)	Southern California (n = 204)	Overall (n=1408)
1,2	Basement	79.29%	68.33%	14.91%	41.55%		57.32%
3	Crawl Space	0.82%		7.02%	2.74%		1.42%
4	Garage	0.41%	1.67%	21.05%	25.57%	16.18%	8.31%
5	Closet	1.77%	6.67%	18.42%	14.61%	65.20%	14.42%
5	Utility	6.27%	18.33%		5.48%		4.90%
6,7	Attic	0.27%		5.26%	0.91%	10.78%	2.27%
-	Other	11.17%	5.00%	33.33%	9.13%	7.84%	11.36%

* ID from Figure 8D.2.2.

Table 8D.2.3 Comparison of Furnace Installation Location Fractions

ID	Furnace Location	GRI 1992 Study	2010 EER Consulting Report	2011 Decision Analysts Survey	DOE Fractions**
1,2	Basement	57.3%	47%	43%	40.4%
3	Crawl Space	1.4%	11%	-	9.4%
4	Garage	8.3%	7%	11%	10.0%
5	Indoor*	19.3%	12%	19%	27.7%
6,7	Attic	2.3%	22%	16%	12.6%
-	Outdoor Closet	-	1%	2%	-
-	Other	11.4%	-	11%	-

* Includes closet and utility room in GRI study.
** DOE fractions include furnace installations in commercial buildings (3 percent of furnace installations), which are all assumed to be indoors.

8D.2.3 Basic Installation Costs

For NWGFs, DOE estimated basic installation costs that are applicable to both replacement and new home installations. These costs, which apply to both condensing and non-condensing NWGFs, include:

- trip charge (replacement only),
- removal of existing furnace (replacement only),
- putting in place and setting up the furnace,
- unit start-up, check, and clean up,
- gas piping,
- electrical hookup for the thermostat,
- permit, removal or disposal fees, and,
- when applicable, additional labor hours for an attic installation.

Table 8D.2.4 and Table 8D.2.5 show a basic installation cost example for installing an 80 kBtu/h NWGF using national labor costs for new construction replacement cases, respectively. The actual costs in the spreadsheet vary for each household depending primarily on the regional labor costs and size of the NWGF that is installed. In addition to the costs presented in the table, DOE assumed that attic installations require an additional labor hour costing $52.17 for replacements and $71.20 for new construction using national labor costs (total including O&P).

Table 8D.2.4 Basic Installation Cost Example Using National Labor Costs: New Construction and New Owner

Description	**Crew**	**Labor Hours**	**Unit**	**Bare Costs** *(2013$)*			**Quantity**	**Total incl. O&P**
				Material	**Labor**	**Total**		
Furnace Installation (putting in place and setting up the furnace)	Q9	4.58*	Ea.	$0.00	$145.07	$145.07	1	$326.08
Unit Start-up, Check, and Clean up	Q9	2	Ea.	$0.00	$63.35	$63.35	1	$142.39
Gas Piping	1 Plum	0.698	Ea.	$19.90	$25.72	$45.62	1	$88.81
Electrical Hookup (Thermostat)	1 Elec	0.4	Ea.	$12.35	$14.04	$26.39	1	$50.66
Add’l Labor for Attic Installation	Q9	1	Ea.	$0.00	$31.68	$31.68	0	$0.00
Removal/Disposal and Permit Fees	-	-						$50.00
Total								**$657.95**

* Labor hours vary by input capacity (see Figure 8D.2.4). The 4.58 hours value is for a 80 kBtu/h NWGF.

Table 8D.2.5 Basic Installation Cost Example Using National Labor Costs: Replacement

Description	Crew	Labor Hours	Unit	Bare Costs *(2013$)*			Quantity	Total incl. O&P
				Material	**Labor**	**Total**		
Trip Charge	Q9	1.00	Ea.	$0.00	$31.68	$31.68	1	$52.74
Remove Old Furnace	Q9	2.29**	Ea.	$0.00	$72.54	$72.54	1	$120.77
Furnace Installation (putting in place and setting up the furnace)	Q9	4.58*	Ea.	$0.00	$145.07	$145.07	1	$241.54
Unit Start-up, Check, and Clean up	Q9	2	Ea.	$0.00	$63.35	$63.35	1	$105.48
Gas Piping	1 Plum	0.698	Ea.	$19.90	$25.72	$45.62	1	$65.79
Electrical Hookup (Thermostat)	1 Elec	0.4	Ea.	$12.35	$12.67	$25.02	1	$37.52
Add'l Labor for Attic Installation	Q9	1	Ea.	$0.00	$31.68	$31.68	0	$0.00
Removal/Disposal and Permit Fees	-							$50.00
Total		**10.968**						**$673.84**

* Labor hours vary by input capacity (see Figure 8D.2.4). The 4.58 hours value is for an 80 kBtu/h NWGF.
** Half of furnace installation labor hours.

Furnace installation cost varies by the NWGF's input capacity. Larger input capacity NWGFs are usually heavier and have larger dimensions, requiring more labor hours. Based on 2013 RS Means Residential Cost Data,[1] DOE used the relationship shown in Figure 8D.2.4 between labor hours for the "Furnace Installation" item and input capacity.

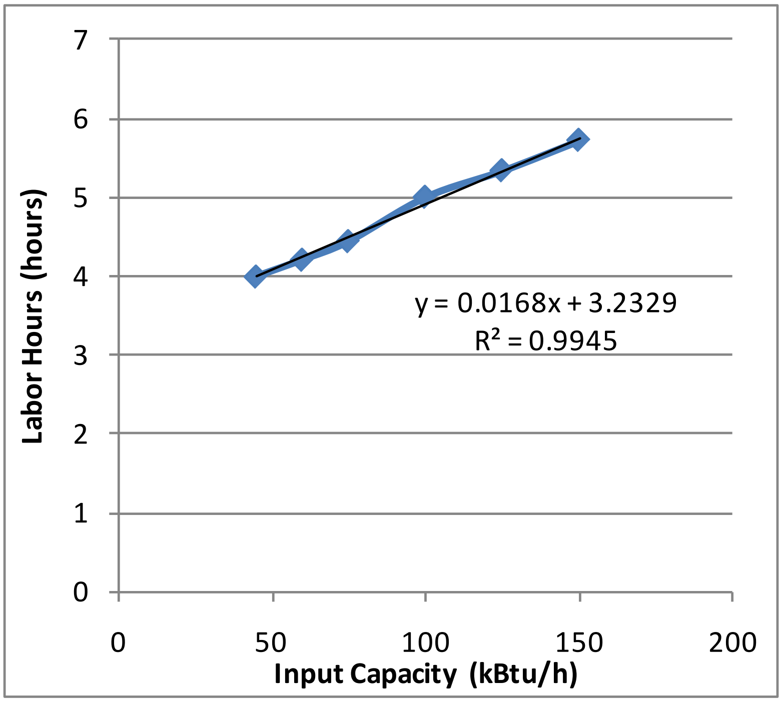

Figure 8D.2.4 Relationship Between Labor Hours and NWGF Input Capacity (RS Means)

Table 8D.2.6 shows the average basic installation cost by region and for new construction and replacements.

Table 8D.2.6 Basic Installation Costs for Non-Weatherized Gas Furnaces (2013$)

Region	**Average Cost *2013$***		
	Market		
	Replacement	*New Owner*	*New Construction*
National	$627	$620	$619
North	$708	$689	$709
Rest of Country	$538	$533	$510

8D.2.4 Venting

Estimating venting costs is complex because there are a large variety of possible installation scenarios. DOE calculated venting costs for each household in the RECS 2009 and CBECS 2003 NWGF sample. To determine venting costs for both new construction and replacement installations, DOE used a number of parameters that have an impact on the venting installation cost, including vent location, installation type (replacement, new owner, or new construction), region (North or Rest of Country), vent material (masonry chimney, metal, or PVC), vent connectors, and chimney type (exterior or interior and lined or unlined). DOE took into account the different components and materials for each vent type as well as the vent pipe length required. The methodologies for determining these costs and the vent length are discussed in the next sections.

Non-condensing NWGFs exhaust high-temperature flue gas, which heats the inside of the vent above the dew point to ensure that water vapor in the flue gas does not condense. If the flue gas does condense and does not re-evaporate quickly during the furnace firing cycle, the condensate could corrode the vent, the furnace heat exchanger, or both, thus reducing the lifetime of the vent system or the NWGF itself. Typically, a small amount of condensate at cold startup is acceptable as long as it dries out quickly. Condensing NWGFs condense the water vapor in a secondary heat exchanger, thus increasing NWGF efficiency by reducing latent heat loss. The condensate is fed to a drain. Because the flue gas temperature is relatively low, condensing NWGFs can be vented through PVC piping.

Figure 8D.2.5 shows the major venting installation components considered for installing a non-condensing and condensing NWGF. Non-condensing NWGF installations could require chimney relining or vent resizing for replacements and a new metal vent for new construction and new owners. Condensing NWGFs could require new PVC venting or have orphaned water heater venting issues in replacement, new owner, and new construction installations.

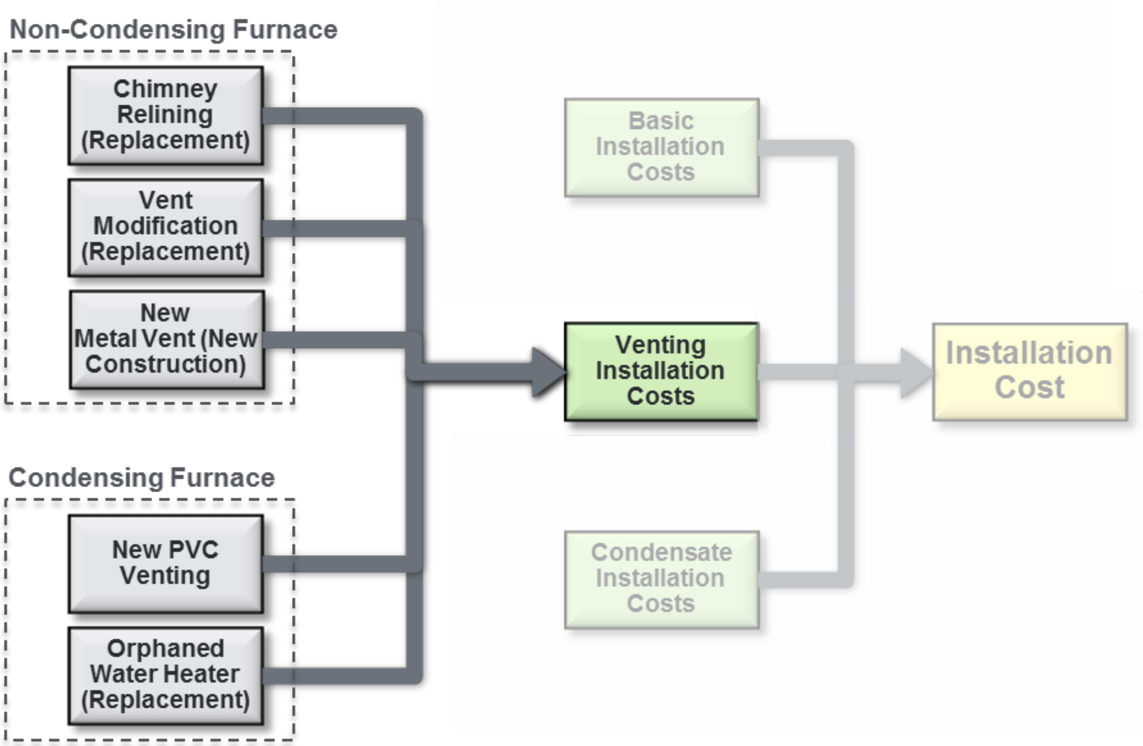

Figure 8D.2.5 Major Venting Installation Cost Components for Non-Condensing and Condensing NWGFs

8D.2.4.1 Venting Types

Masonry chimneys, metal vents, and PVC piping are the most common venting assemblies. Details of these vent types are presented below.

Masonry Chimney. Some non-condensing NWGFs are vented using masonry chimneys, either lined or unlined. Figure 8D.2.6 shows a lined masonry chimney venting a non-condensing NWGF and a water heater. For unlined chimneys, the flexible liner shown is not present, and a clay tile liner is used instead. Since the 1970s, chimney construction techniques have changed. Rather than having a brick chimney with a clay tile liner, newer chimneys are usually constructed with a masonry facade on the exterior that covers a wooden chase with a flexible metal liner on the interior. (These are faster to build than building brick by brick.) If the water heater is isolated,[c] the common water heater vent shown in Figure 8D.2.6 would not be present.

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[c] There are a number of water heater types that would not be vented in common with a NWGF. These include electric, gas direct side-vented, and gas power-vented water heaters. In this appendix, the term "isolated" water heater is defined to include all of these possibilities, but only the most prevalent option – electric water heaters – is modeled as part of the product switching consumer choice model (see appendix 8J).

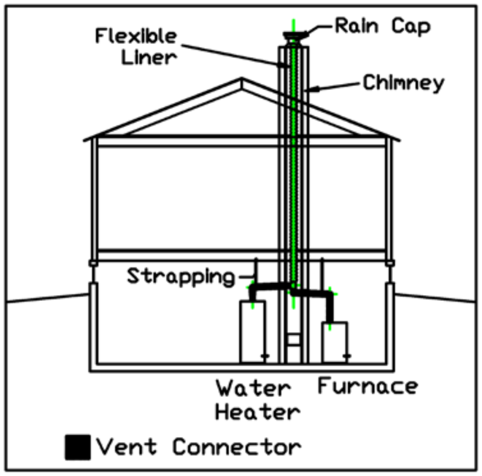


Figure 8D.2.6 Masonry Chimney Venting Installation (Non-Condensing Furnace)

Metal Vents. Some non-condensing NWGFs are vented using metal vents, either single wall or Type B double wall. Figure 8D.2.7 shows a Type B double-wall metal vent. The combination of wall thimbles, storm collar, and flashing replace the chimney. Most metal vents go straight through the roof. If the water heater is isolated, the common water heater vent shown would not be present. For this analysis, DOE assumed that almost all existing and all new metal vents are Type B double wall.

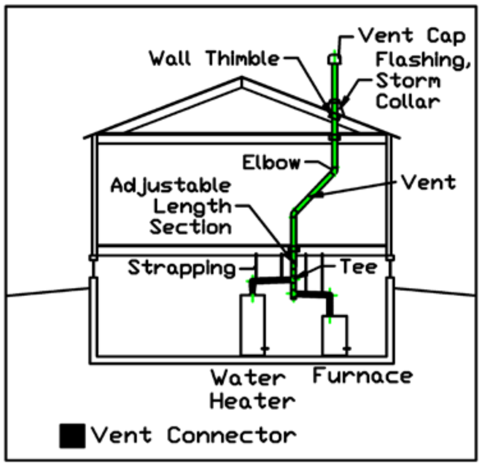


Figure 8D.2.7 Metal Venting Installation (Non-Condensing Furnace)

Plastic PVC. All condensing NWGF are vented using PVC vents, either horizontal or vertical. Figure 8D.2.8 shows a horizontal side-wall plastic vent. The NWGF installation shown below utilizes a two-plastic-pipe venting system. One of the vents exhausts the flue gases and the other brings combustion air from the outside to the furnace. Flue gas piping is sloped downward toward the furnace so that condensate drips back into the NWGF condensate drain. This installation includes a gas water heater (analogous to the common vented scenario above), which requires a separate flue gas exhaust vent.

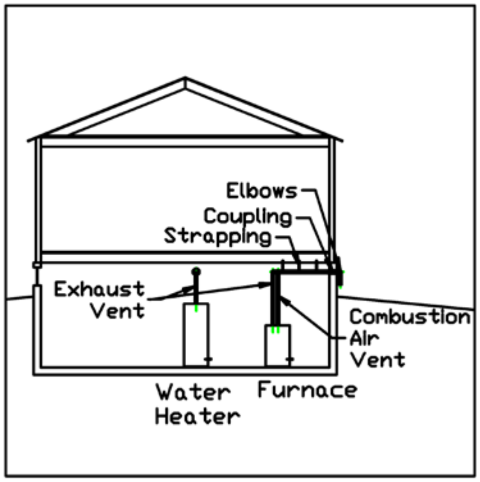


Figure 8D.2.8 Plastic PVC Installation (Condensing Furnace)

Table 8D.2.7 provides the fraction of existing masonry chimneys and metal vent installations by region, based on the 1994 GRI Furnace Survey.[7]

Table 8D.2.7 Fraction of Existing Masonry Chimney and Metal Vent Installations

Venting Type	Northeast	Midwest	South	West
Masonry	73%	53%	10%	27%
Metal Vent	27%	47%	90%	73%

Table 8D.2.8 provides the fraction of existing installations with a commonly-vented gas water heater and non-condensing NWGFs by region, based on the 1991 GTI Water Heater Survey.[10]

Table 8D.2.8 Fraction of Commonly-Vented Furnace and Water Heater Installations

Common Venting	Northeast	Midwest	South	West
Common	78%	68%	22%	65%
Isolated	22%	32%	78%	35%

8D.2.4.2 Vent Pipe Length

Figure 8D.2.9 shows the vent pipe length determination methodology. DOE separately determined the vent length for vertical (through the roof) or horizontal (through the wall) vent applications.

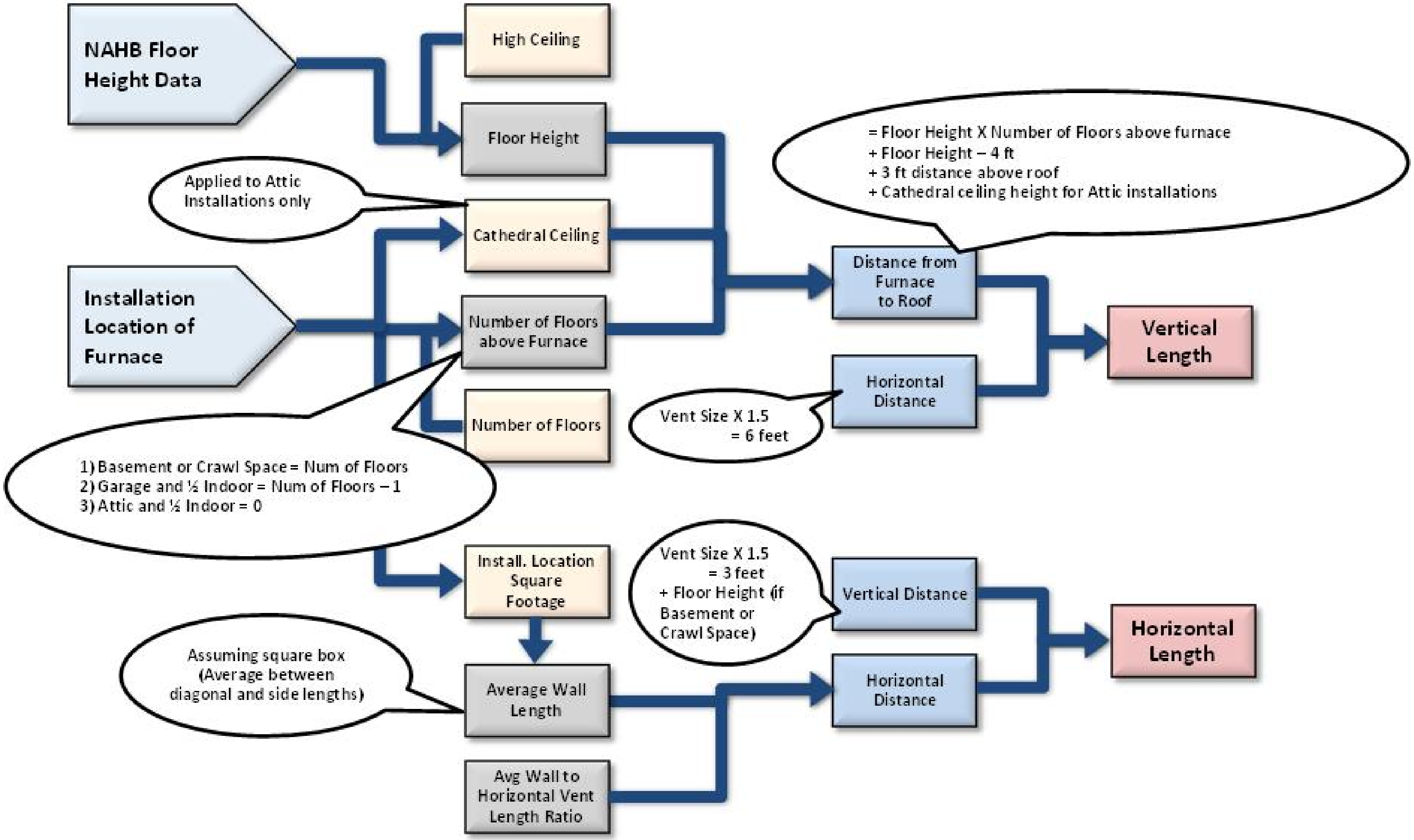


Figure 8D.2.9 **Vent Pipe Length Determination**

Vent pipe length is determined by taking into account:

- furnace location in the house,
- ceiling height,
- number of floors above furnace, and
- square footage of furnace installation location.

DOE assumed that all non-condensing NWGF vent types (*i.e.*, masonry chimneys and metal vents) are vented vertically. DOE assumed that the shortest run between horizontal and vertical venting determined the vent length and orientation of condensing NWGF PVC venting.

To determine the vertical pipe length, DOE used data from RECS 2009 or CBECS 2003 on the number of floors, installation location, and presence of a cathedral ceiling or high ceiling (peach-colored items) as well as data from National Association of Home Builders (NAHB) on floor height (see Figure 8D.2.10).[11] These data were used to determine the number of floors above the furnace and the resulting distance from the furnace to the roof. A horizontal distance is also applied to take into account the horizontal vent pipe length for the vent connector in a common vent installation.

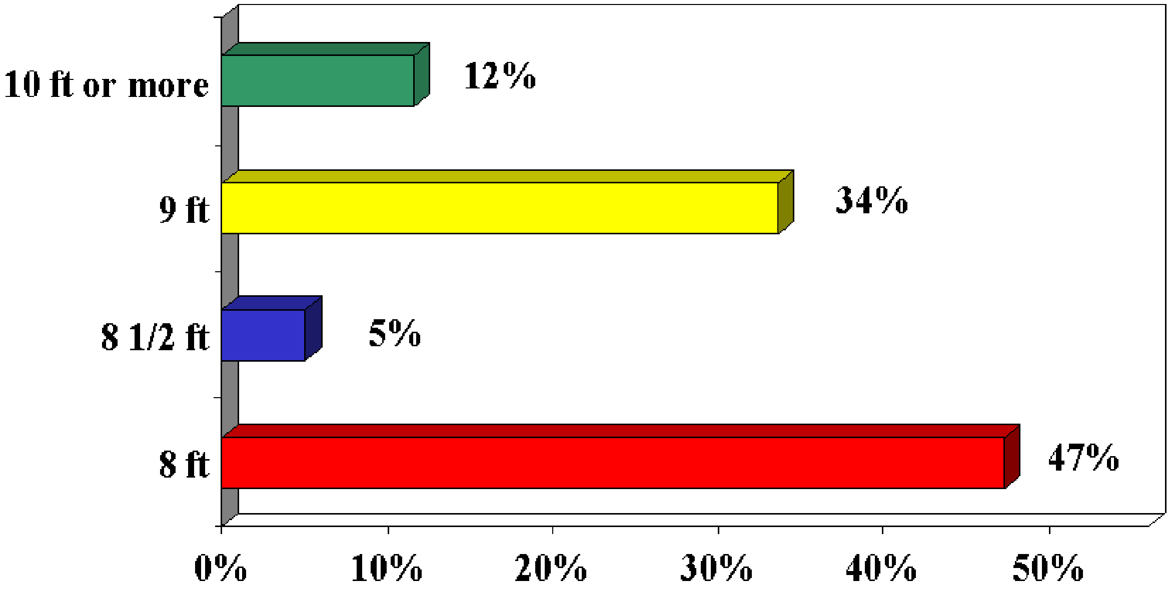
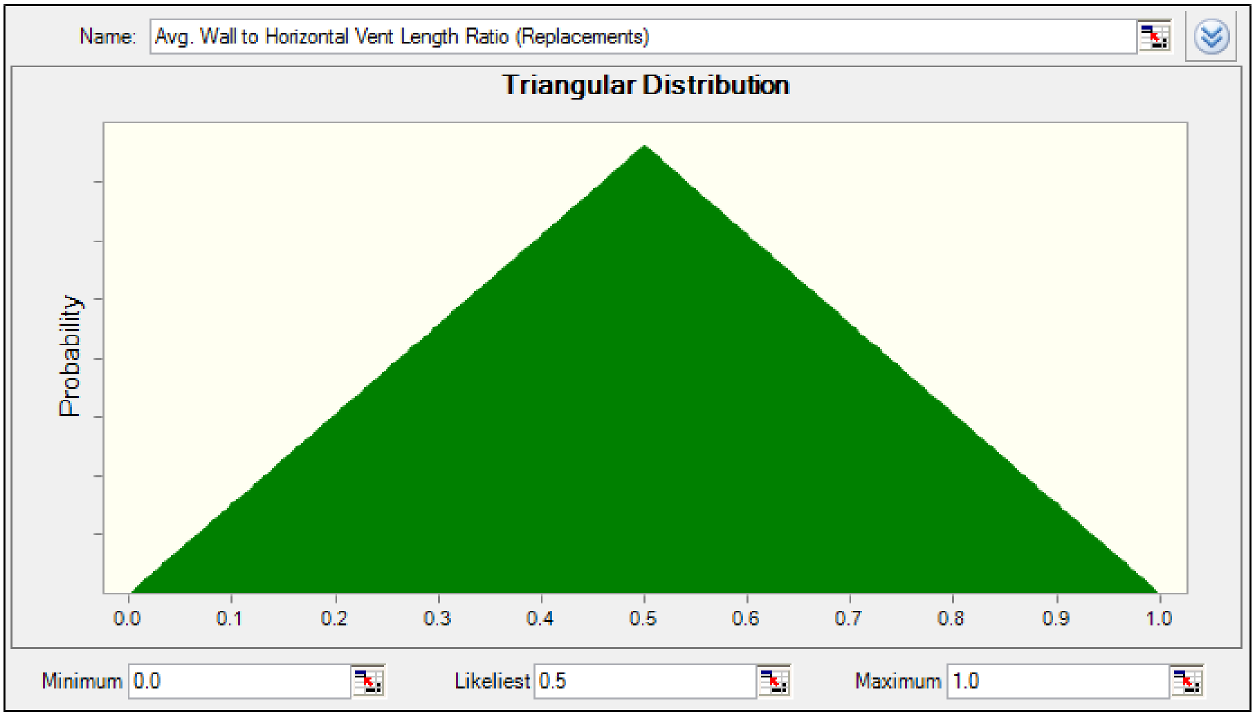


Figure 8D.2.10 First Floor Height Fractions from 2001 NAHB Survey

To determine the horizontal pipe length, DOE used the square footage of the house reported in RECS 2009 or CBECS 2003 to determine the average wall length. DOE used a triangular probability distribution to represent the average ratio between the wall length and horizontal vent length (see Figure 8D.2.11 and Figure 8D.2.12 for replacement and new construction distributions, respectively). The average wall length and ratio of wall length to horizontal vent length were used to determine the pipe horizontal length. DOE also considered the vertical vent length that is required based on the floor height and whether the furnace is in a basement or crawlspace. The vertical vent height is assumed to be high enough to be above the snow level in the winter months.



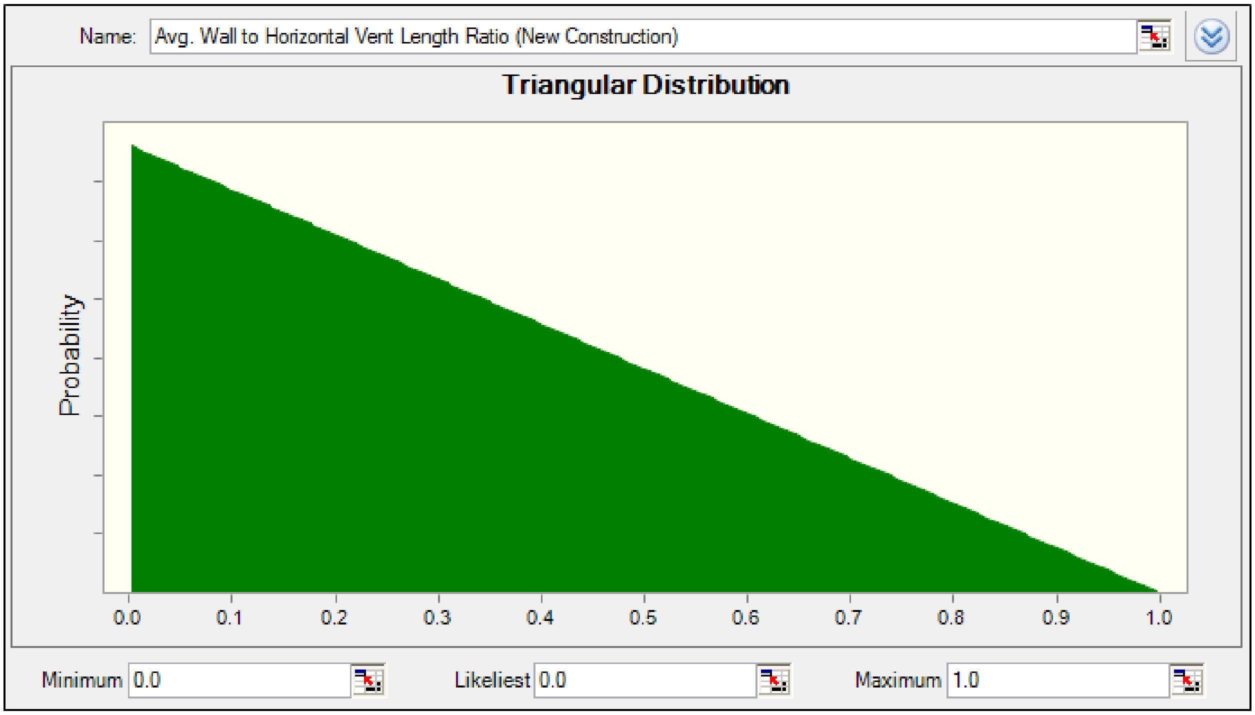
Name: Avg. Wall to Horizontal Vent Length Ratio (Replacements)

Minimum 0.0

Likeliest 0.5

Maximum 1.0

Figure 8D.2.11 Average Wall to Horizontal Vent Length Ratio (Replacements)


Name: Avg. Wall to Horizontal Vent Length Ratio (New Construction)

Minimum 0.0

Likeliest 0.0

Maximum 1.0

Figure 8D.2.12 Average Wall to Horizontal Vent Length Ratio (New Construction)

In addition to the vent pipe length, DOE account for various vent pipe components, including number of elbows and different cost vent wall penetration depending on wall type.

8D.2.4.3 Replacement Installations

For replacements, DOE evaluated five cases of replacement venting situations, as shown in Table 8D.2.9.

Table 8D.2.9 Replacement Venting Situations for NWGFs

Current NWGF	Replacement NWGF
Non-condensing natural draft (≤75% AFUE)	Non-condensing fan-assisted (80% AFUE)
Non-condensing fan-assisted (>75% AFUE)	Non-condensing fan-assisted (80% AFUE)
Non-condensing natural draft (≤75% AFUE)	Condensing (≥90% AFUE)
Non-condensing fan-assisted (>75% AFUE)	Condensing (≥90% AFUE)
Condensing (≥90% AFUE)	Condensing (≥90% AFUE)

DOE did not analyze the potential option of switching from a condensing to a non-condensing NWGF because the significant installation cost to install a new Category I vent system for the non-condensing NWGF makes such switching unlikely to occur.

8D.2.4.3.1 Non-Condensing to Non-Condensing Furnace Replacement Installations

Some non-condensing to non-condensing NWGF replacement installations require venting modifications to meet current safety requirements. There are two main issues that can arise when replacing a non-condensing NWGF with a more efficient non-condensing NWGF: relining an unlined chimney and resizing an existing venting system.

Chimney Relining

There are two types of masonry chimney—interior and exterior. Exterior chimneys are usually exposed on three sides; therefore, they are less insulated by the structure, lowering the internal temperature and making it more likely that exhaust gases will condense inside. Interior chimneys are surrounded by the heated building; the temperature in the chimney tends to be higher, making flue gases less likely to condense. Because of these different insulating properties, the National Fuel Gas Code (NFGC)[12] has different lining requirements for interior and exterior chimneys. These requirements are important because the cost of chimney relining is a major component of the installation cost of a NWGF.

Exterior Chimneys. Prior to 1995, building codes did not require lining of chimneys. In Table 13.11 of the NFGC,[12] the minimum allowable input rating for appliances that are vented in exterior unlined masonry chimneys is 150 kBtu/hour. This rating is the upper limit for input capacity for almost all NWGFs sold today. Therefore, DOE assumed that all exterior unlined chimneys will require relining upon replacement if built before 1995 or if the existing NWGF was installed before 1995.

Interior Chimneys. Prior to 1995, building codes did not require lining of chimneys. The NFGC mandates that all interior chimneys be relined when the furnace is isolated from the water heater (NFGC Tables 13.3 and 13.4).[12] When a NWGF is vented in common with a water heater, the vertical vent upsizing / 7X rule applies. This rule specifies that the flow area of the vertical vent shall not exceed seven times (7X) the flow area of the smallest vent connector—the vent connector for the water heater, for example. Water heater vents are typically 3 inches in diameter, so an interior masonry chimney cannot exceed 49 square inches, corresponding to an 8 x 8 nominal chimney liner size. DOE assumed that all interior chimneys would need to be relined if built before 1995 or existing furnace was installed before 1995.

DOE determined which NWGF installations in the entire NWGF sample would require chimney relining based on RECS 2009 equipment age data and the fraction of chimney installations (see Table 8D.2.7). For each bin DOE assigned an equipment installation year using a uniform distribution with the ranges shown in Table 8D.2.7. Finally, using the fraction of chimney installations shown in Table 8D.2.7, DOE determined if the household had a chimney installation. This resulted in 34 percent of households having a chimney (52 percent in the North and 14 percent in the South).

To determine if a household had an unlined chimney, DOE used the following two criteria:

1) NWGF exhaust gases are vented through a chimney, and
2) The existing NWGF was installed before 1995 when building codes requiring the relining of chimneys were not yet in place.

Based on these criteria, DOE calculated that 11 percent (17 percent in the North and 5 percent in the South) of households in the RECS 2009 sample had an unlined chimney. DOE determined that a fraction of these would be relined already by 2021, based on NWGF product retirements from 2009 to 2021. (By 2021, the existing NWGFs that would require relining would be 26 years old or older). Therefore, the analysis resulted in only 0.9 percent (1.5 percent in the North and 0.2 percent in the South) of the stock needing to be relined in 2021.

Vent Resizing

Vent resizing occurs when the existing vent diameter is too large for the new NWGF or for the commonly vented NWGF and gas water heater. Two solutions are possible: 1) vent connector resizing (most common) or 2) vent resizing (less common). There are three main types of vent connectors: Type B double wall, single-wall galvanized steel, and single-wall aluminum. A double-wall vent uses a galvanized steel outer tube to surround an aluminum inner tube and is sold in multiple section lengths. The air gap in between the tubes provides insulation, which reduces the likelihood of condensation in the vent connector. A single-wall galvanized steel vent is simply a zinc-coated steel tube vent. Aluminum single-wall vent connectors are similar to galvanized steel single-wall vents and are found in some regions. Condensing NWGFs do not require vent connectors. DOE assumed that all new vent connectors are Type B double wall.

The vent connector portion of the vent is the horizontal part of the masonry and metal vent systems shown in Figure 8D.2.6 and Figure 8D.2.7 respectively. In each figure there are two vent connectors shown: one for the water heater, and one for the NWGF. As water heater capacity is typically less than NWGF capacity, in many cases the water heater vent connector diameter will be less than the NWGF vent connector diameter. DOE assumes that the NWGF vent connector diameter is 4 inches on average, while the water heater vent connector diameter is assumed to be 3 inches on average.

DOE assumed that vent resizing occurs only when a non-condensing fan-assisted furnace (an AFUE of 80 percent or greater) replaces a natural draft non-condensing furnace (an AFUE of less than 75 percent). Although fan-assisted NWGFs have been the only installed non-condensing designs since the early 1990s, there is still a fraction of the stock that includes natural draft non-condensing NWGFs, based on RECS 2009 product age and historical shipments by efficiency from GAMA and AHRI.[13, 14] Using this data, DOE determined that natural draft NWGFs will account for about 1.5 percent (1.1 percent in the North and 1.9 percent in the South) of the stock in 2021. Based on a consultant report, DOE assumed that 75 percent of the venting systems with existing natural draft furnaces would need replacement of the vent connectors, while in an additional 20 percent of the installations the entire venting system would have to be resized.[9]

Table 8D.2.10 summarizes the three different venting issues associated with non-condensing NWGFs including the frequency of installation requirements, the fraction of installed NWGFs that could be impacted, the fraction impacted (Frequency * Fraction Possibly Impacted), and the average additional installation cost.

Table 8D.2.10 Non-Condensing to Non-Condensing Venting Issues, Fraction Impacted, and Average Installation Cost

Existing Furnace	Replacement Furnace	Installation Requirement	Frequency	Fraction Possibly Impacted	Fraction Impacted	Avg. Cost
Chimney installed before 1995	80% AFUE	Relining all unlined chimneys	100%	0.9%	0.9%	$960
Natural draft	80 % AFUE	Installing New Vent Connectors (Converting from single-wall to Type B double-wall)	75%	1.5%	1.1%	$190
Natural draft	80% AFUE	Resizing Vent System	20%	1.5%	0.2%	$731

Table 8D.2.11 shows the installation cost details for chimney relining or vent resizing (for a household requiring a total vent length of 19 feet and commonly vented with a water heater). For this analysis, DOE assumes that the cost of chimney relining or vent resizing is similar. Vent length is determined by taking into account the NWGF installation location and the number of floors above the NWGF (see section 8D.2.4.2). The average vent length for a vertical installation is 19 feet.

Table 8D.2.11 Chimney Relining or Vent Resizing (Non-Condensing to Non-Condensing) Cost Example Using National Labor Costs

Description	Crew	Labor Hours	Unit	Bare Costs *(2013$)*			Quantity	Total incl. O&P
				Material	**Labor**	**Total**		
Aluminum Flexible Vent (4" Diameter, includes vent kit)	Q9*	0.235	L.F.**	$12.64	$7.44	$20.08	19	$436.62
Vent Connector - Furnace (4" diameter vent, double wall, type B)	Q9	0.235	Ea.	$6.60	$7.44	$14.04	6	$121.03
Vent Connector - Furnace (4" diameter, elbow)	Q9	0.471	Ea.	$14.50	$14.92	$29.42	1	$41.93
Vent Connector - Water Heater (3" diameter vent, double wall, type B)	Q9	0.222	Ea.	$4.84	$7.03	$11.87	4.5	$78.35
Vent Connector - Water Heater (3" diameter, elbow)	Q9	0.444	Ea.	$12.40	$14.06	$26.46	1	$38.03
Total								**$677.93**

* Q9 means a crew comprised of 1 sheet metal worker and 1 sheet metal worker apprentice.
**"L.F." means "linear foot."

Table 8D.2.12 shows the installation cost details for installing a vent connector for a NWGF.

Table 8D.2.12 Vent Connector Cost Example Using National Labor Costs (NWGF): Replacement

Description	Crew	Labor Hours	Unit	Bare Costs *(2013$)*			Quantity	Total incl. O&P
				Material	Labor	Total		
Vent Connector (Vent chimney, double wall, type B, 4" Diameter)	Q9*	0.235	L.F.	$6.60	$7.44	$14.04	6	$121.03
Vent Connector (Type B Elbows, 45 degree, 4" Diameter)	Q9	0.471	Ea.	$14.50	$14.92	$29.42	1	$41.93
Total								**$162.95**

* Q9 means a crew comprised of 1 sheet metal worker and 1 sheet metal worker apprentice.

Table 8D.2.13 shows the installation cost details for installing a vent connector for a water heater.

Table 8D.2.13 Vent Connector Cost Example Using National Labor Costs (Water Heater): Replacement

Description	Crew	Labor Hours	Unit	Bare Costs *(2013$)*			Quantity	Total incl. O&P
				Material	Labor	Total		
Vent Connector (Vent chimney, double wall, type B, 3" Diameter)	Q9*	0.222	L.F.	$4.84	$7.03	$11.87	4.5	$78.35
Vent Connector (Type B Elbows, 45 degree, 3" Diameter)	Q9	0.444	Ea.	$12.40	$14.06	$26.46	1	$38.03
Total								**$116.38**

* Q9 means a crew comprised of 1 sheet metal worker and 1 sheet metal worker apprentice.

8D.2.4.3.2 Non-Condensing to Condensing Furnace Replacement Installations

DOE estimated that nationally in 2021 the majority of the replacement installations would be from non-condensing to condensing NWGFs. This section explains the changes to the venting systems that would be required when installing condensing furnaces and provide information about the fractions of impacted installations. The sections below address the following four installation issues:

- condensing flue vent (PVC);
- combustion air vent;
- concealing vents in indoor installations; and
- installation with orphaned water heaters.

Condensing Flue Vent (PVC)

When replacing an existing non-condensing NWGF with a condensing NWGF, the existing metal vent is replaced with a plastic (PVC) flue vent. The installation cost of the condensing NWGF flue vent takes into account the following:

- vent length (furnace distance from wall or roof, and whether to install a vertical vent (through the roof) or a horizontal vent (through the wall), see section 8D.2.4.2); and
- wall type, which determines the cost of penetrating the wall.

Table 8D.2.14 shows the 5th percentile, average, and 95th percentile vent length results from the RECS 2009 household sample and the fraction of installations with vertical or horizontal vents.

Table 8D.2.14 Condensing Non-Weatherized Gas Furnace Vent Length: Replacement

Vent Run	Vent Length, ft			Fraction of Installations
	5th Percentile	Average	95th Percentile	
Horizontal	3	12	24	83%
Vertical	7	19	37	17%

Table 8D.2.15 illustrates the development of installation cost components for plastic (PVC) venting for a condensing NWGF in replacement cases. The most common vent size diameter is 2”, which is assumed to be installed with furnaces up to 100 kBtu/h. Larger furnaces are assumed to use 3” vent size diameter. The number of elbows required varies from 1 to 3 (presented as a uniform distribution). The vent termination is assumed to be the same cost as an elbow. The cost of drilling a hole through the building envelope is dependent on the type of outside wall material used for each household, as given in RECS 2009 or CBECS 2003, and whether the PVC venting is horizontal or vertical. All replacement installations going from non-condensing to condensing encounter the cost of a new PVC venting system, which is on average $296.

Table 8D.2.15 Plastic (PVC) Venting Cost Example Using National Labor Costs: Replacement

Description	Crew	Labor Hours	Unit	Bare Costs *(2013$)*			Quantity	Total incl. O&P
				Mat.	Labor	Total		
PVC, couplings 10' O.C., hangars 3 per 10', schedule 40 (2" diameter)	Q1*	0.081	L.F.	$4.36	$2.69	$7.05	12	$114.73
Elbow - PVC, schedule 40, socket joints, 90" elbow, 1/2" (2" diameter)	Q1	0.44	Ea.	$2.75	$14.60	$17.35	1	$27.27
Termination - PVC, schedule 40, socket joints, 90" elbow, 1/2" (2" diameter)	Q1	0.44	Ea.	$2.75	$14.60	$17.35	1	$27.27
Knockouts to 8' high, metal boxes & enclosures (With hole saw, 2" pipe size)	1 ELEC**	0.30	Ea.	$0.00	$10.39	$10.39	1	$16.16
Total								**$185.43**

* Q1 means a crew comprised of 2 plumbers and 1 plumber apprentice.

** 1 ELEC means a crew of 1 electrician.

Combustion Air Vent (PVC)

A fraction of the condensing furnace installations are direct-vent installations, which uses combustion air supplied from the outdoor air. For each household in the RECS 2009 sample, DOE considered the following factors when calculating the installation cost of the combustion air vent for condensing NWGFs in the replacement market:

- combustion air vent length, which is the same as flue pipe length; and
- combustion air vent installation fraction, which depends on the installation location.

Table 8D.2.16 shows the fraction of direct vent installations by installation location, based on a 2010 consultant report.[9] As shown in the table, nationally about 59 percent of condensing NWGF shipments are to direct vent installations. The fraction of condensing NWGF shipments to direct-vent installations for the North and Rest of Country regions are also shown in the table.

Table 8D.2.16 Fraction of Direct Vent Condensing Non-Weatherized Gas Furnace Installations

ID	Installation Location	Fraction of Direct Vent Installations	Fraction of Shipments		
			North	Rest of Country	National
1	Basement (Conditioned)	**67%**	48.69%	7.40%	29.28%
2	Basement (Unconditioned)	**33%**	16.64%	4.85%	11.10%
3	Crawl Space	**33%**	7.91%	11.06%	9.39%
4	Garage	**100%**	3.45%	17.27%	9.95%
5	Indoor (Closet, Alcove, Utility Room)	**67%**	20.04%	36.42%	27.74%
6	Attic (Conditioned)	**67%**	0.06%	1.62%	0.79%
7	Attic (Unconditioned)	**33%**	3.21%	21.38%	11.75%
	Total Fraction of Installations that are Direct Vent		**58.7%**	**60.0%**	**59.3%**

Table 8D.2.17 illustrates the development of installation cost components for direct vent (combustion air vent) using plastic (PVC) venting for a condensing furnace in the replacement cases. Fifty-nine percent of replacement installations going from non-condensing to condensing encounter this cost, which is on average $295.

Table 8D.2.17 Direct Vent Plastic (PVC) Venting Cost Example Using National Labor Costs: Replacement

Description	Crew	Labor Hours	Unit	Bare Costs *(2013$)*			Quantity	Total incl. O&P
				Mat.	Labor	Total		
PVC, couplings 10' O.C., hangars 3 per 10', schedule 40 (2" Diameter)	Q1*	0.081	L.F.	$4.36	$2.69	$7.05	12	$114.73
Elbow - PVC, schedule 40, socket joints, 90" elbow, 1/2" (2" diameter)	Q1	0.44	Ea.	$2.75	$14.60	$17.35	1	$27.27
Termination - PVC, schedule 40, socket joints, 90" elbow, 1/2" (2" diameter)	Q1	0.44	Ea.	$2.75	$14.60	$17.35	1	$27.27
Knockouts to 8' high, metal boxes & enclosures (With hole saw, 2" pipe size)	1 ELEC**	0.30	Ea.	$0.00	$10.39	$10.39	1	$16.16
Total								**$185.43**

* Q1 means a crew comprised of 2 plumbers and 1 plumber apprentice.
** 1 ELEC means a crew of 1 electrician.

Concealing Vent Pipes

For a fraction of indoor installations, DOE added an installation cost to conceal the PVC vent pipes—putting in place structures to mask vents that pass through the living space. DOE assumed that half of the indoor condensing furnace installations that are horizontally vented would require such modifications. Table 8D.2.18 illustrates the development of the installation cost components for concealing the vent piping in such cases. Nine percent of replacement installations going from non-condensing to condensing encounter this cost, which is on average $360.

Table 8D.2.18 Concealing Ductwork Cost Example Using National Labor Costs: Replacement

Description	Crew	Labor Hours	Unit	Bare Costs *(2013$)*			Quantity	Total incl. O&P
				Materials	Labor	Total		
Trip Charge	1 CARP*	0.5	Ea.	$0.00	$15.73	$15.73	1	$26.42
Wallboard repair 8"-12" (cut square, patch san and repair finish)	1 CARP	0.5	C.L.F.	$3.04	$15.73	$18.77	14	$420.01
Total								**$446.42**

* 1 CARP means a crew of 1 carpenter.

Orphaned Water Heaters–Chimney Relining and Vent Resizing

When a condensing NWGF replaces an existing non-condensing NWGF that is commonly vented with a gas water heater, the water heater after the installation becomes "orphaned". Many of these "orphaned water heaters" require venting modifications to meet safety requirements. Such requirements include upgrading the vent connector, resizing metal vents, or masonry chimney relining. Based on a 2010 consultant report,[9] DOE assumed that 100 percent of the venting systems with existing natural draft NWGFs would need to have the vent connectors replaced for the orphaned water heater, while an additional 75 percent would need to have the entire venting system of the orphaned water heater resized or upgraded. DOE assumed that all orphaned water heater chimneys would need to be relined if built before 1990 and if the existing NWGF is a natural draft NWGF. Based on the 2010 consultant report, DOE also assumed that 40 percent of the venting systems with existing fan assisted non-condensing NWGFs would need to have the entire vent of the orphaned water heater resized or upgraded.

Table 8D.2.19 summarizes the four different scenarios that might be encountered in such replacement installations. The table shows the scenario description and the analysis results about the frequency of applying these requirements, fraction of installed furnaces that could be impacted, the fraction impacted (Frequency * Fraction Possibly Impacted), and the average additional installation cost.

Table 8D.2.19 Non-Condensing to Condensing Venting Issues, Fraction Impacted and Average Installation Cost

Existing Non-Condensing Furnace	Replacement Furnace	Installation Requirement	Frequency of applying requirements	Fraction Possibly Impacted	Fraction Impacted	Avg. Cost
Natural Draft	Condensing Furnace	Convert Water Heater from single wall to Type B vent Connector	100%	0.7%	0.1%*	$111
Natural Draft	Condensing Furnace	Resizing Orphaned Water Heater Chimney or upgrading Metal Vent	75%	0.7%	0.6%*	$672
Natural Draft or Fan Assisted	Condensing Furnace	Reline all unlined chimneys for Orphaned Water Heater	100%	0.6%	0.6%	$747
Fan Assisted	Condensing Furnace	Resizing Orphaned Water Heater Chimney or upgrading Metal Vent	40%	45%	18%	$672

* These two fractions add up to 0.7% (the fraction possibly impacted). DOE assumes that the households that are required to resize their water heaters or upgrade their metal venting would be always required to upgrade the vent connector.

Table 8D.2.20 shows the installation cost details for chimney relining or vent resizing for an orphaned water heater.

Table 8D.2.20 Chimney Relining or Vent Resizing (Orphaned Water Heater) Cost Example Using National Labor Costs: Replacement

Description	Crew	Labor Hours	Unit	Bare Costs *(2013$)*			Quantity	Total incl. O&P
				Material	Labor	Total		
Aluminum Flexible Vent (3" diameter vent, includes vent kit)	Q9*	0.222	L.F.	$8.91	$7.03	$15.94	16	$355.25
Vent Connector - Water Heater (3" diameter vent, double wall, type B)	Q9	0.222	Ea.	$4.84	$7.03	$11.87	4.5	$78.35
Vent Connector - Water Heater (3" diameter, elbow)	Q9	0.444	Ea.	$12.40	$14.06	$26.46	1	$38.03
Total								**$471.64**

* Q9 means a crew comprised of 1 sheet metal worker and 1 sheet metal worker apprentice.

Table 8D.2.21 shows the installation cost details for installing a vent connector for a water heater.

Table 8D.2.21 Vent Connector Costs (Water Heater) Example Using National Labor Costs: Replacement

Description	Crew	Labor Hours	Unit	Bare Costs *(2013$)*			Quantity	Total incl. O&P
				Material	Labor	Total		
Vent Connector - Water Heater (3" diameter vent, double wall, type B)	Q9*	0.222	Ea.	$4.84	$7.03	$11.87	4.5	$78.35
Vent Connector - Water Heater (3" diameter, elbow)	Q9	0.444	Ea.	$12.40	$14.06	$26.46	1	$38.03
Total								**$116.38**

* Q9 means a crew comprised of 1 sheet metal worker and 1 sheet metal worker apprentice.

8D.2.4.4 New Construction and New Owner Installations

For NWGF installations in new construction and new owner, DOE accounted for the installation cost of a new venting system for both non-condensing NWGFs and condensing NWGFs.

Table 8D.2.22 illustrates the typical installation cost for venting a non-condensing NWGF in new construction or new owner. As in the replacement case, vent length is determined by taking into account the furnace installation location and the number of floors above the furnace.

Table 8D.2.22 Non-Condensing Venting Cost (Typical 2-Story House) Example Using National Labor Costs: New Construction

Description	Crew	Labor Hours	Unit	Bare Costs *(2013$)*			Quantity	Total incl. O&P
				Mat.	Labor	Total		
Vent pipe, double wall, galvanized steel (4" Diameter)	Q9*	0.24	L.F.	$6.60	$7.44	$14.04	16	$435.70
Double Wall, Galvanized Steel Adjustable Length piece, to 12"	Q9	0.47	Ea.	$14.50	$14.92	$29.42	1	$56.60
Type B Wall Thimble, 4" to 7" Adjustable(4" Diameter)	Q9	0.47	Ea.	$13.25	$14.92	$28.17	1	$54.61
Vent Connector (Type B Elbows, 45 degree, 4" Diameter)	Q9	0.47	Ea.	$14.85	$14.92	$29.77	1	$57.16
Roof Flashing (4" Diameter)	Q9	0.47	Ea.	$9.05	$14.92	$23.97	1	$47.93
Tee (4" Diameter)	Q9	0.62	Ea.	$35.00	$19.48	$54.48	1	$99.47
Tee Cap (4" Diameter)	Q9	0.38	Ea.	$3.65	$12.07	$15.72	1	$32.93
Top (4" Diameter)	Q9	0.36	Ea.	$22.50	$11.53	$34.03	1	$61.71
Total								**$846.11**

* Q9 means a crew comprised of 1 sheet metal worker and 1 sheet metal worker apprentice.

Table 8D.2.23 illustrates the typical installation cost for venting a condensing NWGF in new construction. DOE accounted for the installation of the plastic PVC flue vent, as well as for the combustion air vent in direct-vent systems. For new owners, DOE accounted for a fraction that needed to conceal PVC vent piping.

Table 8D.2.23 Plastic Venting Cost Example Using National Labor Costs: New Construction

Description	Crew	Labor Hours	Unit	Bare Costs *(2013$)*			Quantity	Total incl. O&P
				Mat.	Labor	Total		
PVC, couplings 10' O.C., hangars 3 per 10', schedule 40 (2" Diameter)	Q1*	0.08	L.F.	$4.36	$2.57	$6.93	12	$152.44
PVC, schedule 40, socket joints, 90° elbow, 1/2" (2" diameter)	Q1	0.44	Ea.	$2.75	$13.94	$16.69	1	$35.70
Total								**$188.14**

* Q1 means a crew comprised of 2 plumbers and 1 plumber apprentice.

In the new construction cases, DOE also accounted for the installation costs of commonly vented NWGFs (together with a water heater). When a commonly vented non-condensing NWGF and water heater are installed, then the venting cost is all assigned to the venting cost of the non-condensing NWGF. When installing a condensing NWGF in new construction, which originally planned to install a commonly vented non-condensing NWGF and water heater, 100 percent of the cost to install the orphaned water heater installation venting system is assigned to the condensing NWGF installation cost.

8D.2.5 Condensate Removal for Condensing Furnaces

Condensate removal is required for all condensing NWGF installations in both replacement and new construction cases. DOE considered the following when assessing the cost of condensate removal:

- *Condensate Pipe:* For condensing NWGFs, excess condensate must be deposited in a drain. Therefore, for all installations DOE applied the cost of adding condensate pipe (on average 15 feet).
- *Condensate Pump:* If a drain is not near the furnace, then the condensate must be pumped to a remote drain. If a central air-conditioner is present, then DOE assumed that already there is either a drain nearby or a pump already exists to remove the condensate from the air conditioner during the cooling season. DOE assumed that a condensate pump is required for half of the replacement installations without a central air conditioner. DOE did not include the cost of a condensate pump for new construction installations.
- *Condensate Freeze Protection:* If the condensate is exposed to freezing temperatures, then heat tape and pipe insulation is required. DOE assumed that heat protection is required for all installations in an unconditioned attic for replacements. DOE did not include the cost freeze protection for new construction installations.
- *Drip Pan:* Some building codes require a drip pan. DOE assumed that a drip pan is required for all attic installations or NWGFs installed in a 2nd floor or above in both replacement and new construction installations.
- *Additional Electrical Outlet:* DOE assumed that half of installations requiring a condensate pump or heat tape would also require an additional electrical outlet. DOE included this additional cost in the analysis for replacements, but did not include it for new construction installations.
- *Condensate Neutralizer:* DOE assumed that 12.5 percent of all installations require condensate neutralizer.

Figure 8D.2.13 shows the condensate withdrawal methodology flowchart.

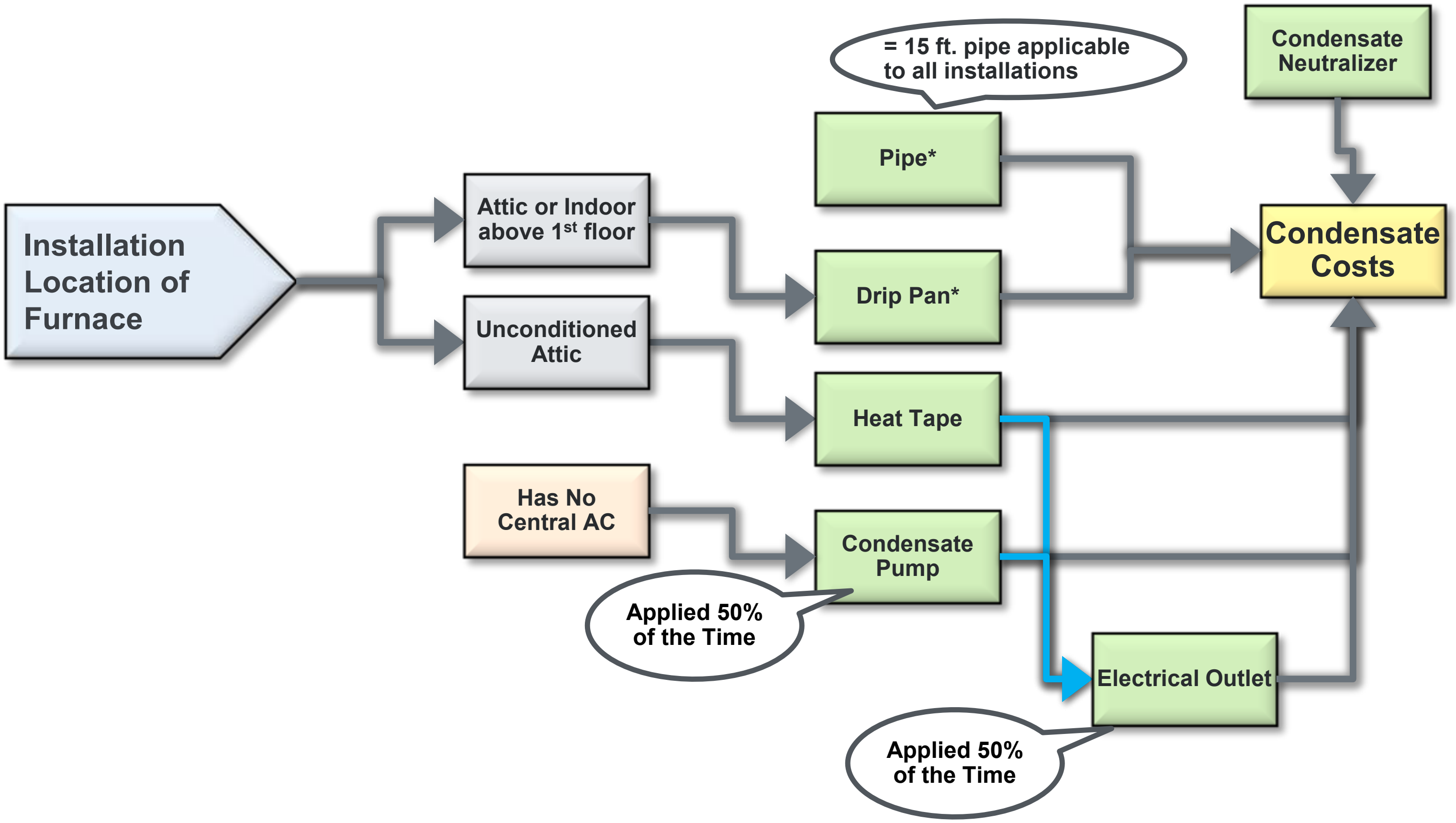


Figure 8D.2.13 Condensate Withdrawal Methodology Flowchart

Table 8D.2.24 and Table 8D.2.25 summarize the condensate removal adders associated with condensing NWGFs. The table shows the criteria, the frequency of applying these criteria, the fraction of installed NWGFs that could be possibly impacted, the fraction impacted (Frequency * Fraction Possibly Impacted), and the average additional installation cost.

Table 8D.2.24 Installation Fractions and Average Costs for Condensate Removal: Replacements

Installation Cost Description	Criteria	Frequency of applying criteria	Fraction Possibly Impacted	Fraction Impacted	Average Cost
Pipe	All installations	100%	100%	100%	$18
Drip Pans	Attics or higher floor installations	100%	25%	25%	$45
Condensate Pump	Installations without AC	50%	11%	6%	$259
Heat Tape and Pipe Insulation	Installations in Unconditioned Attic	100%	5%	5%	$97
Electrical Outlet (additional)	Installations requiring a Pump or Heat Tape	50%	11%	5%	$136
Condensate Neutralizer	Fraction of all installations	12.5%	100%	13%	$103

Table 8D.2.25 Installation Fractions and Average Costs for Condensate Removal: New Owners and New Construction

Installation Cost Description	Criteria	Frequency of applying criteria	Fraction Possibly Impacted	Fraction Impacted	Average Cost
Pipe	All installations	100%	100%	100%	$17
Drip Pans	Attics or higher floor installations	100%	30%	30%	$61
Condensate Neutralizer	Fraction of all installations	12.5%	100%	12%	$100

In addition to the installation costs, the electricity use of the pump and heat tape is taken into account (45 watts for heat tape and 60 watts for the condensate pump) in the energy use calculations (see chapter 7).

8D.2.6 Summary of NWGF Installation Costs

Table 8D.2.26 (for replacements), Table 8D.2.27 (for new owner), and Table 8D.2.28 (for new construction) show the fraction of the impacted installations, the average cost of each installation, and the resulting average total cost for all NWGF installations. The costs are included when applicable.

Table 8D.2.26 Replacement Installations: Average Installation Costs for Non-Weatherized Gas Furnaces

Installation Item	Criteria	Installations Impacted *%*	Average Cost *2013$*	Total Cost *2013$*
Non-Condensing Furnaces				
Basic Installation	100% of Installations	100	631	631
Update Flue Vent	100% of installations requiring chimney relining or resizing	2.3	556	13
			TOTAL	**$643**
Condensing Furnaces				
Basic Installation	100% of installations	100	631	631
New Flue Venting (PVC)	100% of installations	100	296	296
Combustion Air Venting (PVC)	59% of installations	59	295	173
Concealing Vent Pipes	50% of indoor horizontal vented	9	360	34
Orphaned Water Heater	100% of installations requiring chimney relining or resizing	19	672	126
Condensate Removal	100% of installations	100	70	70
			TOTAL	**$1,330**

Table 8D.2.27 New Owner Installations: Average Installation Costs for Non-Weatherized Gas Furnaces

Installation Item	Criteria	Installations Impacted *%*	Average Cost *2013$*	Total Cost *2013$*
Non-Condensing Furnaces				
Basic Installation	100% of installations	100	625	625
New Flue Vent	100% of installations	100	1,280	1,280
			TOTAL	**$1,905**
Condensing Furnaces				
Basic Installations	100% of installations	100	625	625
New Flue Venting (PVC)	100% of installations	100	202	202
Combustion Air Venting (PVC)	60% of installations	60	201	121
Concealing Vent Pipes	50% of indoor horizontal vented	16	125	19
Common Venting Adder	100% of installations planned to be commonly vented with non-condensing design option	45	956	431
Condensate Removal	100% of installations	100	48	48
			TOTAL	**$1,446**

Table 8D.2.28 New Construction Installations: Average Installation Costs for Non-Weatherized Gas Furnaces

Installation Item	Criteria	Installations Impacted *%*	Average Cost *2013$*	Total Cost *2013$*
Non-Condensing Furnaces				
Basic Installation	100% of installations	100	627	627
New Flue Vent	100% of installations	100	1,272	1,272
			TOTAL	**$1,899**
Condensing Furnaces				
Basic Installations	100% of installations	100	627	627
New Flue Venting (PVC)	100% of installations	100	209	209
Combustion Air Venting (PVC)	60% of installations	60	207	125
Common Venting Adder	100% of installations planned to be commonly vented with non-condensing design option	44	996	443
Condensate Removal	100% of installations	100	47	47
			TOTAL	**$1,452**

8D.2.7 Detailed Overview of NWGF Installation Costs

NWGFs have many different possible installation situations. Figure 8D.2.14 illustrates the approach for determining the installation costs of a condensing NWGF under a condensing AFUE standard based on building characteristics (labeled as Cases A to H). Figure 8D.2.14 also shows the average difference in installation cost between the base case and standards case at 90-percent AFUE, as well as the fraction of total NWGF shipments for different housing types with a NWGF AFUE standard of 90-percent AFUE. Note that negative installation costs indicate lower costs on average under the standards case.

Beginning with the sample household or building, DOE determined in which market the NWGF would be installed (new construction, replacement, or new owner). Then, DOE determined whether the household already has a condensing NWGF. For households that already have a condensing NWGF, DOE assumed that there is no difference in installation cost between the base case and standards case. For households that have a non-condensing NWGF, DOE determined whether the household commonly vented the existing NWGF with the water heater based on 1991 GTI Water Heater Survey,[10] and whether vent resizing would be required to accommodate an orphaned water heater.[d] For the new construction and new owner markets, DOE determined which households would have otherwise installed a non-condensing NWGF with a commonly vented water heater in the base case (Cases F and H). On average, new

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[d] An orphaned water heater is a water heater that was commonly vented with a non-condensing NWGF prior to replacing the non-condensing NWGF with a condensing NWGF. After the installation of a condensing NWGF, the water heater must be vented independently.

construction and new owner households experience installation cost savings because PVC venting is less expensive than Type B metal venting.

Table 8D.2.29 through Table 8D.2.31 present detailed installation costs for condensing and non-condensing NWGFs by installation case and housing type and the fraction of shipments affected for applications in replacement, new owners, and new construction, respectively.

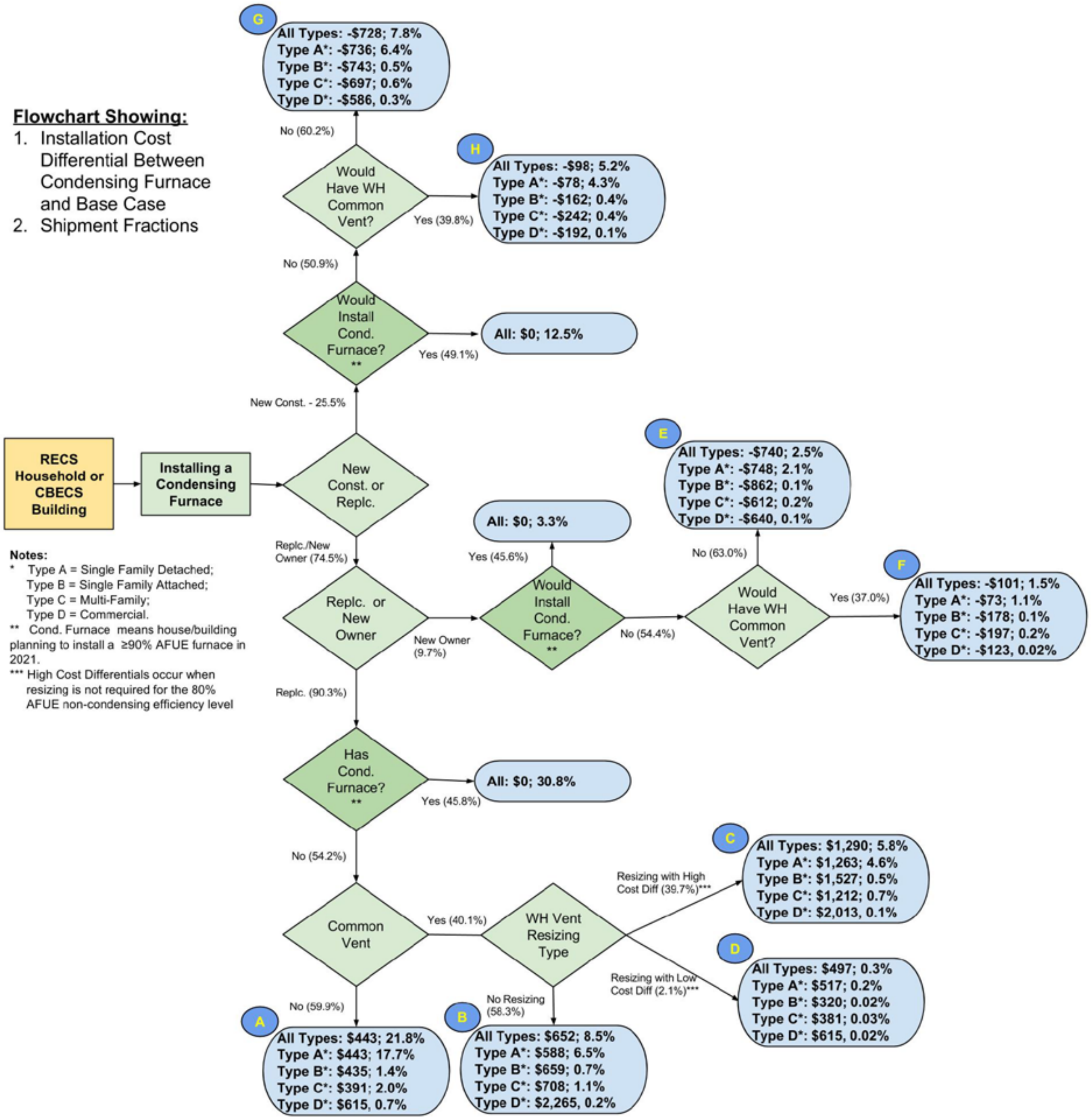

Figure 8D.2.14 Installation Cost Differential Summary between Condensing Furnace and Base Case Furnace Including Shipments Fractions

Table 8D.2.29 Non-Condensing and Condensing Installation Costs for NWGF by Installation Case and Building Type - Replacements

House Type	**Non-Condensing Installation Costs**			**Condensing Installation Costs**					**Install Cost Diff.** *2013$*	**Fraction of Shipments** *%*
	Basic *2013$*	**Venting** *2013$*	**Total** *2013$*	**Basic** *2013$*	**Venting**** *2013$*	**Orphaned WH** *2013$*	**Condensate Removal** *2013$*	**Total Cost** *2013$*		
All Houses (incl. 90%+)*	**$631**	**$13**	**$643**	**$631**	**$503**	**$126**	**$70**	**$1,330**	**$687**	**67.3%**
All Houses (excluding 90%+)*	$603	$9	$612	$603	$456	$107	$74	$1,239	$627	36.4%
Case A										
All Houses (excluding 90%+)	**$555**	**$7**	**$562**	**$555**	**$377**	**$0**	**$74**	**$1,005**	**$443**	**21.8%**
Type A	$548	$7	$555	$548	$377	$0	$73	$998	$443	17.7%
Type B	$569	$4	$573	$569	$363	$0	$76	$1,008	$435	1.4%
Type C	$553	$5	$558	$553	$325	$0	$71	$949	$391	2.0%
Type D	$705	$7	$712	$705	$528	$0	$94	$1,327	$615	0.7%
Case B										
All Houses (excluding 90%+)	**$668**	**$0**	**$668**	**$668**	**$580**	**$0**	**$72**	**$1,320**	**$652**	**8.5%**
Type A	$662	$0	$662	$662	$517	$0	$71	$1,250	$588	6.5%
Type B	$673	$0	$673	$673	$578	$0	$81	$1,332	$659	0.7%
Type C	$653	$0	$653	$653	$644	$0	$64	$1,360	$708	1.1%
Type D	$917	$0	$917	$917	$2,150	$0	$114	$3,182	$2,265	0.2%
Case C										
All Houses (excluding 90%+)	**$681**	**$0**	**$681**	**$681**	**$572**	**$643**	**$76**	**$1,971**	**$1,290**	**5.8%**
Type A	$686	$0	$686	$686	$529	$660	$74	$1,949	$1,263	4.6%
Type B	$663	$0	$663	$663	$735	$707	$86	$2,190	$1,527	0.5%
Type C	$651	$0	$651	$651	$630	$496	$85	$1,863	$1,212	0.7%
Type D	$758	$0	$758	$758	$1,499	$437	$78	$2,771	$2,013	0.1%
Case D										
All Houses (excluding 90%+)	**$694**	**$643**	**$1,337**	**$694**	**$480**	**$581**	**$79**	**$1,834**	**$497**	**0.3%**
Type A	$685	$658	$1,344	$685	$500	$614	$61	$1,861	$517	0.2%
Type B	$752	$713	$1,465	$752	$286	$706	$41	$1,786	$320	0.02%
Type C	$690	$455	$1,145	$690	$246	$339	$252	$1,527	$381	0.03%
Type D	$738	$679	$1,417	$738	$791	$440	$64	$2,032	$615	0.02%

* Including 90%+ means that it includes households that already have or are planning to install a condensing furnace. Excluding 90%+ means that these households are excluded (in other words only households that are planning to install a non-condensing furnace are included).

** Includes New Flue Venting (PVC), Combustion Air Venting (PVC), and Condensate Removal installation costs.

Note: Type A: Single-Family (detached); Type B: Single-Family (attached); Type C: Multi-Family; Type D: Commercial

Table 8D.2.30 Non-Condensing and Condensing Installation Costs for NWGF by Installation Case and Building Type – New Owners

House Type	Non-Condensing Installation Costs			Condensing Installation Costs					Install Cost Diff. *2013$*	Fraction of Shipments *%*
	Basic *2013$*	Venting *2013$*	Total *2013$*	Basic *2013$*	Venting** *2013$*	Orphaned WH *2013$*	Condensate Removal *2013$*	Total Cost *2013$*		
All Houses (incl. 90%+)*	**$625**	**$1,280**	**$1,905**	**$625**	**$343**	**$431**	**$48**	**$1,446**	**-$459**	**7.3%**
All Houses (excluding 90%+)*	$600	$1,200	$1,801	$600	$297	$350	$49	$1,297	-$504	4.0%
Case E										
All Houses (excluding 90%+)	$553	$1,054	$1,607	$553	$264	$0	$50	$867	-$740	2.5%
Type A	$546	$1,061	$1,607	$546	$264	$0	$48	$859	-$748	2.1%
Type B	$578	$1,197	$1,774	$578	$295	$0	$40	$912	-$862	0.1%
Type C	$553	$920	$1,473	$553	$238	$0	$70	$860	-$612	0.2%
Type D	$719	$989	$1,708	$719	$300	$0	$49	$1,068	-$640	0.1%
Case F										
All Houses (excluding 90%+)	$681	$1,449	$2,131	$681	$354	$946	$49	$2,030	-$101	1.5%
Type A	$676	$1,477	$2,152	$676	$386	$974	$44	$2,079	-$73	1.1%
Type B	$717	$1,541	$2,258	$717	$300	$1,012	$52	$2,080	-$178	0.1%
Type C	$690	$1,284	$1,973	$690	$227	$788	$73	$1,777	-$197	0.2%
Type D	$674	$1,086	$1,760	$674	$269	$645	$49	$1,637	-$123	0.0%

* Including 90%+ means that it includes households that already have or are planning to install a condensing furnace. Excluding 90%+ means that these households are excluded (in other words only households that are planning to install a non-condensing furnace are included).

** Includes New Flue Venting (PVC), Combustion Air Venting (PVC), and Condensate Removal installation costs.

Note: Type A: Single-Family (detached); Type B: Single-Family (attached); Type C: Multi-Family; Type D: Commercial

Table 8D.2.31 Non-Condensing and Condensing Installation Costs for NWGF by Installation Case and Building Type – New Construction

House Type	Non-Condensing Installation Costs			Condensing Installation Costs					Install Cost Diff. *2013$*	Fraction of Shipments *%*
	Basic *2013$*	Venting *2013$*	Total *2013$*	Basic *2013$*	Venting** *2013$*	Orphaned WH *2013$*	Condensate Removal *2013$*	Total Cost *2013$*		
All Houses (incl. 90%+)*	**$627**	**$1,272**	**$1,899**	**$627**	**$335**	**$443**	**$47**	**$1,452**	**-$447**	**25.5%**
All Houses (excluding 90%+)*	$604	$1,185	$1,789	$604	$284	$372	$52	$1,312	-$477	13.0%
Case E										
All Houses (excluding 90%+)	**$561**	**$1,032**	**$1,592**	**$561**	**$247**	**$0**	**$56**	**$864**	**-$728**	**7.8%**
Type A	$554	$1,048	$1,601	$554	$258	$0	$54	$865	-$736	6.4%
Type B	$586	$1,050	$1,636	$586	$243	$0	$64	$893	-$743	0.5%
Type C	$581	$912	$1,492	$581	$150	$0	$64	$795	-$697	0.6%
Type D	$631	$884	$1,514	$631	$227	$0	$70	$928	-$586	0.3%
Case F										
All Houses (excluding 90%+)	**$669**	**$1,417**	**$2,086**	**$669**	**$339**	**$935**	**$46**	**$1,988**	**-$98**	**5.2%**
Type A	$673	$1,450	$2,123	$673	$364	$964	$44	$2,044	-$78	4.3%
Type B	$658	$1,374	$2,032	$658	$265	$899	$47	$1,870	-$162	0.4%
Type C	$635	$1,144	$1,778	$635	$146	$691	$65	$1,537	-$242	0.4%
Type D	$695	$1,105	$1,800	$695	$212	$659	$43	$1,608	-$192	0.1%

* Including 90%+ means that it includes households that already have or are planning to install a condensing furnace. Excluding 90%+ means that these households are excluded (in other words only households that are planning to install a non-condensing furnace are included).

** Includes New Flue Venting (PVC), Combustion Air Venting (PVC), and Condensate Removal installation costs.

Note: Type A: Single-Family (detached); Type B: Single-Family (attached); Type C: Multi-Family; Type D: Commercial

8D.3 MOBILE HOME GAS FURNACES

DOE developed installation costs for MHGFs using RS Means cost data, information for industry experts, previous DOE analyses, and a 2010 consultant report. [1, 2, 3, 4, 9] DOE developed separate costs for new construction and replacement markets. Based on the shipments model (see chapter 9), DOE assumed a 50-percent new construction fraction in 2021.

8D.3.1 Basic Installation Costs

Basic installation costs were developed using the same approach as was used for NWGFs. The average basic installation cost for replacements is $597 and for new construction is $626.

8D.3.2 Venting

The U.S. Department of Housing and Urban Development (HUD) code requires sealed combustion (direct vent) for all installations of MHGFs. DOE determined that the average cost for adding PVC venting in the replacement market is $102. For the new construction market, DOE determined that installing a metal vent for non-condensing applications would cost $291, while the PVC venting cost on average would be $86.

8D.3.3 Condensate Removal

DOE assumed that all condensing MHGFs require condensate piping and freeze protection (heat tape and condensate pipe insulation). These costs are applied to both replacement and new construction markets. For half of all installations, DOE assumed an additional electrical outlet was required for the condensate pipe heat tape. Condensate piping, freeze protection, and electrical outlet costs were developed using the same approach as was used for NWGFs. The average installation cost adder for condensate removal for replacements is $117 and for new construction is $73.

8D.4 RS MEANS 2013 REGIONAL LABOR COSTS

DOE used regional material and labor costs to more accurately estimate installation costs by region. RS Means provides average national labor costs for different trade groups as shown in Table 8D.4.1. 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.4.2.

Table 8D.4.1 RS Means 2013 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	$33.18	$54.61
Q9	1 sheet metal worker, 1 sheet metal worker apprentice	2	$31.68	$52.74
Q10	2 sheet metal worker, 1 sheet metal worker apprentice	3	$32.85	$54.70
1 Plum	1 Plumbers	1	$36.85	$60.66
1 Plum Apprentice	1 Plumber Apprentice	1	$29.50	$48.56
1 Elec	1 Electrician	1	$35.10	$57.42
1 Sheet	1 Sheet metal worker	1	$35.20	$58.61
1 Sheet Apprentice	1 Sheet metal worker apprentice	1	$28.15	$46.87
1 Carp	1 Carpenter	1	$31.45	$52.84
Commercial Labors Costs (Standard Union)				
Q1	1 Plumber, 1 Plumber Apprentice	2	$42.65	$64.23
Q9	1 sheet metal worker, 1 sheet metal worker apprentice	2	$40.73	$62.11
Q10	2 sheet metal worker, 1 sheet metal worker apprentice	3	$44.92	$68.50
1 Plum	1 Plumbers	1	$55.80	$84.03
1 Plum Apprentice	1 Plumber Apprentice	1	$29.50	$44.43
1 Elec	1 Electrician	1	$52.40	$78.39
1 Sheet	1 Sheet metal worker	1	$53.30	$81.28
1 Sheet Apprentice	1 Sheet metal worker apprentice	1	$28.15	$42.93
1 Carp	1 Carpenter	1	$44.90	$69.15

* O&P includes markups from Table 8D.4.2.

Table 8D.4.2 RS Means Labor Costs Markups by Trade

Trade	Workers Comp.	Aver Fixed Overhead	Overhead	Profit	Total
Plumber	6.7%	17.9%	30.0%	10.0%	64.6%
Electrician	5.7%	17.9%	30.0%	10.0%	63.6%
Sheet Metal	8.6%	17.9%	30.0%	10.0%	66.5%
Carpenter	15.1%	17.9%	25.0%	10.0%	68.0%

RS Means also provides material and labor cost factors for 295 cities and towns in the U.S. To derive average labor cost values by state, DOE weighted the price factors by 1992-2003 NWGF and MHGF shipments by state. DOE used the material and labor cost factors for cost associated with fire suppression, plumbing, and HVAC. Table 8D.4.3 shows the final regional material and labor price factors used in the analysis by geographical area for residential installations and Table 8D.4.4 by Census division for NWGF installations in commercial buildings.

Table 8D.4.3 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	0.95	1.01	0.94	1.00	0.99
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	0.88	0.98	0.89	0.98	0.89
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	0.94	1.01	0.92	1.00	0.98
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	0.86	0.98	0.95	0.99	0.85
Georgia	0.99	0.66	0.99	0.69	0.97	0.67
North Carolina, South Carolina	1.00	0.37	0.97	0.47	0.99	0.49
Florida	1.00	0.69	0.99	0.68	1.00	0.73
Alabama, Kentucky, Mississippi	0.99	0.63	0.99	0.70	0.97	0.71
Tennessee	1.00	0.71	1.00	0.63	0.98	0.68
Arkansas, Louisiana, Oklahoma	0.99	0.57	0.99	0.62	0.97	0.60
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	0.96	0.69	1.00	0.69
Arizona	1.00	0.80	0.98	0.66	0.97	0.74
Nevada, New Mexico	1.00	0.91	0.95	0.98	0.99	0.95
California	0.99	1.21	1.00	1.21	1.01	1.19
Oregon, Washington	1.00	1.01	1.01	0.97	1.00	0.99
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.4.4 Material and Labor Cost Factors by Census Division (for CBECS 2003 Sample)

Census Division	Plumbing, HVAC		Electrical		Weighted Average	
	Material	Labor	Material	Labor	Material	Labor
New England	0.99	1.07	1.01	1.05	1.00	1.13
Middle Atlantic	0.99	1.34	1.00	1.43	1.00	1.34
East North Central	0.99	1.02	0.97	1.02	0.98	1.05
West North Central	0.99	0.90	1.00	0.89	1.00	0.92
South Atlantic	0.99	0.64	0.98	0.70	0.99	0.68
East South Central	1.00	0.66	0.99	0.67	0.97	0.70
West South Central	0.99	0.56	0.97	0.62	0.98	0.61
Mountain	1.00	0.79	0.98	0.79	1.00	0.79

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APPENDIX 8E. ENERGY PRICE CALCULATIONS FOR RESIDENTIAL FURNACES

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APPENDIX 8E. ENERGY PRICE CALCULATIONS FOR RESIDENTIAL FURNACES

8E.1 INTRODUCTION

Figure 8E.1.1 depicts the energy price calculation process, which also encompasses average energy price, seasonal marginal price factor, and monthly price factor calculations.

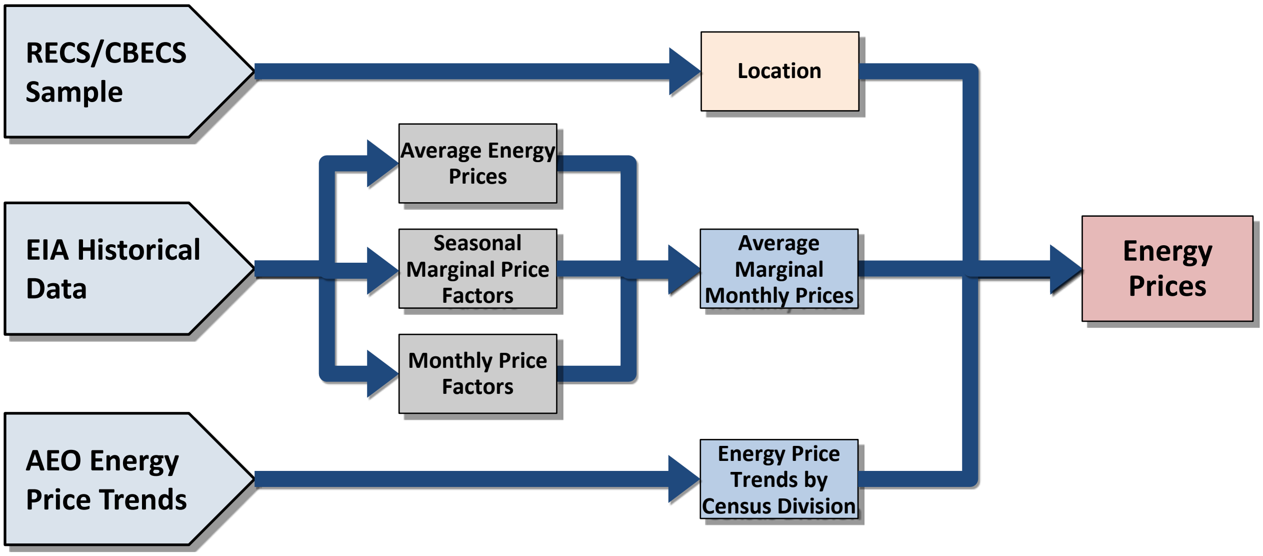

Figure 8E.1.1 Energy Price Calculation Process

8E.2 RECS/CBECS SAMPLE MAPPING PROCESS

To match the state data from the Energy Information Administration (EIA) to the Residential Energy Consumption Survey (RECS) 2009[1] household and Commercial Building Energy Consumption Survey (CBECS) 2003[2] building samples by geographic area, DOE used the average 1992-2003 gas furnace shipments by state from Air-Conditioning, Heating, and Refrigeration Institute (AHRI)[a] to appropriately weight the EIA data.[3] RECS 2009 utilizes 27 regions (also called reportable domains) and CBECS 2003 provides 9 census divisions. DOE further subdivided the RECS 2009 regions into 30 regions based on climate data to disaggregate northern and rest of country states. The 27th RECS 2009 region includes Oregon, Washington, Alaska, and Hawaii. DOE subdivided Alaska and Hawaii into separate regions (28 and 29, respectively), based on cooling and heating degree days. In addition, West Virginia, which is in RECS 2009 region 14, was disaggregated into region 30 based on cooling and heating degree days.

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[a] Previously Gas Appliance Manufacturers Association (GAMA).

8E.3 AVERAGE MARGINAL MONTHLY PRICES

8E.3.1 Average Annual Prices Determination

8E.3.1.1 Annual Electrical Prices

DOE derived 2012 annual electricity prices from EIA Form 826 data.[4] The EIA Form 826 data include residential and commercial energy prices by state. Table 8E.3.1 shows the monthly residential electricity prices for each state reported in the EIA Form 826. Table 8E.3.2 shows the monthly commercial electricity prices for each state reported in the EIA Form 826.

Table 8E.3.1 2012 Monthly Residential Electricity Prices by State from EIA (2012¢/kWh)

Geographical Area	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg. 2012
United States	11.41	11.51	11.70	11.92	11.90	12.09	12.00	12.17	12.30	12.03	11.75	11.62	11.87
Alabama	10.91	11.21	11.48	11.56	11.14	11.56	11.58	11.71	11.76	11.71	11.04	10.96	11.39
Alaska	18.04	17.44	17.97	17.64	18.43	18.10	19.44	19.07	17.34	17.82	17.10	17.06	17.95
Arizona	10.01	10.26	10.44	11.17	11.88	11.90	11.86	11.83	11.66	11.36	10.73	10.41	11.13
Arkansas	8.41	8.68	8.99	9.35	9.14	9.58	9.62	9.69	9.80	9.39	9.46	9.07	9.27
California	15.29	14.56	14.70	14.66	15.02	15.92	15.22	16.46	16.82	14.22	14.88	15.49	15.27
Colorado	10.61	10.76	10.84	11.04	11.27	12.01	12.32	12.15	12.11	11.33	11.38	11.07	11.41
Connecticut	17.32	17.09	17.16	17.64	17.71	17.30	17.08	17.12	17.24	18.08	17.82	17.06	17.39
Delaware	13.03	13.17	13.52	13.93	14.37	13.98	13.32	13.57	13.74	14.53	13.63	13.03	13.65
District of Columbia	11.78	12.21	12.20	12.49	12.39	13.18	12.26	12.23	12.22	12.35	12.21	11.98	12.29
Florida	11.55	11.33	11.09	11.42	11.00	11.49	11.31	11.49	11.60	11.53	11.82	11.38	11.42
Georgia	10.23	10.61	10.58	10.77	11.08	11.88	12.13	12.18	11.87	10.89	10.28	10.29	11.07
Hawaii	36.25	36.80	37.05	37.51	38.21	40.16	37.84	37.18	37.21	36.96	36.81	36.33	37.36
Idaho	8.15	8.09	8.18	8.16	8.39	9.04	9.75	9.77	8.31	9.11	8.67	8.54	8.68
Illinois	11.21	11.45	11.97	12.45	12.73	11.24	10.81	10.78	11.36	11.91	11.35	10.62	11.49
Indiana	10.00	10.18	10.85	11.56	10.85	10.54	9.94	10.44	10.92	11.09	10.45	10.49	10.61
Iowa	9.74	9.77	10.26	11.23	10.98	11.32	11.54	12.03	11.38	10.99	10.34	10.16	10.81
Kansas	10.23	10.71	10.81	11.15	11.28	11.69	11.74	11.72	11.52	11.29	10.96	10.90	11.17
Kentucky	8.98	9.07	9.47	9.63	9.72	9.48	9.27	9.45	9.83	9.72	9.41	9.46	9.46
Louisiana	8.15	8.40	8.40	8.38	8.48	8.01	8.38	8.29	8.56	8.68	8.39	8.47	8.38
Maine	15.02	15.07	14.28	14.46	14.41	14.21	14.63	14.66	14.81	14.76	14.83	14.70	14.65
Maryland	12.48	12.55	12.86	12.90	12.95	13.14	12.88	13.09	13.17	13.03	12.40	12.67	12.84
Massachusetts	15.10	15.41	15.72	14.80	15.39	15.48	14.58	14.16	15.20	14.38	13.77	15.19	14.93
Michigan	13.48	13.48	13.63	13.69	14.39	14.13	15.06	14.53	14.37	14.22	13.98	14.08	14.09
Minnesota	10.76	10.71	10.94	11.14	11.30	11.79	11.84	12.18	12.09	11.54	11.03	10.95	11.36
Mississippi	10.03	10.43	10.62	10.66	10.37	10.26	10.14	9.95	9.98	10.31	10.65	10.29	10.31
Missouri	8.66	8.90	9.33	10.06	10.90	11.53	11.31	11.49	10.46	9.89	9.20	9.03	10.06
Montana	9.57	9.59	9.70	9.86	10.13	10.43	10.60	10.52	10.74	10.54	10.04	9.89	10.13
Nebraska	8.61	8.86	9.16	9.95	9.68	10.71	11.38	11.24	11.50	10.43	9.43	9.13	10.01
Nevada	11.38	12.55	12.16	12.40	12.10	11.80	11.52	11.46	11.58	12.04	12.45	11.82	11.94
New Hampshire	16.17	16.12	16.33	16.45	16.53	16.51	15.81	15.59	15.88	16.03	15.90	15.83	16.10

Geographical Area	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg. 2012
New Jersey	16.07	16.22	15.86	15.91	15.93	15.67	16.12	15.81	15.57	15.17	15.24	15.49	15.76
New Mexico	10.79	10.62	10.71	10.77	11.04	12.08	12.19	12.49	11.98	11.51	10.69	10.71	11.30
New York	16.79	16.51	16.64	16.70	17.33	18.31	18.38	18.12	18.52	18.44	17.44	17.47	17.55
North Carolina	10.09	10.76	11.00	11.42	10.80	11.00	11.03	11.23	11.52	11.41	10.53	10.41	10.93
North Dakota	7.65	8.12	8.43	9.22	9.60	10.57	10.00	10.27	10.47	9.42	8.61	8.61	9.25
Ohio	11.08	11.04	11.35	11.93	11.85	12.24	12.16	12.14	12.27	12.06	11.67	11.39	11.77
Oklahoma	8.70	9.48	9.87	10.31	9.53	9.50	9.12	9.70	10.13	10.09	9.57	8.71	9.56
Oregon	9.58	9.63	9.66	9.73	9.86	9.92	10.01	10.01	10.00	10.00	9.82	9.74	9.83
Pennsylvania	12.82	12.79	12.77	12.97	12.99	12.89	12.62	12.68	12.57	12.80	12.60	12.62	12.76
Rhode Island	14.75	14.94	14.82	13.15	14.41	15.32	13.90	14.00	15.09	13.66	13.06	15.70	14.40
South Carolina	11.15	11.64	12.04	11.94	11.40	12.32	11.48	12.14	11.85	11.80	11.67	11.87	11.78
South Dakota	9.22	9.26	9.49	10.22	10.61	10.47	10.59	10.60	10.85	10.66	10.01	9.59	10.13
Tennessee	9.80	9.64	9.83	10.11	10.24	10.24	10.14	10.00	10.18	10.41	10.33	10.48	10.12
Texas	10.77	11.05	11.01	11.02	10.84	10.97	10.87	10.96	11.11	11.16	11.11	10.99	10.99
Utah	9.23	9.33	9.36	9.47	9.87	10.35	10.68	10.66	10.23	9.59	9.70	9.73	9.85
Vermont	16.52	17.07	16.76	16.87	16.41	16.93	16.77	16.38	16.38	17.51	19.26	17.20	17.01
Virginia	10.45	10.89	11.09	11.38	11.50	11.84	11.42	11.25	11.10	11.03	10.71	10.51	11.10
Washington	8.37	8.28	8.35	8.46	8.52	8.70	8.70	8.72	8.79	8.68	8.61	8.53	8.56
West Virginia	9.49	9.68	9.85	9.84	10.48	9.92	9.88	9.85	10.04	10.18	9.85	9.63	9.89
Wisconsin	12.66	12.88	13.10	13.36	13.35	13.36	13.28	13.50	13.83	13.43	13.16	12.61	13.21
Wyoming	9.12	9.16	9.40	9.74	10.08	10.22	10.38	10.27	10.38	10.36	10.01	9.89	9.92

Table 8E.3.2 2012 Monthly Commercial Electricity Prices by State from EIA (2012¢/kWh)

Geographical Area	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg. 2012
United States	10.16	10.28	10.23	10.20	10.37	10.61	10.60	10.52	10.54	10.35	10.22	10.22	10.36
Alabama	10.52	10.71	10.56	10.50	10.38	10.74	10.74	10.83	10.59	10.76	10.62	10.58	10.63
Alaska	15.16	14.83	14.99	14.69	15.26	15.13	15.14	14.90	14.14	15.53	14.70	14.69	14.93
Arizona	8.61	8.69	8.77	9.27	10.03	10.09	10.23	10.19	9.87	9.72	8.94	9.00	9.45
Arkansas	7.57	7.53	7.57	7.43	7.57	7.83	7.87	7.88	7.90	7.76	7.73	7.75	7.70
California	11.73	11.99	11.70	11.93	12.65	15.19	14.80	15.52	15.86	13.52	12.66	11.81	13.28
Colorado	8.49	8.86	8.94	9.04	9.27	9.93	9.80	9.83	9.82	9.70	9.53	9.19	9.37
Connecticut	15.00	14.73	14.53	14.76	14.69	14.55	14.59	14.51	14.51	14.73	14.86	14.45	14.66
Delaware	9.77	10.05	9.92	9.84	9.88	10.17	10.10	10.27	10.14	10.36	10.48	10.51	10.12
District of Columbia	12.33	12.27	12.22	12.30	12.26	12.03	11.86	11.76	11.74	12.10	11.63	11.88	12.03
Florida	9.93	9.85	9.53	9.67	9.36	9.61	9.46	9.56	9.68	9.69	10.10	9.69	9.68
Georgia	9.51	9.51	9.40	9.38	9.65	9.58	10.10	9.65	9.61	9.56	9.47	9.33	9.56
Hawaii	34.02	34.45	34.99	35.30	35.85	37.21	35.41	34.31	34.81	34.32	34.15	33.81	34.89
Idaho	6.52	6.50	6.55	6.72	6.78	7.06	7.41	7.42	6.79	6.94	6.84	6.70	6.85
Illinois	8.06	8.24	8.10	8.16	8.26	7.76	7.98	7.99	8.04	7.79	7.88	7.64	7.99
Indiana	9.10	9.30	9.41	9.49	9.21	9.14	8.92	8.96	9.01	8.99	9.05	9.25	9.15
Iowa	7.22	7.37	7.53	7.79	7.83	8.45	8.82	9.25	8.38	7.88	7.51	7.65	7.97
Kansas	8.74	9.04	8.95	9.06	9.23	9.70	9.45	9.50	9.53	9.36	9.01	8.93	9.21
Kentucky	8.34	8.63	8.79	8.70	9.10	8.91	8.54	8.63	9.03	8.47	8.79	8.84	8.73

Geographical Area	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg. 2012
Louisiana	8.08	8.15	7.95	7.73	7.67	7.20	7.52	7.40	7.69	7.91	7.92	8.16	7.78
Maine	12.72	12.51	11.60	11.31	11.33	10.74	11.31	11.13	11.32	11.19	11.57	11.84	11.55
Maryland	10.67	10.71	10.36	10.46	10.25	10.62	10.45	10.44	10.51	10.54	9.79	10.35	10.43
Massachusetts	13.67	13.90	14.05	13.28	13.68	14.27	14.17	13.59	14.12	13.05	13.32	14.90	13.83
Michigan	10.35	10.67	10.70	10.52	11.29	11.10	11.58	11.05	11.08	10.90	10.85	10.87	10.91
Minnesota	8.26	8.42	8.60	8.44	8.59	9.25	9.18	9.44	9.50	8.93	8.66	8.61	8.82
Mississippi	9.55	9.57	9.62	9.22	9.16	9.26	9.29	9.16	9.13	9.20	9.45	9.53	9.35
Missouri	7.25	7.37	7.40	7.43	8.67	9.54	9.46	9.50	8.41	7.55	7.40	7.40	8.12
Montana	8.89	8.95	9.05	9.04	9.17	9.10	9.12	9.15	9.21	9.37	9.31	9.20	9.13
Nebraska	7.80	7.91	8.11	8.01	8.07	8.71	9.12	8.90	9.08	8.52	7.98	8.02	8.35
Nevada	8.65	9.27	8.73	9.06	8.83	8.60	8.75	8.72	8.89	8.90	8.78	8.94	8.84
New Hampshire	13.59	13.53	13.46	13.44	13.40	13.34	13.32	13.09	13.18	13.21	13.40	13.46	13.37
New Jersey	12.85	12.54	12.29	12.19	12.72	13.56	13.65	13.47	13.09	12.13	12.31	11.98	12.73
New Mexico	8.68	8.97	8.83	8.52	8.93	9.79	10.04	10.15	9.69	9.41	8.93	9.39	9.28
New York	14.44	14.25	14.30	14.53	14.61	15.93	16.46	15.31	16.22	15.14	14.25	14.48	14.99
North Carolina	8.35	8.67	8.72	8.40	8.53	8.64	9.06	8.84	8.90	8.78	8.36	8.56	8.65
North Dakota	7.07	7.60	7.77	7.95	7.92	8.70	8.30	8.62	8.61	8.14	8.00	7.78	8.04
Ohio	9.52	9.68	9.49	9.59	9.43	9.28	9.33	9.37	9.54	9.59	9.59	9.33	9.48
Oklahoma	7.18	7.42	7.14	6.93	7.15	7.54	7.47	7.92	7.72	7.31	6.88	6.88	7.30
Oregon	8.20	8.22	8.31	8.42	8.47	8.35	8.28	8.19	8.33	8.40	8.47	8.13	8.31
Pennsylvania	9.54	9.57	9.48	9.49	9.51	9.28	9.34	9.33	9.32	9.34	9.55	9.54	9.44
Rhode Island	12.97	13.15	12.59	11.03	11.68	12.13	11.63	11.20	11.44	11.01	11.23	12.57	11.89
South Carolina	9.28	9.54	9.51	9.33	9.19	9.96	9.87	9.87	9.84	9.30	9.95	9.75	9.62
South Dakota	7.75	7.85	7.89	8.02	8.15	8.21	8.36	8.39	8.51	8.24	7.95	7.76	8.09
Tennessee	10.15	10.02	10.09	10.08	10.22	10.47	10.48	10.21	10.42	10.23	10.45	10.82	10.30
Texas	8.41	8.51	8.27	8.18	8.09	8.15	8.08	8.15	8.14	8.06	7.96	7.97	8.16
Utah	7.37	7.73	7.57	7.82	8.50	8.84	8.29	8.16	8.57	8.28	7.72	7.49	8.03
Vermont	14.22	14.24	14.26	14.73	14.63	14.42	14.58	14.22	14.27	14.62	13.75	13.86	14.32
Virginia	8.16	8.29	8.32	8.18	8.38	8.29	8.03	7.87	7.93	7.85	7.89	7.81	8.08
Washington	7.66	7.73	7.75	7.68	7.56	7.59	7.58	7.58	7.63	7.70	7.87	7.76	7.67
West Virginia	8.23	8.46	8.60	8.51	8.71	8.01	8.49	8.04	8.57	8.70	8.59	8.27	8.43
Wisconsin	10.28	10.36	10.41	10.40	10.53	10.64	10.78	10.80	10.90	10.49	10.46	9.95	10.50
Wyoming	7.79	7.97	8.08	8.28	8.37	8.34	8.23	8.25	8.43	8.59	8.49	8.15	8.25

DOE calculated both residential and commercial annual electricity prices for each RECS 2009 or CBECS 2003 geographical area by averaging monthly electricity prices by State to get State electricity prices in 2012. For areas with more than one State, DOE weighted each state's average price by its number of shipments. Note that all prices in 2012$ were converted to 2013$ using the Consumer Price Index (CPI) to be consistent with the prices used in the rest of the analysis.[b] Table 8E.3.3 shows the shipment-weighted average residential electricity prices in 2012 for each adjusted RECS 2009 geographic area. Table 8E.3.4 shows the shipment-weighted average commercial electricity prices for each CBECS 2003 geographic area.

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[b] www.bls.gov/cpi/

Table 8E.3.3 DOE Average Residential Electricity Prices by Region in 2012

	Geographic Area	2013$/kWh
1	Connecticut, Maine, New Hampshire, Rhode Island, Vermont	$0.17
2	Massachusetts	$0.15
3	New York	$0.18
4	New Jersey	$0.16
5	Pennsylvania	$0.13
6	Illinois	$0.12
7	Indiana, Ohio	$0.11
8	Michigan	$0.14
9	Wisconsin	$0.13
10	Iowa, Minnesota, North Dakota, South Dakota	$0.11
11	Kansas, Nebraska	$0.11
12	Missouri	$0.10
13	Virginia	$0.11
14	Delaware, District of Columbia, Maryland	$0.13
15	Georgia	$0.11
16	North Carolina, South Carolina	$0.11
17	Florida	$0.12
18	Alabama, Kentucky, Mississippi	$0.11
19	Tennessee	$0.10
20	Arkansas, Louisiana, Oklahoma	$0.09
21	Texas	$0.11
22	Colorado	$0.12
23	Idaho, Montana, Utah, Wyoming	$0.10
24	Arizona	$0.11
25	Nevada, New Mexico	$0.12
26	California	$0.15
27	Oregon, Washington	$0.09
28	Alaska	$0.18
29	Hawaii	$0.38
30	West Virginia	$0.10
31	U.S. Average	$0.12

Table 8E.3.4 DOE Average Commercial Electricity Prices by Region in 2012

	Geographic Area	2013$/kWh
1	New England	$0.14
2	Middle Atlantic	$0.12
3	East North Central	$0.10
4	West North Central	$0.09
5	South Atlantic	$0.10
6	East South Central	$0.10
7	West South Central	$0.08
8	Mountain	$0.09
9	Pacific	$0.12
10	U.S. Average	$0.11

8E.3.1.2 Annual Natural Gas Prices

DOE obtained the data for natural gas prices from EIA's Natural Gas Navigator,[5] which includes monthly natural gas prices by state for residential, commercial, and industrial customers. Table 8E.3.5 shows the monthly residential natural gas prices for each state. Table 8E.3.6 shows the monthly commercial natural gas prices for each state.

Table 8E.3.5 2012 Monthly Residential Natural Gas Prices by State from EIA (2012$/tcf)

Geographical Area	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg. 2012
United States	9.67	9.52	10.45	11.01	12.66	14.25	15.2	15.89	14.81	11.78	10.06	9.75	12.09
Alabama	14.27	14.41	15.25	18.67	19.77	21.34	21.77	21.96	21.04	20.05	15.9	15.25	18.31
Alaska	8.26	8.48	8.17	8.47	8.93	9.57	9.7	10.07	8.74	8.21	7.86	8.57	8.75
Arizona	13.3	14.09	14.68	15.94	18.55	20.39	21.99	22.43	21.8	19.34	15.74	14.94	17.77
Arkansas	10.57	10.78	11.84	15.02	13.59	15.26	16.64	17.47	16.27	13.67	10.96	10.71	13.57
California	9.27	8.36	8.69	8.48	9.04	9.7	9.97	10.12	10.07	9.79	9.09	9.33	9.33
Colorado	7.68	7.79	8.65	8.23	10.36	12.9	12.92	12.93	11.44	8.62	7.64	7.06	9.69
Connecticut	12.11	12.16	12.54	14.53	16.24	20.41	20.85	21.47	20.45	17.85	14.74	13.08	16.37
Delaware	13.87	14.03	14.52	16.12	17.76	22.2	23.55	24.59	24.14	20.49	14.52	12.8	18.22
District of Columbia	11.92	11.11	12.64	11.93	17.28	17.62	17.96	14.31	13.35	12.38	11	11.58	13.59
Florida	16.19	15.93	16.65	18.02	19.39	21.14	21.43	22.42	21.81	21.43	17.98	16.29	19.06
Georgia	14	14.66	14.86	16.65	20.53	21.52	22.29	23.82	23.03	21.8	16.39	15.09	18.72
Hawaii	49.97	54.89	57.26	54.93	50.72	51.23	51.92	54.81	56.21	52.76	49.59	49.76	52.84
Idaho	8.43	8.27	8.45	8.37	8.6	9.07	8.8	9.28	9.15	8.01	7.71	7.81	8.50
Illinois	7.09	6.66	8.25	7.62	11.49	12.67	15.31	15.68	13.14	9.12	7.83	7.56	10.20
Indiana	8.06	8.31	11.24	11.18	12.18	12.89	14.84	14.7	12.23	8.04	7.04	7.63	10.70
Iowa	8.26	7.97	10.34	9.04	10.86	13.41	17.34	17.16	14.6	11.78	8.84	8.23	11.49
Kansas	8.16	8.66	8.92	12.31	14.22	16.09	17.69	19.11	18.15	13.67	9.87	9.07	12.99
Kentucky	8.62	9.2	11.41	11.97	15.02	16.95	19.34	18.81	17.68	11.16	8.36	8.44	13.08
Louisiana	10.24	10.91	11.63	12.3	12.24	13.48	14.12	14.92	13.86	13.51	10.84	10.06	12.34
Maine	15.87	16.65	16.44	17.12	16.33	16.62	16.47	17.93	16.55	13.28	13.41	15.81	16.04
Maryland	11.33	11.06	13.63	13.91	16.1	17.83	18.44	18.5	15.81	12.91	10.01	10.74	14.19

Geographical Area	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg. 2012
Massachusetts	13.69	12.59	12.83	12.75	12.54	12.18	14.1	14.84	14.9	12.74	13.77	13.28	13.35
Michigan	10.32	10.35	11.12	10.64	13.95	14.34	15.99	16.16	13.66	10.79	9.99	9.67	12.25
Minnesota	7.53	7.42	8.2	7.41	9.34	10.56	11.47	11.86	9.95	7.85	7.81	7.55	8.91
Mississippi	7.55	9.41	10.28	12.28	12.26	12.21	12.59	13.05	12	11.6	8.52	8.39	10.85
Missouri	9.41	9.6	11.07	17.24	18.56	22.53	24.82	26.15	23.73	16.25	11.86	9.9	16.76
Montana	8.05	7.78	7.82	7.99	8.03	8.48	10.61	10.81	11.02	8.06	7.61	7.56	8.65
Nebraska	7.57	7.37	7.47	10.34	10.64	12.06	12.4	15.01	14.43	11.49	8.61	8.08	10.46
Nevada	9.07	9.43	9.77	10.62	12.08	12.75	13.36	13.8	13.37	12.43	9.44	8.46	11.22
New Hampshire	13.02	13.25	13.56	15.41	13.94	16.03	18.18	19.98	18.85	14.63	12.74	12.19	15.15
New Jersey	10.29	9.82	10.46	11.11	12.01	13.21	13.77	14.34	13.83	12.51	11.61	11.27	12.02
New Mexico	7.41	7.41	7.48	8.65	10.23	11.82	13.71	14.31	14.3	12.59	9.32	8.17	10.45
New York	11.67	11.69	12.99	13.06	15.13	18	17.4	18.78	18.16	15.26	11.35	11.97	14.62
North Carolina	10.95	10.44	13.92	15.21	16.87	18.85	21.56	21.41	20.48	14.26	10.32	10.84	15.43
North Dakota	7.18	6.53	7.28	7.2	8.78	12.45	13.95	14.17	11.99	7.1	6.55	6.69	9.16
Ohio	8.56	8.05	8.53	10.74	13.9	22.17	28.1	29.98	25.43	14.67	9.93	9.27	15.78
Oklahoma	8.33	8.07	9.03	14.4	17.92	19.96	22.84	24.51	23.52	17.7	11.78	9.16	15.60
Oregon	11.47	11.53	10.7	10.56	12.33	12.25	12.53	13.18	14.12	11.79	10.49	10.27	11.77
Pennsylvania	11	11.12	11.34	12.04	13.42	18.09	18.65	19.7	18.56	13.9	11	10.68	14.13
Rhode Island	13.1	13.96	14.16	16.06	18.05	17.88	18.91	19.36	19.58	14.84	12.33	12.01	15.85
South Carolina	11.28	11.18	13.94	17.96	19.81	23.52	25.17	22.38	24.25	15.79	10.63	11.78	17.31
South Dakota	7.84	7.64	9.14	7.78	8.55	10.89	13.37	13.71	12.44	8.82	7.81	7.66	9.64
Tennessee	8.97	8.73	9.48	12.53	13.79	14.54	15.55	17.35	15.22	12.3	9.13	8.87	12.21
Texas	8.56	8.2	9.7	12.05	13.18	14.18	14.51	16.21	15.67	14.54	11.35	10.11	12.36
Utah	7.97	8.5	8.66	9.13	8.87	9.09	9.92	10.24	10.13	9.88	8.76	8.47	9.14
Vermont	15.64	15.45	15.79	16.53	17.4	21.35	23.4	24.02	23.23	19.28	16.62	15.21	18.66
Virginia	11.86	11.14	13.19	13.43	15.77	19.29	19.93	20.13	19.31	12.97	9.94	11.04	14.83
Washington	11.25	11.38	11.45	11.9	12.7	13.53	14.85	15.59	15.63	13.1	11.41	10.56	12.78
West Virginia	10.32	10.29	10.81	11.1	14.33	18	18.38	17.85	14.51	12.02	9.65	9.35	13.05
Wisconsin	8.63	8.73	10.05	9.73	9.58	11.44	13.35	13.6	10.83	8.25	9.03	8.93	10.18
Wyoming	7.87	7.7	7.59	8.06	8.74	10.58	14.37	14.9	14.23	9.7	7.87	7.51	9.93

Note: tcf = thousand cubic feet

Table 8E.3.6 2012 Monthly Commercial Natural Gas Prices by State from EIA (2012$/tcf)

Geographical Area	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg. 2012
United States	8.06	7.77	8.16	8	8.12	8.4	8.49	8.65	8.32	8.03	8.01	8.11	8.18
Alabama	11.95	11.91	12.32	12.99	13.22	13.49	13.55	13.51	13.16	12.85	12.43	12.26	12.80
Alaska	8.29	8.32	8.09	7.99	7.93	7.88	8.08	7.99	7.91	7.87	7.79	8.4	8.05
Arizona	9.43	9.99	9.64	9.33	9.32	9.34	9.37	9.37	9.26	9.02	8.89	8.88	9.32
Arkansas	8.47	8.61	8.88	8.46	7.15	7.24	7.19	7.12	6.86	6.55	7.42	7.85	7.65
California	7.71	6.58	7.31	6.34	5.98	6.76	7.09	7.14	6.77	6.82	7.45	8.05	7.00
Colorado	7.15	7.55	7.32	7.27	8.41	8.68	9.09	8.7	8.43	7.98	7.68	7.09	7.95
Connecticut	7.78	7.49	7.63	8.32	8.86	10.02	10.13	9.02	9.48	9.09	9.07	7.97	8.74
Delaware	12.82	12.86	13.18	13.77	14.4	15.35	15.87	16.01	16.45	15.12	12.58	11.39	14.15
District of	11.57	11	11.46	11.19	11.28	11.63	11.97	11.6	11.02	10.48	10.63	11.18	11.25

Geographical Area	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg. 2012
Columbia													
Florida	10.47	10.99	10.52	10.53	10.67	10.42	10.31	10.34	10.08	10.21	10.22	10.02	10.40
Georgia	9.98	9.63	9.18	8.96	9.91	9.6	9.72	10.32	10.06	10.05	9.84	10	9.77
Hawaii	43.59	49.01	51.72	49.37	45.75	45.12	45.99	49.81	50.58	46.61	43.39	43.77	47.06
Idaho	7.65	7.43	7.49	7.61	7.54	7.54	7.32	7.35	7.4	7.08	7	7	7.37
Illinois	6.92	6.52	7.77	7.63	10.34	10.61	12.04	11.79	10.02	8.29	7.5	7.27	8.89
Indiana	7.54	7.68	10.01	7.9	9.53	8.58	9.28	8.83	7.52	6.45	6.42	7.27	8.08
Iowa	6.97	6.8	8.09	6.16	6.51	7.45	9.02	8.76	7.44	6.2	7.52	7.07	7.33
Kansas	7.62	8.12	8.02	10.02	10.84	11	11.49	11.83	11.94	10.71	8.84	8.44	9.91
Kentucky	7.85	8.33	9.57	8.98	9.51	9.13	9.49	9.6	9.15	7.84	7.3	7.51	8.69
Louisiana	9.95	9.23	9.19	7.72	7.03	7.61	7.79	7.82	7.64	7.88	8.36	8.8	8.25
Maine	12.76	13.39	12.56	12.6	11.28	9.41	10.14	10.44	9.91	9.35	11.4	13.67	11.41
Maryland	9.9	9.59	11.02	10.94	10.71	11.25	11.87	11.23	11.29	10.21	8.4	9.32	10.48
Massachusetts	11.95	10.83	11	10.24	8.75	8.7	8.85	8.91	9.02	9.57	11.24	11.18	10.02
Michigan	8.35	8.27	8.41	8.03	8.67	9.44	10.31	10.6	9.6	8.39	7.93	7.78	8.82
Minnesota	6.63	6.51	6.79	5.62	5.53	6.46	6.36	6.97	5.92	5.76	6.38	6.58	6.29
Mississippi	7.48	8.23	8.54	6.59	6.81	6.57	6.74	6.74	6.65	7.07	7.3	7.8	7.21
Missouri	8.58	8.59	9.05	10.93	10.97	11.82	12.12	12.91	11.7	10.49	9.57	8.75	10.46
Montana	8.13	7.86	7.89	7.98	7.74	8.24	9.25	9.4	9.67	7.73	7.58	7.62	8.26
Nebraska	6.48	6.33	6.14	6.32	5.44	5.1	6.08	6.19	6.2	5.8	5.93	6.52	6.04
Nevada	7.35	7.58	7.62	7.74	8.11	8.21	8.07	7.96	7.87	7.44	6.52	6.26	7.56
New Hampshire	12.15	12.21	12.55	13.67	11.7	11.58	12.66	13.3	12.58	10.89	10.59	10.84	12.06
New Jersey	8.79	8.12	7.92	7	6.7	8.11	8.03	9.07	8.35	8.6	9.78	9.86	8.36
New Mexico	6.19	6	5.88	6.1	6.18	6.11	6.85	6.99	7.32	6.97	6.65	6.56	6.48
New York	8.26	7.76	8.88	7.87	7.56	6.96	6.62	6.5	6.39	7.61	7.72	8.64	7.56
North Carolina	9.01	8.33	8.66	8.34	8.8	8.59	8.99	8.45	8.52	8.3	8.67	8.68	8.61
North Dakota	6.49	5.96	5.97	5.41	5.4	6.17	6.85	6.94	6.7	5.47	5.81	6.15	6.11
Ohio	6.58	6.05	6.14	8.31	10.5	12.94	11.64	14.43	12.79	8.83	7.27	7.74	9.44
Oklahoma	7.39	6.93	7.75	10.84	12.74	14.67	15.03	14.65	14.36	12.86	9.82	7.68	11.23
Oregon	9.38	9.26	8.85	8.54	8.96	8.82	8.65	9.44	9.67	9.22	8.34	8.34	8.96
Pennsylvania	10.16	10.24	10.33	10.12	11.43	12.31	11.81	11.99	11.57	10.13	9.29	9.5	10.74
Rhode Island	12.07	12.07	12.23	13.54	13.87	16.59	16.57	16.56	14.04	12.7	11.15	9.93	13.44
South Carolina	9.09	8.63	8.79	8.24	8.08	9.08	8.41	8.14	7.17	8.21	8.86	9.87	8.55
South Dakota	6.62	6.36	7.2	5.43	5.56	5.97	7.01	7.33	6.73	6.19	6.47	6.46	6.44
Tennessee	8.52	8.12	8.11	8.81	8.82	8.04	8.25	9.14	8.68	8.68	8.05	8.1	8.44
Texas	6.89	6.66	6.19	5.88	6.14	6.36	6.22	6.89	6.87	6.99	6.89	7.1	6.59
Utah	6.63	6.98	7.23	7.3	6.76	6.78	7.06	7.43	7.33	7.33	7.09	7.05	7.08
Vermont	12.34	12.14	12.18	12.14	12.14	12.86	12.85	12.58	12.38	11.75	11.56	11.39	12.19
Virginia	9.4	8.82	9	8.45	8.56	9.79	9.65	9.61	9.04	7.88	7.66	8.63	8.87
Washington	9.56	9.65	9.63	9.9	10.11	10.4	10.78	10.86	11.16	10.23	9.55	8.88	10.06
West Virginia	9.33	9.25	9.5	9.74	10.82	11.43	11.64	11.5	10.74	9.78	8.45	8.28	10.04
Wisconsin	7.54	7.57	8.1	7.64	5.77	6.43	6.87	7.06	6.64	5.99	7.45	7.65	7.06
Wyoming	8.08	6.65	6.49	6.3	5.97	6.43	7.27	7.4	7.16	6.31	6.19	6.23	6.71

Note: tcf = thousand cubic feet

DOE calculated both residential and commercial annual natural gas prices for each RECS 2009 or CBECS 2003 geographical area by averaging monthly natural gas prices by state to get State natural gas prices in 2012. For areas with more than one State, DOE weighted each State's average price by its shipments. All prices in 2012$ were converted to 2013$ using the CPI to be consistent with the prices used in the rest of the analysis. DOE also used a conversion factor (1.023) to convert cubic feet of natural gas to MMBtu.[c] Table 8E.3.7 displays the 2012 shipment-weighted average residential natural gas prices by adjusted RECS 2009 geographic region. Table 8E.3.8 displays the 2012 shipment-weighted average commercial natural gas prices by CBECS 2003 geographic region.

Table 8E.3.7 Calculated Average Residential Natural Gas Prices by Region in 2012

	Geographic Area	2013$/MMBtu
1	Connecticut, Maine, New Hampshire, Rhode Island, Vermont	$15.76
2	Massachusetts	$13.24
3	New York	$14.50
4	New Jersey	$11.92
5	Pennsylvania	$14.01
6	Illinois	$10.12
7	Indiana, Ohio	$13.76
8	Michigan	$12.15
9	Wisconsin	$10.10
10	Iowa, Minnesota, North Dakota, South Dakota	$9.71
11	Kansas, Nebraska	$11.53
12	Missouri	$16.62
13	Virginia	$14.71
14	Delaware, District of Columbia, Maryland	$14.29
15	Georgia	$18.57
16	North Carolina, South Carolina	$15.78
17	Florida	$18.90
18	Alabama, Kentucky, Mississippi	$14.64
19	Tennessee	$12.10
20	Arkansas, Louisiana, Oklahoma	$13.75
21	Texas	$12.25
22	Colorado	$9.61
23	Idaho, Montana, Utah, Wyoming	$8.90
24	Arizona	$17.62
25	Nevada, New Mexico	$10.89
26	California	$9.25
27	Oregon, Washington	$12.07
28	Alaska	$8.68
29	Hawaii	$52.40
30	West Virginia	$12.94
31	U.S. Average	$12.26

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[c] www.eia.gov/tools/faqs/faq.cfm?id=45&t=7

Table 8E.3.8 Calculated Average Commercial Natural Gas Prices by Region in 2012

	Geographic Area	2013$/MMBtu
1	New England	$10.46
2	Middle Atlantic	$8.98
3	East North Central	$8.58
4	West North Central	$8.09
5	South Atlantic	$9.53
6	East South Central	$9.41
7	West South Central	$7.34
8	Mountain	$7.72
9	Pacific	$7.62
10	U.S. Average	$8.11

8E.3.1.3 Annual LPG Prices

DOE collected 2012 average LPG prices from EIA's 2012 State Energy Consumption, Price, and Expenditures Estimates (SEDS).[6] SEDS includes annual LPG prices for residential, commercial, industrial, and transportation consumers by state. Table 8E.3.9 shows the annual residential LPG prices for each state. Table 8E.3.10 shows the annual commercial LPG prices for each state.

Table 8E.3.9 2012 Residential Average LPG Prices by State from EIA (2012$/MMBtu)

Geographical Area	Avg. 2012
United States	28.18
Alabama	29.73
Alaska	38.46
Arizona	35.22
Arkansas	30.25
California	33.84
Colorado	21.93
Connecticut	34.13
Delaware	33.37
District of Columbia	35.37
Florida	42.42
Georgia	28.42
Hawaii	64.01
Idaho	22.59
Illinois	23.02
Indiana	24.78
Iowa	22.97
Kansas	23.03
Kentucky	28.49
Louisiana	29.68
Maine	36
Maryland	38.13
Massachusetts	38.04
Michigan	22.97

Geographical Area	Avg. 2012
Minnesota	23.16
Mississippi	30.74
Missouri	22.58
Montana	21.31
Nebraska	22.86
Nevada	35.45
New Hampshire	34.83
New Jersey	37.58
New Mexico	28.8
New York	35.44
North Carolina	30.28
North Dakota	22.75
Ohio	28.19
Oklahoma	22.64
Oregon	28.85
Pennsylvania	31.96
Rhode Island	43.86
South Carolina	31.84
South Dakota	22.53
Tennessee	29.9
Texas	30.76
Utah	22.58
Vermont	34.44
Virginia	26.67
Washington	29.24
West Virginia	35.78
Wisconsin	20.8
Wyoming	22.16

Table 8E.3.10 2012 Commercial Average LPG Prices by State from EIA (2012$/MMBtu)

Geographical Area	Avg. 2012
United States	21.06
Alabama	22.14
Alaska	20.16
Arizona	21.49
Arkansas	22.57
California	21.62
Colorado	19.09
Connecticut	25.55
Delaware	23.21
District of Columbia	24.6
Florida	17.38
Georgia	17.05
Hawaii	20.96
Idaho	19.67

Geographical Area	Avg. 2012
Illinois	19.47
Indiana	19.6
Iowa	19.42
Kansas	19.47
Kentucky	19.42
Louisiana	22.14
Maine	25.23
Maryland	24.6
Massachusetts	25.53
Michigan	19.42
Minnesota	19.58
Mississippi	22.78
Missouri	19.09
Montana	18.55
Nebraska	19.33
Nevada	21.54
New Hampshire	24.03
New Jersey	24.83
New Mexico	22.38
New York	24.14
North Carolina	17.17
North Dakota	19.24
Ohio	19.33
Oklahoma	19.14
Oregon	20.16
Pennsylvania	24.6
Rhode Island	25.71
South Carolina	17.38
South Dakota	19.05
Tennessee	19.6
Texas	22.62
Utah	19.66
Vermont	25.47
Virginia	17.21
Washington	21.47
West Virginia	17.38
Wisconsin	19.24
Wyoming	19.3

For areas with more than one state, DOE weighted each state's average price by its shipments. All prices in 2012$ were converted to 2013$ using the CPI to be consistent with the prices used in the rest of the analysis. Table 8E.3.11 shows the 2012 shipment-weighted average residential LPG prices for each adjusted RECS 2009 geographic area. Table 8E.3.12 shows the 2012 shipment-weighted average commercial LPG prices for each CBECS 2003 geographic area.

Table 8E.3.11 Average Residential LPG Prices by Region in 2012

	Geographic Area	**2013$/MMBtu**
1	Connecticut, Maine, New Hampshire, Rhode Island, Vermont	$32.64
2	Massachusetts	$34.94
3	New York	$33.08
4	New Jersey	$34.31
5	Pennsylvania	$31.19
6	Illinois	$21.69
7	Indiana, Ohio	$25.33
8	Michigan	$23.30
9	Wisconsin	$21.51
10	Iowa, Minnesota, North Dakota, South Dakota	$22.34
11	Kansas, Nebraska	$21.70
12	Missouri	$22.09
13	Virginia	$24.48
14	Delaware, District of Columbia, Maryland	$34.00
15	Georgia	$26.61
16	North Carolina, South Carolina	$26.67
17	Florida	$27.55
18	Alabama, Kentucky, Mississippi	$23.53
19	Tennessee	$26.99
20	Arkansas, Louisiana, Oklahoma	$22.09
21	Texas	$15.30
22	Colorado	$24.35
23	Idaho, Montana, Utah, Wyoming	$23.83
24	Arizona	$29.91
25	Nevada, New Mexico	$26.17
26	California	$28.49
27	Oregon, Washington	$25.80
28	Alaska	$28.45
29	Hawaii	$38.22
30	West Virginia	$31.69
31	U.S. Average	$18.28

Table 8E.3.12 Average Commercial LPG Prices by Region in 2012

	Geographic Area	2013$/MMBtu
1	New England	$26.13
2	Middle Atlantic	$25.36
3	East North Central	$20.10
4	West North Central	$20.02
5	South Atlantic	$19.40
6	East South Central	$21.38
7	West South Central	$22.99
8	Mountain	$20.90
9	Pacific	$22.14
10	U.S. Average	$21.81

8E.3.2 Monthly Energy Price Factors Determination

For non-weatherized gas furnaces (NWGFs) and mobile home gas furnaces (MHGFs), the Department of Energy (DOE) developed monthly energy price factors and used monthly energy consumption data for the life-cycle cost and payback period calculation. DOE developed monthly energy price factors to capture robust seasonal trends in monthly energy prices. To convert available annual energy prices into monthly energy prices, DOE determined monthly energy price factors.

8E.3.2.1 Monthly Residential Electricity Price Factor Calculations

DOE collected historical electricity prices from 1993 to 2012 from EIA's Form 826.[4] These data are published annually and include monthly electricity sales, revenues from electricity sales, and average price for the residential, commercial, industrial, and transportation sectors by year and by state. DOE aggregated the data into 30 geographical areas as described in section 8E.2.

For each geographic region, DOE determined average electricity prices from 1993 to 2012 by weighting the average residential electricity prices for each state by the number of shipments projected in 2021 in each state.

As an example, to illustrate the methodology for producing monthly price factors, the following tables and charts show the calculation of monthly average electricity price factors, based on New York historic electricity price data. Table 8E.3.13 shows the average residential electricity prices for New York.

Table 8E.3.13 1990-2011 Average Residential Electricity Prices for New York from EIA (nominal cents/kWh)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
1990	10.71	11.12	11.19	11.02	11.31	11.64	11.80	11.89	11.98	11.71	11.62	11.48	11.46
1991	11.48	11.44	11.63	11.58	11.82	12.41	12.38	12.63	12.57	12.02	11.84	11.77	11.96
1992	11.43	11.42	11.49	11.60	12.21	13.09	13.31	13.46	13.46	12.95	12.71	12.55	12.47
1993	12.17	12.14	12.35	12.71	13.35	13.93	13.94	13.92	13.90	13.28	13.35	13.10	13.18
1994	12.92	12.74	13.01	13.19	13.61	14.11	14.19	14.30	14.37	13.43	13.50	13.15	13.54
1995	13.16	13.11	13.34	13.54	14.06	14.63	14.69	14.58	14.51	13.76	13.81	13.50	13.89
1996	13.39	13.46	13.71	13.80	14.00	14.54	14.67	14.78	14.59	13.97	13.83	13.75	14.04
1997	13.75	13.67	13.83	13.69	13.84	14.70	14.80	14.68	14.56	14.01	13.93	13.84	14.11
1998	13.87	13.73	13.77	13.84	14.05	13.78	13.78	13.65	13.66	13.29	13.04	12.92	13.62
1999	12.85	12.75	12.95	13.34	12.85	13.44	13.44	13.54	13.74	13.64	13.44	13.24	13.27
2000	12.90	13.18	13.33	13.52	13.54	14.22	15.40	14.77	14.52	14.12	13.94	13.98	13.95
2001	13.89	13.93	13.58	13.44	14.01	14.41	14.99	14.61	14.23	14.22	13.53	13.25	14.01
2002	12.95	13.00	12.81	12.69	13.30	14.01	14.19	14.16	14.42	13.87	13.37	13.19	13.50
2003	12.77	13.30	13.91	14.55	14.77	14.98	15.14	14.94	14.92	14.75	14.23	13.63	14.32
2004	13.32	14.02	13.98	14.03	14.20	14.99	15.36	15.32	15.10	14.93	14.88	14.29	14.53
2005	14.05	14.53	14.40	14.64	15.36	15.58	15.63	16.16	16.69	17.36	17.57	16.53	15.71
2006	16.61	16.66	15.89	16.36	16.56	17.33	17.56	17.74	17.92	17.22	16.33	15.88	16.84
2007	16.09	15.89	16.83	17.14	17.50	18.17	17.27	17.96	17.15	17.48	16.94	16.66	17.09
2008	16.86	17.31	16.92	18.08	18.79	19.42	19.66	20.93	19.49	17.57	16.95	16.61	18.22
2009	16.83	16.72	16.40	16.57	16.86	18.22	18.79	18.21	18.75	18.12	16.72	17.47	17.47
2010	17.29	18.04	17.55	18.92	19.21	19.41	20.11	19.35	20.09	18.36	18.25	17.72	18.69
2011	17.25	17.45	17.58	17.63	18.30	19.07	19.22	19.25	18.84	18.78	17.93	17.26	18.21

DOE then calculated monthly energy price factors by dividing the monthly prices by the annual average for each year. Table 8E.3.14 and Figure 8E.3.1 show the calculated results for New York.

Table 8E.3.14 Monthly Electricity Price Factors for 1990-2011 for New York

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1990	0.94	0.97	0.98	0.96	0.99	1.02	1.03	1.04	1.05	1.02	1.01	1.00
1991	0.96	0.96	0.97	0.97	0.99	1.04	1.03	1.06	1.05	1.00	0.99	0.98
1992	0.92	0.92	0.92	0.93	0.98	1.05	1.07	1.08	1.08	1.04	1.02	1.01
1993	0.92	0.92	0.94	0.96	1.01	1.06	1.06	1.06	1.05	1.01	1.01	0.99
1994	0.95	0.94	0.96	0.97	1.00	1.04	1.05	1.06	1.06	0.99	1.00	0.97
1995	0.95	0.94	0.96	0.97	1.01	1.05	1.06	1.05	1.04	0.99	0.99	0.97
1996	0.95	0.96	0.98	0.98	1.00	1.04	1.04	1.05	1.04	0.99	0.98	0.98
1997	0.97	0.97	0.98	0.97	0.98	1.04	1.05	1.04	1.03	0.99	0.99	0.98
1998	1.02	1.01	1.01	1.02	1.03	1.01	1.01	1.00	1.00	0.98	0.96	0.95
1999	0.97	0.96	0.98	1.01	0.97	1.01	1.01	1.02	1.04	1.03	1.01	1.00
2000	0.92	0.94	0.96	0.97	0.97	1.02	1.10	1.06	1.04	1.01	1.00	1.00
2001	0.99	0.99	0.97	0.96	1.00	1.03	1.07	1.04	1.02	1.02	0.97	0.95
2002	0.96	0.96	0.95	0.94	0.99	1.04	1.05	1.05	1.07	1.03	0.99	0.98
2003	0.89	0.93	0.97	1.02	1.03	1.05	1.06	1.04	1.04	1.03	0.99	0.95
2004	0.92	0.96	0.96	0.97	0.98	1.03	1.06	1.05	1.04	1.03	1.02	0.98
2005	0.89	0.93	0.92	0.93	0.98	0.99	0.99	1.03	1.06	1.11	1.12	1.05
2006	0.99	0.99	0.94	0.97	0.98	1.03	1.04	1.05	1.06	1.02	0.97	0.94
2007	0.94	0.93	0.98	1.00	1.02	1.06	1.01	1.05	1.00	1.02	0.99	0.97
2008	0.93	0.95	0.93	0.99	1.03	1.07	1.08	1.15	1.07	0.96	0.93	0.91
2009	0.96	0.96	0.94	0.95	0.97	1.04	1.08	1.04	1.07	1.04	0.96	1.00
2010	0.93	0.97	0.94	1.01	1.03	1.04	1.08	1.04	1.07	0.98	0.98	0.95
2011	0.95	0.96	0.97	0.97	1.00	1.05	1.06	1.06	1.03	1.03	0.98	0.95

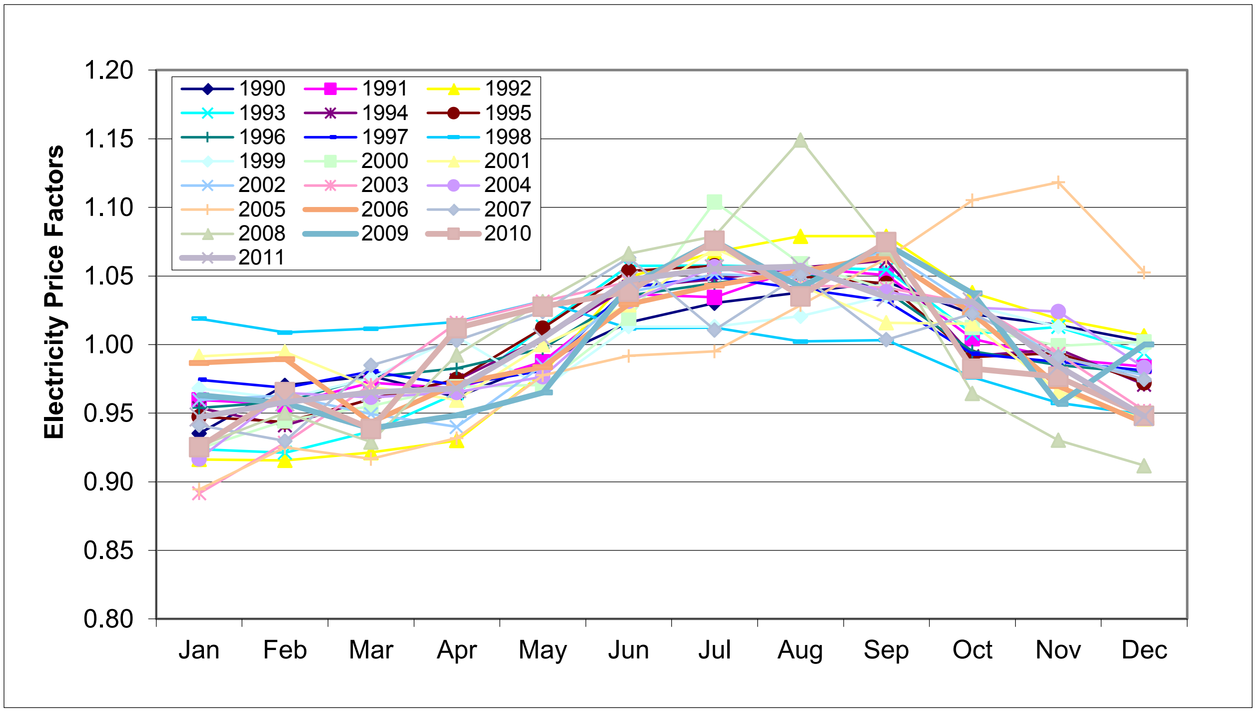

Figure 8E.3.1 Monthly Electricity Price Factors for 1990-2011 for New York

DOE then averaged the monthly energy price factors for 1993 to 2012 to develop an average energy price factor for each month. DOE performed the same calculations for each geographic region to develop the shipment-weighted average monthly energy price factors shown in Table 8E.3.15, which includes the results for New York.

Table 8E.3.15 Monthly Residential Electricity Price Factors

Geographical Area	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Connecticut, Maine, New Hampshire, Rhode Island, Vermont	0.97	0.98	0.99	1.00	1.01	1.01	1.01	1.01	1.01	1.02	1.00	1.00
Massachusetts	0.98	0.99	0.99	0.99	1.00	1.03	1.00	1.00	1.02	1.01	0.99	1.01
New York	0.95	0.96	0.96	0.98	1.00	1.04	1.05	1.05	1.05	1.02	0.99	0.97
New Jersey	0.95	0.95	0.96	0.96	0.98	1.06	1.08	1.08	1.06	0.97	0.97	0.97
Pennsylvania	0.93	0.94	0.95	0.98	1.02	1.06	1.07	1.06	1.04	1.02	0.98	0.95
Illinois	0.89	0.93	0.96	1.01	1.05	1.07	1.06	1.04	1.05	1.06	0.97	0.91
Indiana, Ohio	0.90	0.92	0.95	1.02	1.05	1.06	1.03	1.03	1.05	1.05	1.01	0.94
Michigan	0.97	0.97	0.97	0.98	0.99	1.03	1.05	1.05	1.02	0.99	0.98	0.99
Wisconsin	0.96	0.99	0.98	1.00	1.02	1.03	1.00	1.01	1.01	1.02	1.00	0.98
Iowa, Minnesota, North Dakota, South Dakota	0.91	0.93	0.95	0.98	1.03	1.07	1.08	1.07	1.04	1.01	0.97	0.95
Kansas, Nebraska	0.86	0.90	0.93	0.97	1.01	1.11	1.12	1.12	1.11	1.00	0.96	0.91
Missouri	0.84	0.86	0.90	0.96	1.08	1.18	1.17	1.16	1.06	0.98	0.94	0.87
Virginia	0.91	0.93	0.95	0.99	1.04	1.06	1.07	1.07	1.04	1.02	0.98	0.93
Delaware, District of Columbia, Maryland	0.90	0.90	0.92	0.94	1.04	1.12	1.11	1.11	1.08	0.99	0.95	0.93
Georgia	0.90	0.93	0.96	0.97	1.01	1.09	1.10	1.11	1.06	1.00	0.95	0.91
North Carolina, South Carolina	0.94	0.96	0.98	1.01	1.01	1.00	1.02	1.02	1.03	1.05	1.01	0.97
Florida	0.98	0.99	1.00	1.01	1.00	0.99	1.00	1.00	1.00	1.01	1.02	1.00
Alabama, Kentucky, Mississippi	0.92	0.94	0.97	1.02	1.03	1.03	1.02	1.03	1.02	1.03	1.01	0.96
Tennessee	0.96	0.96	0.98	1.01	1.02	1.01	0.99	0.99	1.00	1.04	1.03	1.01
Arkansas, Louisiana, Oklahoma	0.90	0.93	0.96	1.00	1.02	1.06	1.05	1.05	1.07	1.04	0.99	0.94
Texas	0.92	0.93	0.97	0.99	1.02	1.05	1.05	1.05	1.04	1.04	0.98	0.96
Colorado	0.95	0.96	0.97	0.99	1.02	1.03	1.02	1.02	1.03	1.02	1.00	0.97
Idaho, Montana, Utah, Wyoming	0.96	0.97	0.97	0.98	1.01	1.04	1.04	1.04	1.02	1.01	0.98	0.98
Arizona	0.88	0.91	0.93	0.98	1.09	1.08	1.07	1.06	1.06	1.06	0.94	0.95
Nevada, New Mexico	0.97	0.99	1.00	1.02	1.01	0.99	0.98	0.99	1.00	1.03	1.03	1.00
California	1.00	0.97	0.97	0.97	1.00	1.02	1.05	1.05	1.01	0.96	1.00	1.01
Oregon, Washington	0.97	0.99	0.98	0.98	0.99	1.00	1.01	1.01	1.02	1.02	1.02	1.01
Alaska	0.95	0.96	0.98	0.99	1.02	1.02	1.04	1.03	1.01	1.01	1.00	0.99
Hawaii	0.96	0.97	0.96	0.97	0.99	1.00	1.01	1.02	1.02	1.03	1.03	1.02
West Virginia	0.94	0.95	0.98	1.01	1.04	1.02	1.00	1.00	1.02	1.05	1.02	0.97
United States	0.93	0.94	0.96	0.99	1.02	1.04	1.04	1.05	1.04	1.02	0.99	0.96

8E.3.2.2 Monthly Commercial Electricity Price Factor Calculations

DOE collected historical electricity prices from 1993 to 2012 from EIA's Form 826.[4] These data are published annually and include annual electricity sales, revenues from electricity sales, and average price for the residential, commercial, industrial, and transportation sectors by State. DOE aggregated the data into the nine Census divisions as described in section 8E.2.

For each geographic area, DOE determined average natural gas prices from 1993 to 2012 by weighting the average commercial natural gas prices for each state by the number of shipments projected in 2021 in each state. The shipment-weighted average monthly commercial electricity price factors are shown in Table 8E.3.16.

Table 8E.3.16 Monthly Commercial Electricity Price Factors

Geographical Area	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
New England	0.97	0.98	0.97	0.98	0.98	1.04	1.04	1.03	1.05	1.00	0.97	0.99
Middle Atlantic	0.95	0.96	0.96	0.96	0.99	1.05	1.07	1.06	1.05	1.01	0.97	0.96
East North Central	0.95	0.98	0.99	1.00	1.01	1.02	1.02	1.02	1.02	1.03	0.99	0.97
West North Central	0.91	0.93	0.94	0.95	1.02	1.11	1.12	1.12	1.05	0.96	0.94	0.93
South Atlantic	0.96	0.98	0.98	0.98	1.00	1.03	1.03	1.04	1.03	1.01	0.99	0.98
East South Central	0.97	0.99	0.99	1.00	1.00	1.01	1.00	1.01	1.00	1.01	1.01	1.01
West South Central	0.97	0.99	1.00	0.99	1.00	1.03	1.02	1.02	1.01	1.01	0.99	0.98
Mountain	0.96	0.98	0.98	0.99	1.02	1.04	1.01	1.01	1.02	1.03	1.00	0.97
Pacific	0.91	0.94	0.93	0.93	0.97	1.06	1.11	1.10	1.08	1.05	0.99	0.94
United States	0.95	0.97	0.97	0.97	0.99	1.04	1.05	1.05	1.04	1.02	0.98	0.97

8E.3.2.3 Monthly Residential Natural Gas Price Factor Calculations

DOE collected historical natural gas prices from 1993 to 2012 from the Energy Information Administration's (EIA's) Natural Gas Navigator.[5] The Natural Gas Navigator includes annual and monthly natural gas prices for residential, commercial, and industrial consumers by State. DOE aggregated the data into 30 geographical areas for residential buildings and nine census division for commercial buildings as described in section 8E.2.

For each geographic area, DOE determined average natural gas prices from 1993 to 2012 by weighting the average residential natural gas prices for each state by the number of shipments projected in 2019 in each state.

Again, as an example for how DOE determined monthly natural gas price factors, the methodology used to determine monthly average price factors can be seen below. Table 8E.3.17 shows the historic average residential gas prices for New York.

Table 8E.3.17 1989-2010 Average Residential Natural Gas Prices for New York ($/tcf)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
1990	6.60	6.66	7.46	6.87	7.11	8.31	9.01	9.36	9.18	7.98	7.58	6.77	7.74
1991	6.77	7.18	6.91	7.08	7.64	8.13	9.02	9.61	9.01	8.38	7.41	7.35	7.87
1992	6.96	6.97	6.82	6.91	7.53	8.91	9.53	9.79	8.90	8.03	7.44	7.14	7.91
1993	7.10	6.83	6.89	6.79	7.40	8.70	9.70	10.28	9.92	8.62	8.68	7.74	8.22
1994	7.57	7.20	7.14	7.71	9.17	9.83	10.95	11.43	10.88	9.33	8.38	8.43	9.00
1995	7.69	7.99	8.33	8.87	9.20	10.64	11.64	12.00	11.42	9.70	9.36	8.64	9.62
1996	8.10	7.66	7.66	7.88	8.70	10.20	11.64	12.00	11.81	11.09	8.70	7.77	9.43
1997	8.01	8.22	8.12	8.39	8.80	10.03	11.08	0.00	0.00	0.00	0.00	0.00	5.22
1998	9.88	9.55	8.86	8.51	9.01	10.83	12.70	11.62	12.59	11.38	9.93	9.34	10.35
1999	9.17	9.09	8.90	9.56	10.73	11.99	7.08	13.24	12.66	11.62	9.50	9.30	10.24
2000	8.21	8.49	8.05	8.74	10.10	11.79	12.65	12.01	11.93	10.29	9.66	9.01	10.08
2001	7.97	8.49	9.55	9.82	11.66	13.30	14.81	14.68	15.05	12.15	10.16	9.02	11.39
2002	12.47	11.24	10.53	11.43	13.50	13.84	14.25	14.41	13.14	11.57	11.16	10.89	12.37
2003	9.35	8.65	9.17	9.34	9.96	11.66	13.04	13.18	13.21	11.84	10.08	9.48	10.75
2004	9.63	9.88	11.69	12.22	12.93	14.71	16.01	16.17	15.58	13.01	12.02	11.36	12.93
2005	11.41	11.33	11.48	11.51	13.07	15.34	16.29	16.89	16.22	14.41	13.44	13.19	13.72
2006	12.80	12.65	12.42	13.45	14.49	16.16	17.62	18.48	20.78	22.24	20.21	17.44	16.56
2007	16.61	15.11	13.99	14.58	16.09	16.69	18.04	18.91	18.43	13.37	14.75	14.97	15.96
2008	15.24	14.43	15.08	15.47	17.33	19.59	19.95	18.94	18.53	18.64	16.04	14.83	17.01
2009	14.99	14.91	15.21	16.76	19.95	22.88	24.96	24.20	21.66	18.42	16.48	16.26	18.89
2010	15.46	14.84	14.63	14.19	15.13	16.82	18.24	17.81	17.74	14.71	14.97	14.02	15.71
2011	12.97	13.01	13.60	15.08	15.82	18.42	20.00	20.17	18.54	16.47	13.88	12.09	15.84

DOE then calculated monthly energy price factors for each year by dividing the residential natural gas prices for each month by the natural gas annual average price for each year. Table 8E.3.18 and Figure 8E.3.2 show the calculated results for New York.

Table 8E.3.18 1989-2011 Monthly Natural Gas Price Factors for New York

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1990	0.85	0.86	0.96	0.89	0.92	1.07	1.16	1.21	1.19	1.03	0.98	0.87
1991	0.86	0.91	0.88	0.90	0.97	1.03	1.15	1.22	1.14	1.06	0.94	0.93
1992	0.88	0.88	0.86	0.87	0.95	1.13	1.20	1.24	1.13	1.02	0.94	0.90
1993	0.86	0.83	0.84	0.83	0.90	1.06	1.18	1.25	1.21	1.05	1.06	0.94
1994	0.84	0.80	0.79	0.86	1.02	1.09	1.22	1.27	1.21	1.04	0.93	0.94
1995	0.80	0.83	0.87	0.92	0.96	1.11	1.21	1.25	1.19	1.01	0.97	0.90
1996	0.86	0.81	0.81	0.84	0.92	1.08	1.23	1.27	1.25	1.18	0.92	0.82
1997	0.95	0.92	0.86	0.82	0.87	1.05	1.23	1.12	1.22	1.10	0.96	0.90
1998	0.90	0.89	0.87	0.93	1.05	1.17	0.69	1.29	1.24	1.14	0.93	0.91
1999	0.81	0.84	0.80	0.87	1.00	1.17	1.26	1.19	1.18	1.02	0.96	0.89
2000	0.70	0.75	0.84	0.86	1.02	1.17	1.30	1.29	1.32	1.07	0.89	0.79
2001	1.01	0.91	0.85	0.92	1.09	1.12	1.15	1.16	1.06	0.94	0.90	0.88
2002	0.87	0.80	0.85	0.87	0.93	1.08	1.21	1.23	1.23	1.10	0.94	0.88
2003	0.74	0.76	0.90	0.94	1.00	1.14	1.24	1.25	1.20	1.01	0.93	0.88
2004	0.83	0.83	0.84	0.84	0.95	1.12	1.19	1.23	1.18	1.05	0.98	0.96
2005	0.77	0.76	0.75	0.81	0.87	0.98	1.06	1.12	1.25	1.34	1.22	1.05
2006	1.04	0.95	0.88	0.91	1.01	1.05	1.13	1.18	1.15	0.84	0.92	0.94
2007	0.90	0.85	0.89	0.91	1.02	1.15	1.17	1.11	1.09	1.10	0.94	0.87
2008	0.79	0.79	0.81	0.89	1.06	1.21	1.32	1.28	1.15	0.98	0.87	0.86
2009	0.98	0.94	0.93	0.90	0.96	1.07	1.16	1.13	1.13	0.94	0.95	0.89
2010	0.82	0.82	0.86	0.95	1.00	1.16	1.26	1.27	1.17	1.04	0.88	0.76
2011	0.77	0.78	0.81	0.86	1.01	1.26	1.26	1.26	1.26	1.05	0.89	0.80

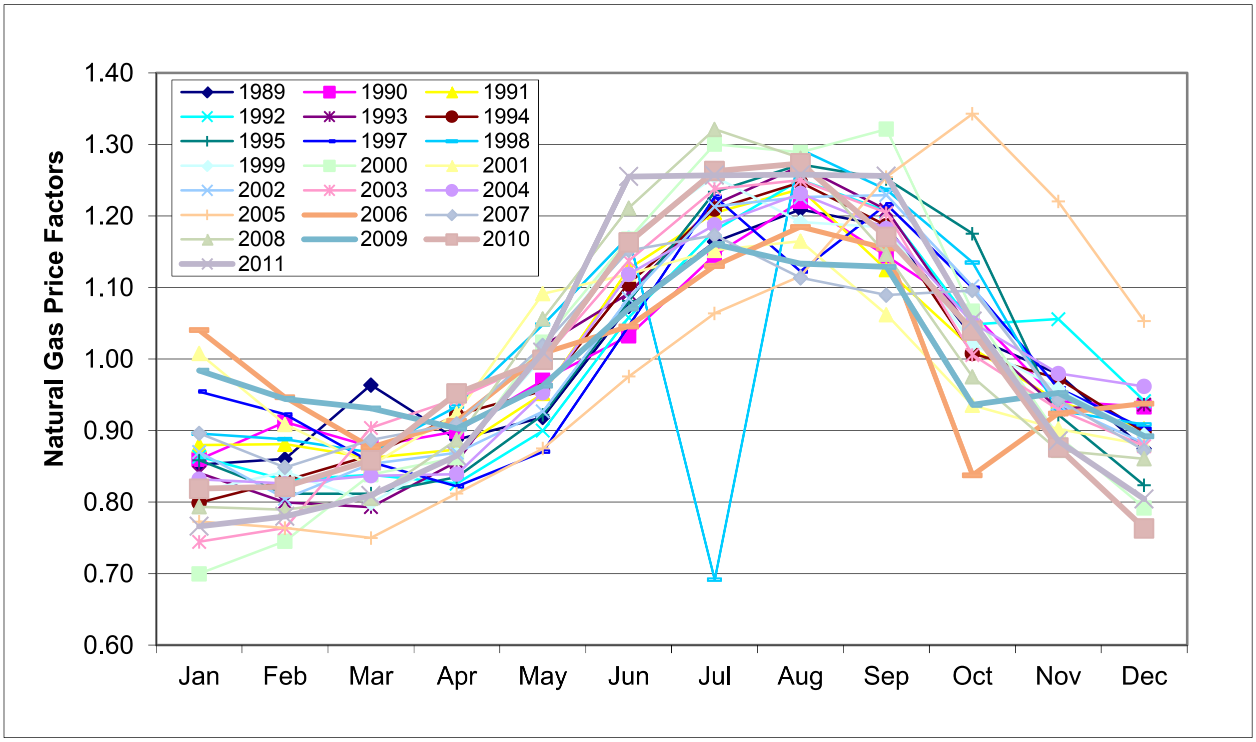

Figure 8E.3.2 1989-2011 Monthly Natural Gas Price Factors for New York

DOE then averaged the monthly energy price factors for 1993 to 2012 to develop an average energy price factor for each month. DOE performed the same calculations for each geographic area to develop the shipment-weighted average monthly energy price factors shown in Table 8E.3.19, which also includes the monthly energy price factor results calculated for New York.

Table 8E.3.19 Monthly Residential Natural Gas Energy Price Factors

Geographical Area	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Connecticut, Maine, New Hampshire, Rhode Island, Vermont	0.90	0.90	0.91	0.91	0.95	1.04	1.15	1.17	1.14	1.01	0.97	0.94
Massachusetts	0.98	0.98	0.97	0.99	0.93	0.96	1.05	1.11	1.07	0.93	1.00	1.00
New York	0.88	0.87	0.88	0.92	1.02	1.16	1.23	1.16	1.13	1.00	0.89	0.84
New Jersey	0.91	0.90	0.90	0.93	0.98	1.08	1.12	1.12	1.10	1.01	0.96	0.94
Pennsylvania	0.82	0.82	0.84	0.88	0.99	1.14	1.26	1.29	1.23	1.00	0.89	0.84
Illinois	0.80	0.81	0.81	0.86	1.04	1.20	1.29	1.31	1.21	0.96	0.85	0.80
Indiana, Ohio	0.82	0.82	0.85	0.92	1.02	1.18	1.28	1.29	1.20	0.96	0.85	0.83
Michigan	0.83	0.83	0.84	0.89	0.99	1.13	1.25	1.29	1.19	0.99	0.90	0.87
Wisconsin	0.95	0.93	0.94	0.96	0.96	1.10	1.14	1.15	1.06	0.88	0.97	0.95
Iowa, Minnesota, North Dakota, South Dakota	0.85	0.84	0.85	0.87	0.99	1.16	1.25	1.29	1.20	0.95	0.89	0.85
Kansas, Nebraska	0.80	0.80	0.80	0.87	0.98	1.15	1.24	1.30	1.26	1.08	0.88	0.83
Missouri	0.73	0.73	0.74	0.83	0.96	1.17	1.34	1.42	1.32	1.12	0.88	0.78
Virginia	0.82	0.79	0.78	0.87	1.03	1.20	1.29	1.27	1.26	1.02	0.84	0.82
Delaware, District of Columbia, Maryland	0.82	0.81	0.83	0.91	1.04	1.18	1.26	1.25	1.21	0.99	0.87	0.83
Georgia	0.72	0.77	0.80	0.89	1.10	1.23	1.29	1.28	1.24	1.07	0.82	0.77
North Carolina, South Carolina	0.79	0.78	0.81	0.87	1.00	1.18	1.26	1.30	1.25	1.04	0.86	0.84
Florida	0.81	0.83	0.88	0.94	1.02	1.09	1.12	1.14	1.13	1.11	1.02	0.90
Alabama, Kentucky, Mississippi	0.80	0.80	0.83	0.91	1.04	1.16	1.19	1.22	1.19	1.08	0.92	0.85
Tennessee	0.82	0.83	0.83	0.90	0.99	1.13	1.20	1.24	1.19	1.08	0.91	0.86
Arkansas, Louisiana, Oklahoma	0.77	0.77	0.79	0.87	1.04	1.15	1.22	1.26	1.22	1.12	0.94	0.81
Texas	0.77	0.78	0.80	0.92	1.05	1.17	1.21	1.24	1.23	1.11	0.91	0.80
Colorado	0.81	0.82	0.85	0.88	0.97	1.23	1.24	1.31	1.22	0.97	0.88	0.83
Idaho, Montana, Utah, Wyoming	0.94	0.94	0.96	0.92	0.96	1.03	1.11	1.15	1.09	0.97	0.98	0.96
Arizona	0.77	0.79	0.82	0.90	1.01	1.11	1.21	1.26	1.22	1.14	0.96	0.83
Nevada, New Mexico	0.81	0.83	0.85	0.92	1.03	1.17	1.17	1.22	1.18	1.06	0.91	0.82
California	1.00	0.99	0.95	0.95	0.99	1.04	1.05	1.03	1.01	1.01	0.98	0.98
Oregon, Washington	0.90	0.91	0.91	0.93	0.96	1.02	1.13	1.17	1.14	1.03	0.95	0.93
Alaska	0.94	0.94	0.95	0.96	1.01	1.05	1.13	1.10	1.02	0.97	0.94	0.97
Hawaii	0.95	0.97	0.97	0.97	0.99	1.00	1.02	1.05	1.05	1.04	1.02	1.00
West Virginia	0.83	0.84	0.84	0.87	0.97	1.17	1.30	1.29	1.18	0.96	0.88	0.86
United States	0.85	0.86	0.87	0.91	1.00	1.12	1.19	1.22	1.16	1.00	0.91	0.87

8E.3.2.4 Monthly Commercial Natural Gas Price Factor Calculations

DOE collected historical natural gas prices from 1993 to 2012 from the Energy Information Administration's (EIA's) Natural Gas Navigator.[5] The Natural Gas Navigator includes annual and monthly natural gas prices for residential, commercial, and industrial consumers by State. DOE aggregated the 30 geographical areas for residential buildings and nine census divisions for commercial buildings as described in section 8E.2.

For each geographic area, DOE determined average natural gas prices from 1993 to 2012 by weighting the average commercial natural gas prices for each state by the number of shipments projected in 2021 in each state (Table 8E.3.20).

Table 8E.3.20 Monthly Commercial Natural Gas Energy Price Factors

Geographical Area	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
New England	1.05	1.06	1.06	1.04	0.95	0.93	0.96	0.95	0.94	0.92	1.03	1.08
Middle Atlantic	1.04	1.03	1.01	1.00	1.00	1.00	0.98	0.95	0.95	0.96	1.00	1.03
East North Central	0.94	0.93	0.94	0.96	1.01	1.08	1.11	1.11	1.05	0.96	0.95	0.94
West North Central	0.97	0.96	0.96	0.96	0.99	1.03	1.05	1.06	1.03	0.97	0.98	0.98
South Atlantic	0.96	0.97	0.96	0.97	0.99	1.03	1.05	1.03	1.02	1.01	0.98	0.97
East South Central	0.97	0.97	0.96	0.98	0.99	1.01	1.02	1.03	1.01	1.02	1.01	1.00
West South Central	0.99	0.98	0.94	0.96	1.00	1.00	1.01	0.99	1.00	1.02	1.04	1.00
Mountain	0.97	0.97	0.98	0.96	0.98	1.00	1.03	1.05	1.03	1.00	1.00	0.99
Pacific	1.07	1.04	1.02	0.99	0.95	0.98	0.97	0.98	0.96	0.96	0.98	1.04
United States	1.00	1.00	0.99	0.99	1.00	1.01	1.01	1.00	0.99	0.98	1.00	1.00

8E.3.2.5 Monthly Residential Liquid Petroleum Gas Price Factor Calculations

DOE collected historical liquid petroleum gas (LPG) prices from 1995 to 2009 from EIA's Short-Term Energy Outlook.[7] The Short-Term Energy Outlook includes monthly LPG prices by Census Region (Northeast, South, Midwest, and West).[d]

The same process as used for electricity and natural gas price factors was used for calculating the monthly LPG price factors. These monthly price factors were calculated below, using data from the Northeast region. Table 8E.3.21 shows the Northeast residential LPG prices from 1995 to 2009.

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[d] Refer to https://www.census.gov/geo/maps-data/maps/pdfs/reference/us_regdiv.pdf.

Table 8E.3.21 Average LPG Prices for the Northeast (nominal cents/gallon)

	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
1995	119	118	120	121	124	126	126	125	122	121	118	117
1996	123	125	128	125	130	131	129	127	127	133	135	145
1997	143	137	131	131	130	130	130	127	126	127	123	122
1998	121	120	120	123	124	124	122	121	119	118	115	114
1999	112	113	114	118	122	124	126	129	127	129	128	128
2000	132	148	148	145	148	151	155	154	157	159	156	160
2001	176	170	162	160	162	160	156	152	150	150	144	139
2002	139	138	139	143	142	144	143	141	141	142	142	142
2003	150	166	182	164	161	161	159	156	155	155	155	158
2004	169	173	171	168	170	173	173	176	181	187	193	187
2005	186	186	190	197	199	200	202	205	217	224	220	217
2006	221	220	220	225	231	237	242	244	240	232	229	228
2007	227	229	235	239	247	252	253	252	254	260	274	275
2008	282	280	284	292	306	320	333	329	324	305	280	267
2009	268	267	267	263	258	255	255	251	249	250	252	255

DOE then calculated monthly energy price factors for each year by dividing the prices for each month by the average price for each year. Table 8E.3.22 and Figure 8E.3.3 show the calculated results for the Northeast.

Table 8E.3.22 Monthly LPG Price Factors for 1995-2009 for the Northeast

	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
1995	0.98	0.97	0.99	1.00	1.02	1.03	1.04	1.03	1.00	1.00	0.97	0.96
1996	0.94	0.97	0.99	0.96	1.00	1.01	0.99	0.98	0.98	1.02	1.04	1.12
1997	1.10	1.06	1.01	1.01	1.01	1.00	1.00	0.98	0.97	0.98	0.95	0.94
1998	1.01	1.00	1.00	1.02	1.03	1.03	1.02	1.01	0.99	0.98	0.96	0.95
1999	0.92	0.92	0.93	0.96	1.00	1.02	1.03	1.05	1.04	1.06	1.05	1.04
2000	0.87	0.98	0.98	0.96	0.98	1.00	1.03	1.02	1.04	1.05	1.03	1.06
2001	1.12	1.08	1.03	1.02	1.04	1.02	0.99	0.97	0.96	0.96	0.92	0.89
2002	0.98	0.97	0.98	1.01	1.01	1.02	1.01	1.00	1.00	1.01	1.00	1.00
2003	0.94	1.04	1.13	1.03	1.01	1.00	1.00	0.97	0.97	0.97	0.97	0.99
2004	0.95	0.98	0.96	0.95	0.96	0.98	0.98	1.00	1.02	1.06	1.09	1.06
2005	0.91	0.91	0.93	0.97	0.98	0.98	0.99	1.01	1.07	1.10	1.08	1.07
2006	0.96	0.95	0.95	0.98	1.00	1.03	1.05	1.06	1.04	1.01	0.99	0.99
2007	0.91	0.92	0.94	0.96	0.99	1.01	1.01	1.01	1.02	1.04	1.10	1.10
2008	0.94	0.93	0.95	0.97	1.02	1.06	1.11	1.10	1.08	1.02	0.93	0.89
2009	1.04	1.04	1.04	1.02	1.00	0.99	0.99	0.97	0.97	0.97	0.98	0.99
Avg	0.97	0.98	0.99	0.99	1.00	1.01	1.02	1.01	1.01	1.01	1.00	1.00

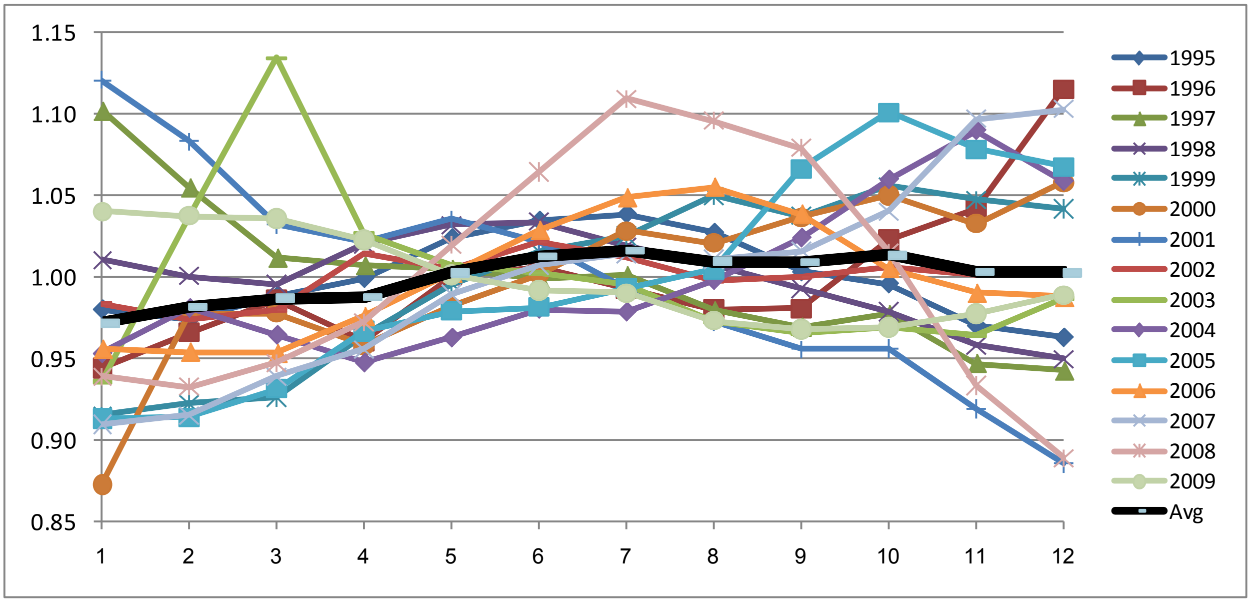

Figure 8E.3.3 Monthly LPG Factors for 1995-2009 for the Northeast

DOE then averaged the monthly energy price factors for 1995 to 2009 to develop an average energy price factor for each month. DOE performed the same calculations for each Census region to develop the shipment-weighted average monthly energy price factors shown in Table 8E.3.23, which includes the calculated Northeast region monthly LPG energy price factors from 1995 to 2009.

Table 8E.3.23 Monthly Residential LPG Energy Price Factors

Census Regions	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Northeast	0.97	0.98	0.99	0.99	1.00	1.01	1.02	1.01	1.01	1.01	1.00	1.00
South	1.04	1.04	1.03	1.01	1.00	0.97	0.94	0.93	0.96	0.98	1.03	1.07
Midwest	1.04	1.04	1.03	1.01	0.99	0.97	0.95	0.93	0.96	1.00	1.03	1.06
West	1.05	1.05	1.03	1.01	0.99	0.96	0.92	0.91	0.95	1.01	1.04	1.08
U.S.	1.02	1.03	1.02	1.02	1.02	1.00	0.95	0.93	0.96	0.99	1.02	1.05

8E.3.2.6 Monthly Commercial Liquid Petroleum Gas Price Factor Calculations

The commercial LPG monthly price factors were calculated using the same historical liquid petroleum gas (LPG) prices from 1995 to 2009 from EIA's Short-Term Energy Outlook[7] as the residential LPG price factors.

8E.3.3 Seasonal Marginal Price Factors Determination

Marginal energy prices are the prices consumers pay for the last unit of energy used. DOE used the marginal energy prices for each building to determine the cost of saved energy associated with the use of higher-efficiency products. Because marginal prices reflect a change in a consumer's bill associated with a change in energy consumed, such prices are appropriate for determining energy cost savings associated with possible changes to efficiency standards.

EIA provides historical monthly electricity and natural gas consumption and expenditures by state. This data was used to determine 10-year average marginal prices for the RECS 2009 geographical areas, which are then used to convert average monthly energy prices into marginal monthly energy prices. Because a furnace operates during both the heating and cooling seasons, DOE determined summer and winter marginal price factors.

EIA also provides RECS 2009 billing data that was gathered from a subset of RECS housing records. For each household with billing data, the following are provided for each billing cycle: the start and end date, the electricity consumption in kWh, the electricity cost in dollars, the natural gas bill in dollars, and the gas consumption in hundreds of cubic feet. This data was used to validate marginal energy price factors by RECS 2009 geographical area.

For LPG-fired furnaces, DOE used the average LPG prices for each building for both base case products and higher-efficiency products, as the data necessary for estimating marginal prices were not available.

8E.3.3.1 Marginal Price Factor Calculation for Electricity and Natural Gas

Table 8E.3.24 through Table 8E.3.27 show the resulting electricity and natural gas marginal price factors for both residential and commercial sectors.

Table 8E.3.24 Residential Marginal Electricity Price Factors using EIA 2003-2012 Data

Geographical Area	Summer	Winter
Connecticut, Maine, New Hampshire, Rhode Island, Vermont	0.94	1.01
Massachusetts	0.96	1.04
New York	1.13	0.87
New Jersey	1.21	0.98
Pennsylvania	1.08	0.83
Illinois	0.98	0.72
Indiana, Ohio	1.00	0.75
Michigan	1.14	0.97
Wisconsin	1.01	0.89
Iowa, Minnesota, North Dakota, South Dakota	1.09	0.85
Kansas, Nebraska	1.19	0.73
Missouri	1.21	0.76
Virginia	1.08	0.85
Delaware, District of Columbia, Maryland	1.17	0.91
Georgia	1.16	0.84
North Carolina, South Carolina	0.97	0.83
Florida	1.01	0.93
Alabama, Kentucky, Mississippi	1.00	0.82
Tennessee	0.93	0.84
Arkansas, Louisiana, Oklahoma	1.05	0.73
Texas	1.05	0.90
Colorado	1.08	0.79
Idaho, Montana, Utah, Wyoming	1.13	0.96
Arizona	1.05	0.84
Nevada, New Mexico	1.02	0.88
California	1.21	1.13
Oregon, Washington	0.90	0.94
Alaska	0.85	0.91
Hawaii	1.46	0.89
West Virginia	0.92	0.84
United States	1.07	0.81

Table 8E.3.25 Commercial Marginal Electricity Price Factors using EIA 2003-2012 Data

Geographical Area	Summer	Winter
New England	1.15	0.91
Middle Atlantic	1.39	0.85
East North Central	1.10	0.72
West North Central	1.59	0.66
South Atlantic	1.16	0.94
East South Central	1.03	0.76
West South Central	1.17	0.76
Mountain	1.10	1.03
Pacific	1.54	0.82
United States	1.34	0.80

Table 8E.3.26 Residential Marginal Natural Gas Price Factors using EIA 2003-2012 Data

Geographical Area	**Summer**	**Winter**
Connecticut, Maine, New Hampshire, Rhode Island, Vermont	0.82	0.91
Massachusetts	0.89	1.03
New York	0.75	0.89
New Jersey	0.84	0.95
Pennsylvania	0.73	0.93
Illinois	0.68	0.97
Indiana, Ohio	0.73	0.92
Michigan	0.78	0.93
Wisconsin	0.79	0.98
Iowa, Minnesota, North Dakota, South Dakota	0.72	0.97
Kansas, Nebraska	0.69	0.93
Missouri	0.60	0.82
Virginia	0.68	0.93
Delaware, District of Columbia, Maryland	0.69	0.92
Georgia	0.56	0.87
North Carolina, South Carolina	0.67	0.89
Florida	0.64	0.82
Alabama, Kentucky, Mississippi	0.74	0.86
Tennessee	0.74	0.94
Arkansas, Louisiana, Oklahoma	0.66	0.85
Texas	0.59	0.85
Colorado	0.69	0.91
Idaho, Montana, Utah, Wyoming	0.84	0.96
Arizona	0.64	0.85
Nevada, New Mexico	0.73	0.88
California	0.85	1.08
Oregon, Washington	0.84	0.94
Alaska	0.86	0.96
Hawaii	0.77	0.91
West Virginia	0.80	0.95
United States	0.74	0.94

Table 8E.3.27 Commercial Marginal Natural Gas Price Factors using EIA 2003-2012 Data

Geographical Area	Summer	Winter
New England	1.04	0.98
Middle Atlantic	0.99	0.98
East North Central	0.82	0.97
West North Central	0.86	0.97
South Atlantic	0.85	0.95
East South Central	0.92	0.94
West South Central	0.78	0.90
Mountain	0.90	0.97
Pacific	0.98	1.17
United States	0.93	0.98

8E.3.4 Results

DOE applied the regional monthly energy price factors to develop residential and commercial average monthly energy prices for 2012 for electricity and natural gas (Table 8E.3.28 through Table 8E.3.31). Each geographical area was matched with the appropriate Census Region.

Table 8E.3.28 Residential Average Monthly Electricity Prices for 2012 Using Monthly Price Factors (2013$/kWh)

Geographical Area	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Connecticut, Maine, New Hampshire, Rhode Island, Vermont	0.16	0.16	0.16	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17
Massachusetts	0.15	0.15	0.15	0.15	0.15	0.16	0.15	0.15	0.15	0.15	0.15	0.15
New York	0.17	0.17	0.17	0.17	0.18	0.18	0.19	0.19	0.19	0.18	0.18	0.17
New Jersey	0.15	0.15	0.15	0.15	0.16	0.17	0.17	0.17	0.17	0.16	0.16	0.16
Pennsylvania	0.12	0.12	0.12	0.13	0.13	0.14	0.14	0.14	0.13	0.13	0.13	0.12
Illinois	0.10	0.11	0.11	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.11	0.11
Indiana, Ohio	0.10	0.11	0.11	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.11
Michigan	0.14	0.14	0.14	0.14	0.14	0.15	0.15	0.15	0.15	0.14	0.14	0.14
Wisconsin	0.13	0.13	0.13	0.13	0.14	0.14	0.13	0.13	0.14	0.14	0.13	0.13
Iowa, Minnesota, North Dakota, South Dakota	0.10	0.10	0.11	0.11	0.11	0.12	0.12	0.12	0.12	0.11	0.11	0.11
Kansas, Nebraska	0.09	0.10	0.10	0.10	0.11	0.12	0.12	0.12	0.12	0.11	0.10	0.10
Missouri	0.09	0.09	0.09	0.10	0.11	0.12	0.12	0.12	0.11	0.10	0.10	0.09
Virginia	0.10	0.10	0.11	0.11	0.12	0.12	0.12	0.12	0.12	0.11	0.11	0.10
Delaware, District of Columbia, Maryland	0.12	0.12	0.12	0.12	0.14	0.15	0.15	0.14	0.14	0.13	0.12	0.12
Georgia	0.10	0.10	0.11	0.11	0.11	0.12	0.12	0.13	0.12	0.11	0.11	0.10
North Carolina, South Carolina	0.11	0.11	0.11	0.11	0.11	0.11	0.12	0.12	0.12	0.12	0.11	0.11
Florida	0.11	0.11	0.12	0.12	0.12	0.11	0.12	0.12	0.12	0.12	0.12	0.12
Alabama, Kentucky, Mississippi	0.10	0.10	0.10	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.10
Tennessee	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.11	0.11	0.10
Arkansas, Louisiana, Oklahoma	0.08	0.09	0.09	0.09	0.09	0.10	0.10	0.10	0.10	0.10	0.09	0.09
Texas	0.10	0.10	0.11	0.11	0.11	0.12	0.12	0.12	0.12	0.12	0.11	0.11
Colorado	0.11	0.11	0.11	0.11	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.11
Idaho, Montana, Utah, Wyoming	0.09	0.09	0.09	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Arizona	0.10	0.10	0.11	0.11	0.12	0.12	0.12	0.12	0.12	0.12	0.11	0.11
Nevada, New Mexico	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12
California	0.15	0.15	0.15	0.15	0.16	0.16	0.16	0.16	0.16	0.15	0.15	0.16
Oregon, Washington	0.09	0.09	0.09	0.09	0.09	0.09	0.10	0.10	0.10	0.10	0.10	0.10
Alaska	0.17	0.17	0.18	0.18	0.19	0.19	0.19	0.19	0.18	0.18	0.18	0.18
Hawaii	0.36	0.37	0.37	0.37	0.38	0.38	0.38	0.39	0.39	0.39	0.39	0.39
West Virginia	0.09	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.11	0.10	0.10
United States	0.11	0.11	0.11	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.11

Table 8E.3.29 Commercial Average Monthly Electricity Prices for 2012 Using Monthly Price Factors (2013$/kWh)

Geographical Area	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
New England	0.13	0.14	0.13	0.14	0.14	0.14	0.15	0.14	0.15	0.14	0.14	0.14
Middle Atlantic	0.12	0.12	0.12	0.12	0.12	0.13	0.13	0.13	0.13	0.12	0.12	0.12
East North Central	0.09	0.09	0.09	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.09
West North Central	0.08	0.08	0.08	0.08	0.09	0.10	0.10	0.10	0.09	0.08	0.08	0.08
South Atlantic	0.09	0.09	0.09	0.09	0.09	0.10	0.10	0.10	0.10	0.10	0.09	0.09
East South Central	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
West South Central	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
Mountain	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
Pacific	0.11	0.11	0.11	0.11	0.12	0.13	0.14	0.13	0.13	0.13	0.12	0.11
United States	0.10	0.10	0.10	0.10	0.10	0.11	0.11	0.11	0.11	0.11	0.10	0.10

Table 8E.3.30 Residential Average Monthly Natural Gas Prices for 2012 Using Monthly Price Factors (2012$/MMBtu)

Geographical Area	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Connecticut, Maine, New Hampshire, Rhode Island, Vermont	14.2	14.2	14.4	14.3	15.0	16.3	18.1	18.5	17.9	15.9	15.4	14.8
Massachusetts	12.9	12.9	12.8	13.1	12.3	12.6	13.9	14.7	14.2	12.3	13.3	13.2
New York	12.8	12.6	12.8	13.3	14.8	16.9	17.8	16.8	16.4	14.4	12.9	12.1
New Jersey	10.9	10.7	10.7	11.0	11.7	12.9	13.4	13.4	13.2	12.1	11.5	11.2
Pennsylvania	11.4	11.6	11.8	12.3	13.8	15.9	17.6	18.1	17.2	14.0	12.4	11.8
Illinois	8.1	8.2	8.2	8.7	10.6	12.2	13.1	13.3	12.3	9.7	8.6	8.1
Indiana, Ohio	11.2	11.3	11.7	12.6	14.0	16.2	17.6	17.8	16.6	13.2	11.7	11.5
Michigan	10.1	10.1	10.3	10.8	12.0	13.7	15.2	15.7	14.5	12.1	10.9	10.5
Wisconsin	9.6	9.3	9.5	9.6	9.7	11.1	11.5	11.7	10.7	8.8	9.8	9.6
Iowa, Minnesota, North Dakota, South Dakota	8.3	8.1	8.3	8.5	9.6	11.2	12.1	12.5	11.6	9.3	8.7	8.3
Kansas, Nebraska	9.2	9.3	9.3	10.1	11.3	13.3	14.3	15.0	14.5	12.5	10.2	9.5
Missouri	12.2	12.2	12.3	13.8	15.9	19.4	22.2	23.5	21.9	18.6	14.6	13.0
Virginia	12.1	11.6	11.5	12.8	15.1	17.6	18.9	18.6	18.6	15.1	12.4	12.0
Delaware, District of Columbia, Maryland	11.7	11.5	11.8	13.0	14.8	16.8	17.9	17.9	17.3	14.2	12.4	11.9
Georgia	13.4	14.2	14.9	16.5	20.5	22.8	24.0	23.8	23.1	19.9	15.3	14.3
North Carolina, South Carolina	12.4	12.4	12.7	13.7	15.8	18.7	19.8	20.6	19.7	16.4	13.6	13.2
Florida	15.4	15.7	16.7	17.7	19.3	20.5	21.2	21.6	21.3	20.9	19.2	17.0
Alabama, Kentucky, Mississippi	11.7	11.7	12.1	13.4	15.3	17.0	17.5	17.9	17.4	15.7	13.4	12.5
Tennessee	9.9	10.0	10.0	10.9	12.0	13.7	14.6	15.0	14.3	13.0	11.0	10.4
Arkansas, Louisiana, Oklahoma	10.6	10.6	10.8	12.0	14.3	15.8	16.8	17.3	16.8	15.5	13.0	11.2
Texas	9.5	9.5	9.8	11.2	12.9	14.4	14.8	15.2	15.1	13.6	11.2	9.9
Colorado	7.8	7.9	8.2	8.4	9.3	11.8	11.9	12.6	11.7	9.3	8.4	8.0
Idaho, Montana, Utah, Wyoming	8.4	8.4	8.6	8.2	8.6	9.2	9.8	10.3	9.7	8.6	8.7	8.5
Arizona	13.5	14.0	14.5	15.8	17.7	19.6	21.4	22.1	21.4	20.0	16.9	14.6
Nevada, New Mexico	8.8	9.1	9.3	10.0	11.2	12.7	12.7	13.3	12.8	11.5	9.9	9.0
California	9.2	9.1	8.8	8.8	9.2	9.6	9.7	9.6	9.3	9.4	9.0	9.0
Oregon, Washington	10.8	10.9	11.0	11.2	11.6	12.3	13.6	14.1	13.7	12.5	11.5	11.2
Alaska	8.1	8.2	8.3	8.4	8.8	9.1	9.8	9.6	8.9	8.4	8.2	8.4
Hawaii	49.6	50.7	50.8	51.0	51.8	52.3	53.6	54.9	54.8	54.5	53.7	52.6
West Virginia	10.8	10.8	10.9	11.3	12.5	15.1	16.9	16.6	15.3	12.5	11.5	11.1
United States	10.5	10.5	10.6	11.2	12.3	13.8	14.6	14.9	14.3	12.3	11.2	10.7

Table 8E.3.31 Commercial Average Monthly Natural Gas Prices for 2012 Using Monthly Price Factors (2012$/MMBtu)

Geographical Area	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
New England	11.02	11.06	11.09	10.87	9.93	9.72	10.00	9.92	9.83	9.60	10.77	11.28
Middle Atlantic	9.37	9.25	9.07	8.95	8.96	8.94	8.78	8.55	8.54	8.61	8.97	9.29
East North Central	8.03	7.96	8.04	8.23	8.69	9.29	9.55	9.52	8.99	8.21	8.15	8.09
West North Central	7.87	7.79	7.74	7.74	8.05	8.31	8.51	8.59	8.33	7.85	7.91	7.95
South Atlantic	9.20	9.24	9.19	9.23	9.45	9.84	10.01	9.85	9.76	9.63	9.33	9.27
East South Central	9.12	9.08	9.04	9.20	9.35	9.48	9.61	9.69	9.55	9.56	9.50	9.39
West South Central	7.28	7.19	6.93	7.04	7.37	7.35	7.38	7.27	7.37	7.51	7.62	7.36
Mountain	7.51	7.52	7.57	7.44	7.57	7.75	7.97	8.10	7.97	7.69	7.74	7.62
Pacific	8.15	7.96	7.79	7.56	7.21	7.46	7.37	7.48	7.33	7.31	7.49	7.92
United States	8.09	8.07	8.03	8.03	8.08	8.19	8.16	8.07	8.05	7.91	8.08	8.13

DOE applied the marginal price factors to the monthly energy prices to develop marginal residential and commercial monthly energy prices for 2012 for electricity and natural gas (Table 8E.3.32 through Table 8E.3.35).

Table 8E.3.32 Residential Marginal Monthly Electricity Prices for 2012 Using Marginal Price Factors (2013$/kWh)

Geographical Area	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Connecticut, Maine, New Hampshire, Rhode Island, Vermont	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.17	0.17
Massachusetts	0.15	0.16	0.16	0.14	0.15	0.15	0.14	0.15	0.15	0.15	0.16	0.16
New York	0.15	0.15	0.15	0.20	0.20	0.21	0.21	0.21	0.21	0.20	0.15	0.15
New Jersey	0.15	0.15	0.15	0.19	0.19	0.20	0.21	0.21	0.21	0.19	0.15	0.15
Pennsylvania	0.10	0.10	0.10	0.14	0.14	0.15	0.15	0.15	0.15	0.14	0.11	0.10
Illinois	0.07	0.08	0.08	0.11	0.12	0.12	0.12	0.12	0.12	0.12	0.08	0.08
Indiana, Ohio	0.08	0.08	0.08	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.09	0.08
Michigan	0.13	0.14	0.13	0.16	0.16	0.17	0.17	0.17	0.17	0.16	0.14	0.14
Wisconsin	0.11	0.12	0.12	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.12	0.12
Iowa, Minnesota, North Dakota, South Dakota	0.09	0.09	0.09	0.12	0.12	0.13	0.13	0.13	0.13	0.12	0.09	0.09
Kansas, Nebraska	0.07	0.07	0.07	0.12	0.13	0.14	0.14	0.14	0.14	0.13	0.07	0.07
Missouri	0.07	0.07	0.07	0.12	0.13	0.15	0.14	0.14	0.13	0.12	0.07	0.07
Virginia	0.09	0.09	0.09	0.12	0.13	0.13	0.13	0.13	0.13	0.12	0.09	0.09
Delaware, District of Columbia, Maryland	0.11	0.11	0.11	0.14	0.16	0.17	0.17	0.17	0.17	0.15	0.11	0.11
Georgia	0.09	0.09	0.09	0.13	0.13	0.14	0.14	0.15	0.14	0.13	0.09	0.09
North Carolina, South Carolina	0.09	0.09	0.09	0.11	0.11	0.11	0.11	0.11	0.11	0.12	0.09	0.09
Florida	0.11	0.11	0.11	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.11	0.11
Alabama, Kentucky, Mississippi	0.08	0.08	0.08	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.09	0.08
Tennessee	0.08	0.08	0.08	0.10	0.10	0.10	0.10	0.09	0.10	0.10	0.09	0.09
Arkansas, Louisiana, Oklahoma	0.06	0.06	0.07	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.07	0.06
Texas	0.09	0.09	0.10	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.10	0.10
Colorado	0.09	0.09	0.09	0.12	0.13	0.13	0.13	0.13	0.13	0.13	0.09	0.09
Idaho, Montana, Utah, Wyoming	0.09	0.09	0.09	0.11	0.11	0.11	0.12	0.12	0.11	0.11	0.09	0.09
Arizona	0.08	0.09	0.09	0.12	0.13	0.13	0.13	0.13	0.13	0.12	0.09	0.09
Nevada, New Mexico	0.10	0.10	0.10	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.11	0.10
California	0.17	0.17	0.17	0.18	0.19	0.19	0.20	0.20	0.19	0.18	0.18	0.18
Oregon, Washington	0.09	0.09	0.09	0.08	0.08	0.08	0.09	0.09	0.09	0.09	0.09	0.09
Alaska	0.16	0.16	0.16	0.15	0.16	0.16	0.16	0.16	0.16	0.16	0.17	0.16
Hawaii	0.33	0.33	0.33	0.54	0.55	0.55	0.56	0.56	0.56	0.57	0.35	0.35
West Virginia	0.08	0.08	0.08	0.09	0.10	0.09	0.09	0.09	0.09	0.10	0.09	0.08
United States	0.09	0.09	0.09	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.10	0.09

Table 8E.3.33 Commercial Marginal Monthly Electricity Prices for 2012 Using Marginal Price Factors (2013$/kWh)

Geographical Area	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
New England	0.12	0.12	0.12	0.16	0.16	0.17	0.17	0.17	0.17	0.16	0.12	0.12
Middle Atlantic	0.10	0.10	0.10	0.17	0.17	0.18	0.18	0.18	0.18	0.17	0.10	0.10
East North Central	0.07	0.07	0.07	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.07	0.07
West North Central	0.05	0.05	0.05	0.13	0.14	0.15	0.15	0.15	0.14	0.13	0.05	0.05
South Atlantic	0.09	0.09	0.09	0.11	0.11	0.11	0.11	0.12	0.11	0.11	0.09	0.09
East South Central	0.07	0.08	0.08	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.08	0.08
West South Central	0.06	0.06	0.06	0.09	0.09	0.10	0.10	0.10	0.10	0.10	0.06	0.06
Mountain	0.09	0.09	0.09	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.09	0.09
Pacific	0.09	0.09	0.09	0.18	0.18	0.20	0.21	0.21	0.20	0.20	0.10	0.09
United States	0.08	0.08	0.08	0.14	0.14	0.15	0.15	0.15	0.15	0.14	0.08	0.08

Table 8E.3.34 Residential Marginal Monthly Natural Gas Prices for 2012 Using Marginal Price Factors (2012$/MMBtu)

Geographical Area	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Connecticut, Maine, New Hampshire, Rhode Island, Vermont	12.8	12.9	13.0	11.8	12.4	13.5	14.9	15.2	14.7	13.1	13.9	13.4
Massachusetts	13.3	13.3	13.2	11.7	11.0	11.3	12.5	13.1	12.7	11.0	13.7	13.6
New York	11.4	11.2	11.4	10.0	11.1	12.7	13.4	12.6	12.4	10.8	11.5	10.8
New Jersey	10.3	10.2	10.2	9.2	9.8	10.8	11.2	11.2	11.0	10.1	10.9	10.6
Pennsylvania	10.6	10.7	10.9	8.9	10.0	11.5	12.8	13.1	12.4	10.2	11.5	10.9
Illinois	7.9	8.0	8.0	5.9	7.2	8.3	8.9	9.0	8.3	6.6	8.4	7.9
Indiana, Ohio	10.4	10.5	10.8	9.2	10.2	11.8	12.8	12.9	12.0	9.6	10.8	10.6
Michigan	9.4	9.4	9.5	8.4	9.3	10.7	11.8	12.2	11.3	9.4	10.2	9.8
Wisconsin	9.4	9.2	9.3	7.7	7.7	8.8	9.1	9.3	8.5	7.0	9.6	9.4
Iowa, Minnesota, North Dakota, South Dakota	8.1	7.9	8.1	6.1	6.9	8.0	8.7	9.0	8.3	6.6	8.4	8.1
Kansas, Nebraska	8.6	8.6	8.6	7.0	7.8	9.2	9.9	10.4	10.1	8.6	9.5	8.9
Missouri	10.0	10.0	10.1	8.2	9.5	11.6	13.3	14.0	13.1	11.1	12.0	10.7
Virginia	11.2	10.8	10.7	8.6	10.2	12.0	12.8	12.6	12.6	10.2	11.5	11.2
Delaware, District of Columbia, Maryland	10.7	10.6	10.9	8.9	10.2	11.6	12.4	12.4	11.9	9.8	11.5	10.9
Georgia	11.6	12.3	12.9	9.2	11.4	12.7	13.4	13.3	12.9	11.1	13.2	12.4
North Carolina, South Carolina	11.1	11.1	11.4	9.1	10.5	12.4	13.2	13.7	13.1	10.9	12.2	11.8
Florida	12.7	12.9	13.8	11.4	12.4	13.2	13.6	13.9	13.7	13.5	15.8	14.0
Alabama, Kentucky, Mississippi	10.2	10.1	10.5	9.9	11.3	12.6	13.0	13.3	12.9	11.7	11.6	10.8
Tennessee	9.3	9.4	9.4	8.0	8.8	10.1	10.8	11.1	10.6	9.6	10.4	9.8
Arkansas, Louisiana, Oklahoma	9.0	9.0	9.2	7.9	9.4	10.4	11.1	11.5	11.1	10.2	11.0	9.5
Texas	8.0	8.1	8.3	6.7	7.7	8.5	8.8	9.0	9.0	8.1	9.5	8.4
Colorado	7.1	7.2	7.4	5.8	6.4	8.1	8.2	8.7	8.0	6.4	7.7	7.3
Idaho, Montana, Utah, Wyoming	8.0	8.0	8.2	6.9	7.2	7.8	8.3	8.7	8.2	7.3	8.3	8.2
Arizona	11.5	11.9	12.3	10.0	11.3	12.5	13.6	14.1	13.6	12.7	14.3	12.4
Nevada, New Mexico	7.8	8.0	8.2	7.3	8.2	9.3	9.3	9.7	9.4	8.4	8.7	7.9
California	9.9	9.8	9.5	7.4	7.8	8.2	8.2	8.1	7.9	8.0	9.7	9.8
Oregon, Washington	10.2	10.2	10.3	9.5	9.8	10.4	11.5	11.9	11.6	10.5	10.8	10.5
Alaska	7.8	7.9	8.0	7.2	7.6	7.8	8.4	8.2	7.6	7.2	7.9	8.1
Hawaii	45.4	46.3	46.4	39.5	40.1	40.5	41.4	42.5	42.4	42.2	49.1	48.1
West Virginia	10.3	10.3	10.4	9.0	10.0	12.1	13.4	13.3	12.2	9.9	10.9	10.6
United States	9.8	9.9	10.0	8.3	9.1	10.2	10.9	11.1	10.6	9.1	10.5	10.0

Table 8E.3.35 Commercial Marginal Monthly Natural Gas Prices for 2012 Using Marginal Price Factors (2012$/MMBtu)

Geographical Area	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
New England	10.75	10.79	10.82	11.31	10.34	10.12	10.42	10.33	10.24	10.00	10.51	11.00
Middle Atlantic	9.17	9.05	8.88	8.88	8.89	8.87	8.71	8.48	8.47	8.54	8.78	9.09
East North Central	7.78	7.72	7.79	6.78	7.16	7.65	7.87	7.85	7.41	6.77	7.89	7.84
West North Central	7.65	7.57	7.51	6.63	6.89	7.11	7.28	7.36	7.13	6.72	7.68	7.72
South Atlantic	8.73	8.77	8.72	7.81	8.00	8.32	8.46	8.34	8.26	8.15	8.86	8.79
East South Central	8.61	8.58	8.54	8.50	8.63	8.75	8.87	8.94	8.81	8.82	8.97	8.86
West South Central	6.57	6.50	6.27	5.47	5.73	5.72	5.74	5.65	5.73	5.84	6.88	6.65
Mountain	7.27	7.28	7.33	6.68	6.79	6.96	7.15	7.27	7.15	6.90	7.49	7.38
Pacific	9.55	9.33	9.12	7.43	7.08	7.33	7.24	7.35	7.20	7.18	8.78	9.28
United States	7.92	7.90	7.86	7.46	7.51	7.61	7.58	7.50	7.48	7.35	7.90	7.96

DOE applied the regional monthly energy price factors to the annual LPG data presented in section 8E.3.1.3 to develop residential and commercial monthly energy prices for 2012 (Table 8E.3.36). Each geographical area was matched with the appropriate Census Region.

Table 8E.3.36 Residential Monthly LPG Prices for 2012 Using Average Price Factors (2013$/MMBtu)

Geographical Area	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Connecticut, Maine, New Hampshire, Rhode Island, Vermont	31.7	32.1	32.2	32.2	32.7	33.1	33.2	33.0	32.9	33.1	32.8	32.7
Massachusetts	34.0	34.3	34.5	34.5	35.0	35.4	35.5	35.3	35.3	35.4	35.1	35.0
New York	32.1	32.5	32.7	32.7	33.2	33.5	33.6	33.4	33.4	33.5	33.2	33.2
New Jersey	33.3	33.7	33.9	33.9	34.4	34.8	34.9	34.6	34.6	34.8	34.4	34.4
Pennsylvania	30.3	30.6	30.8	30.8	31.3	31.6	31.7	31.5	31.5	31.6	31.3	31.3
Illinois	22.6	22.6	22.3	22.0	21.7	20.9	20.3	20.3	20.7	21.3	22.3	23.3
Indiana, Ohio	26.4	26.4	26.1	25.6	25.3	24.4	23.7	23.6	24.2	24.9	26.0	27.2
Michigan	24.3	24.3	24.0	23.6	23.3	22.5	21.8	21.8	22.3	22.9	24.0	25.0
Wisconsin	22.4	22.4	22.1	21.8	21.5	20.8	20.1	20.1	20.5	21.2	22.1	23.1
Iowa, Minnesota, North Dakota, South Dakota	23.3	23.3	23.0	22.6	22.3	21.6	20.9	20.9	21.3	22.0	23.0	24.0
Kansas, Nebraska	22.6	22.6	22.3	22.0	21.7	20.9	20.3	20.3	20.7	21.3	22.3	23.3
Missouri	23.0	23.0	22.7	22.4	22.1	21.3	20.7	20.6	21.1	21.7	22.7	23.7
Virginia	25.4	25.5	25.1	24.7	24.3	23.8	23.3	22.8	23.4	24.4	25.1	25.9
Delaware, District of Columbia, Maryland	35.3	35.5	34.9	34.2	33.7	33.1	32.3	31.7	32.5	33.8	34.9	36.0
Georgia	27.7	27.8	27.3	26.8	26.4	25.9	25.3	24.8	25.4	26.5	27.3	28.2
North Carolina, South Carolina	27.7	27.8	27.4	26.9	26.4	25.9	25.3	24.9	25.5	26.5	27.4	28.3
Florida	28.6	28.7	28.3	27.7	27.3	26.8	26.2	25.7	26.3	27.4	28.3	29.2
Alabama, Kentucky, Mississippi	24.5	24.5	24.2	23.7	23.3	22.9	22.4	21.9	22.5	23.4	24.2	24.9
Tennessee	28.1	28.1	27.7	27.2	26.8	26.2	25.6	25.2	25.8	26.9	27.7	28.6
Arkansas, Louisiana, Oklahoma	23.0	23.0	22.7	22.2	21.9	21.5	21.0	20.6	21.1	22.0	22.7	23.4
Texas	15.9	15.9	15.7	15.4	15.2	14.9	14.5	14.3	14.6	15.2	15.7	16.2
Colorado	25.6	25.6	25.2	24.6	24.0	23.3	22.5	22.2	23.1	24.5	25.3	26.2
Idaho, Montana, Utah, Wyoming	25.0	25.1	24.7	24.1	23.5	22.8	22.0	21.7	22.6	24.0	24.7	25.7
Arizona	31.4	31.5	30.9	30.2	29.5	28.7	27.6	27.3	28.4	30.1	31.0	32.2
Nevada, New Mexico	27.5	27.5	27.1	26.5	25.8	25.1	24.2	23.9	24.8	26.3	27.1	28.2
California	29.9	30.0	29.5	28.8	28.1	27.3	26.3	26.0	27.0	28.6	29.6	30.7
Oregon, Washington	27.1	27.2	26.7	26.1	25.5	24.7	23.8	23.5	24.5	25.9	26.8	27.8
Alaska	29.9	29.9	29.4	28.8	28.1	27.3	26.3	26.0	27.0	28.6	29.5	30.7
Hawaii	40.2	40.2	39.5	38.6	37.7	36.6	35.3	34.9	36.3	38.4	39.7	41.2
West Virginia	32.9	33.0	32.5	31.9	31.4	30.8	30.1	29.5	30.3	31.5	32.5	33.6
United States	18.7	18.8	18.7	18.6	18.6	18.2	17.4	17.0	17.5	18.1	18.7	19.2

Table 8E.3.37 Commercial Monthly LPG Prices for 2012 Using Average Price Factors (2012$/MMBtu)

Geographical Area	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
New England	25.40	25.66	25.79	25.81	26.21	26.47	26.55	26.39	26.37	26.49	26.22	26.20
Middle Atlantic	24.65	24.90	25.03	25.05	25.43	25.68	25.77	25.61	25.59	25.70	25.45	25.43
East North Central	20.94	20.93	20.68	20.36	20.11	19.40	18.82	18.77	19.20	19.77	20.67	21.59
West North Central	20.85	20.84	20.59	20.27	20.02	19.32	18.74	18.69	19.12	19.69	20.58	21.49
South Atlantic	20.17	20.23	19.93	19.54	19.23	18.87	18.44	18.09	18.54	19.31	19.91	20.56
East South Central	22.23	22.30	21.96	21.54	21.20	20.80	20.32	19.94	20.43	21.28	21.94	22.66
West South Central	23.90	23.97	23.61	23.16	22.79	22.36	21.85	21.44	21.97	22.88	23.59	24.36
Mountain	21.97	22.01	21.63	21.14	20.63	20.04	19.32	19.07	19.83	21.01	21.69	22.53
Pacific	23.26	23.31	22.91	22.39	21.85	21.22	20.46	20.20	21.00	22.25	22.97	23.86
United States	22.31	22.45	22.30	22.15	22.16	21.71	20.74	20.27	20.88	21.56	22.25	22.93

8E.4 HOUSEHOLD ENERGY PRICE ADJUSTMENT FACTOR

RECS 2009 reports the total annual consumption and expenditure of each energy use type. From this data DOE determined average energy prices per geographical area. To take into account that household energy prices vary inside a geographical area, DOE developed 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 was 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.

8E.5 NATURAL GAS TARIFF ANALYSIS

DOE received comment about the use of average natural gas prices. The Gas Technology Institute (GTI) commented that, because the monthly fixed charge contributes to the average price, marginal prices may generally be lower than average prices. As described above, DOE developed marginal price factors to account for this difference, but these factors were developed from EIA data, not directly from gas tariff documents. GTI submitted documents describing a total of 23 residential gas tariffs for 13 companies operating in multiple states.[8] DOE used this information to validate the residential natural gas marginal price factors presented in Table 8E.3.26.

8E.5.1 Calculation Methodology

DOE used the following calculation approach to estimate the ratio of marginal to average prices, or the marginal price factors, for the 23 tariffs submitted by GTI.

Tariffs have one or more tiers. The simplest tariff structure consists of a monthly fixed cost (*FC*) and a commodity cost (*i.e.*, for units of gas) (*CC*). The total monthly bill (*MonthlyBill*) is:

$$MonthlyBill = FC + U \times CC$$

Eq. 8E.1

Where:

FC = monthly fixed cost for natural gas,
U = monthly consumer natural gas usage, and
CC = commodity cost for natural gas.

The average monthly price (*AveragePrice*) is equal to the ratio of the monthly bill to the total monthly usage:

$$AveragePrice = \frac{MonthlyBill}{U} = \frac{FC}{U} + CC$$

Eq. 8E.2

The marginal price is equal to the commodity cost CC; therefore, for this type of tariff, the average price exceeds the marginal price by the amount FC/U:

$$AveragePrice = MarginalPrice + \frac{FC}{U}$$

Eq. 8E.3

Where:

MarginalPrice = marginal price, which is equal to the commodity cost CC.

The difference between the average and marginal prices decreases with customer usage U, and thus should be larger in the summer, when usage is lower. For tariffs with multiple tiers, the difference depends on tier in which the customer is.

To determine the marginal price factors for each season (summer or winter) ($MarginalPriceFactor_{Season}$) for each of the 23 tariffs, DOE calculated the ratio of the average monthly natural gas price to the marginal price:

$$MarginalPriceFactor_{Season} = \frac{AveragePrice_{Season}}{MarginalPrice_{Season}}$$

Eq. 8E.4

Where:

Season = summer or winter.

8E.5.2 Data Inputs

DOE estimated the monthly usage U based on the RECS 2009 average annual natural gas consumption by RECS 2009 region. DOE used monthly natural gas consumption data from

EIA's Natural Gas Navigator to allocate natural gas usage to summer and winter months. These data show that on average 70 percent of annual consumption occurs in the winter (the 5 months from November through March) and 30 percent during the rest of the year (the remaining 7 months). Hence, DOE defined summer monthly usage as:

$$Summer\ Monthly\ NG\ Usage = \frac{30\%\ of\ Annual\ NG\ Usage}{7\ summer\ months/year} \times Annual\ Average\ NG\ Usage$$

Eq. 8E.5

and winter monthly usage as:

$$Winter\ Monthly\ NG\ Usage = \frac{70\%\ of\ Annual\ NG\ Usage}{5\ winter\ months/year} \times Annual\ Average\ NG\ Usage$$

Eq. 8E.6

DOE obtained the fixed charges and commodity charges from the tariff documents submitted by GTI. Of these 23 tariffs, eight have more than one tier. For the eight tariffs with multiple tiers, DOE estimated the commodity cost as the average of the two-tier charges.

8E.5.3 Results

Table 8E.5.1 lists the marginal price factors for each of the 23 tariffs submitted by GTI. Table 8E.5.1 also includes the marginal price factors estimated from the EIA data for comparison, and the assumed monthly summer and winter natural gas usage in therms. The EIA data and usage estimates depend only on the region. In general, the tariff-based marginal price factors for winter are less than one, as expected.

The winter price factors used by DOE are generally comparable to those computed from the tariff data, indicating that DOE's marginal price estimates are reasonable at average usage levels. The summer factors, which are less relevant for analysis of furnaces, are also generally comparable. Of the 23 tariffs analyzed, eight have multiple tiers, and of these eight, six have ascending rates and two have descending rates. Because this analysis uses an average of the two tiers as the commodity price, it will generally underestimate the marginal prices for consumers subject to the second tier.

A full tariff-based analysis would require information about the household's total baseline gas usage (to establish which tier the consumer is in), and a weight factor for each tariff that determines how many customers are served by that utility on that tariff. These data are generally not available in the public domain. DOE's use of EIA state-level data effectively averages over all consumer sales in each state, and so incorporates information about all utilities. DOE's approach is therefore more likely to provide prices representative of a typical consumer than any individual tariff.

Table 8E.5.1 Tariff-Based (GTI) and EIA Marginal Price Factors and Natural Gas Consumption by Season

Region ID	State	Summer		Winter		Natural Gas Consumption *Therms*	
		GTI	EIA	GTI	EIA	Summer	Winter
1	CT	0.54	0.82	0.79	0.91	33	109
1	CT	0.59	0.82	0.82	0.91	33	109
1	CT	0.74	0.82	0.90	0.91	33	109
5	PA	0.65	0.73	0.86	0.93	31	102
7	IA	0.61	0.73	0.84	0.92	37	120
10	MN	0.76	0.72	0.92	0.97	37	120
11	KS	0.56	0.69	0.81	0.93	33	107
13	VA	0.70	0.68	0.89	0.93	28	90
14	DC	0.60	0.70	0.83	0.92	27	90
14	DE	0.66	0.70	0.87	0.92	27	90
14	MD	0.73	0.70	0.91	0.92	27	90
14	MD	0.73	0.70	0.90	0.92	27	90
14	MD	0.72	0.70	0.89	0.92	27	90
22	CO	0.70	0.69	0.88	0.91	35	116
22	CO	0.67	0.69	0.87	0.91	35	116
22	CO	0.69	0.69	0.88	0.91	35	116
23	ID	0.88	0.84	0.96	0.96	34	110
23	ID	0.85	0.84	0.94	0.96	34	110
24	AZ	0.61	0.64	0.84	0.85	13	43
25	NV	0.68	0.72	0.87	0.89	23	74
26	CA	0.84	0.85	0.95	1.08	17	57
27	OR	0.80	0.84	0.93	0.94	32	105
27	WA	0.76	0.84	0.91	0.94	32	105

8E.6 ENERGY PRICE TRENDS

8E.6.1 Residential Energy Price Trends

DOE used *Annual Energy Outlook 2014 (AEO 2014)*[9] Reference Case scenarios for the nine census divisions. DOE applied the projected energy price for each of the nine census divisions to each household in the sample based on the household's location.

To arrive at prices in future years, DOE multiplied the prices described in the preceding section by the forecast of annual average price changes in EIA's *AEO 2014.* DOE converted the forecasted energy prices into energy price factors, with 2012 as the base year. Figure 8E.6.1 shows the national residential electricity price factor trend. To estimate the trend after 2040, DOE followed past guidelines provided to the Federal Energy Management Program (FEMP) by EIA and used the average rate of change during 2025–2040 for electricity, natural gas, and LPG.

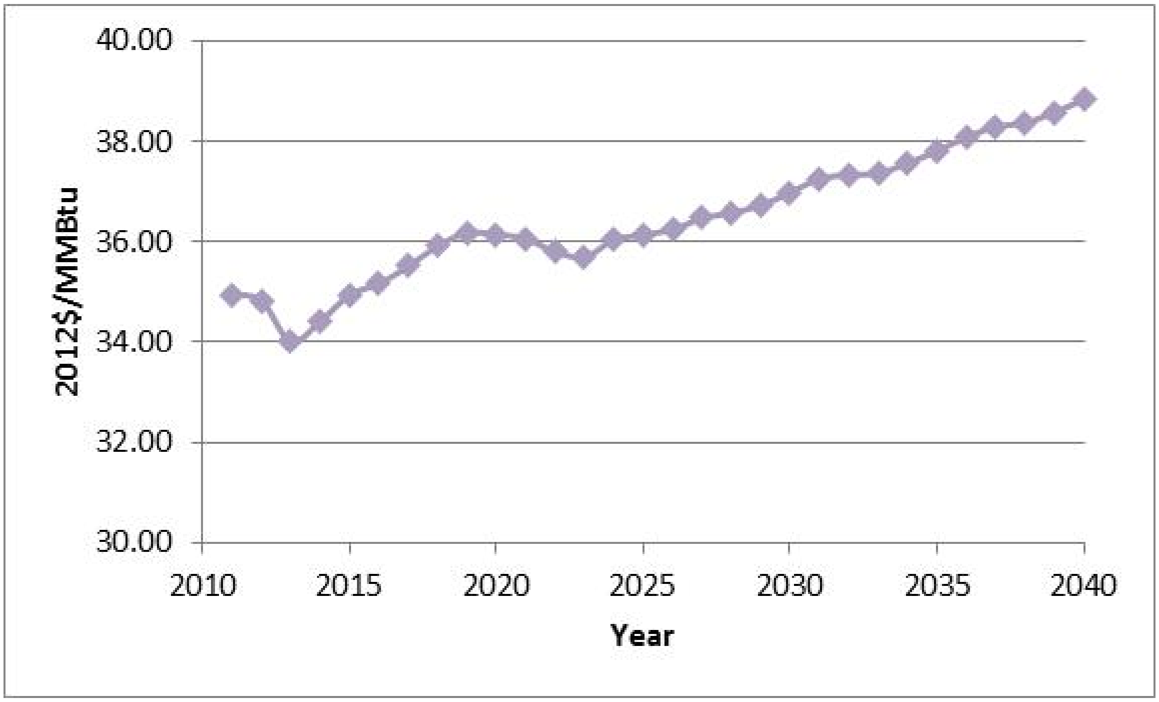

Figure 8E.6.1 Projected Residential National Electricity Price Factor

Figure 8E.6.2 shows the residential regional electricity price factor trends, disaggregated by the nine census divisions.

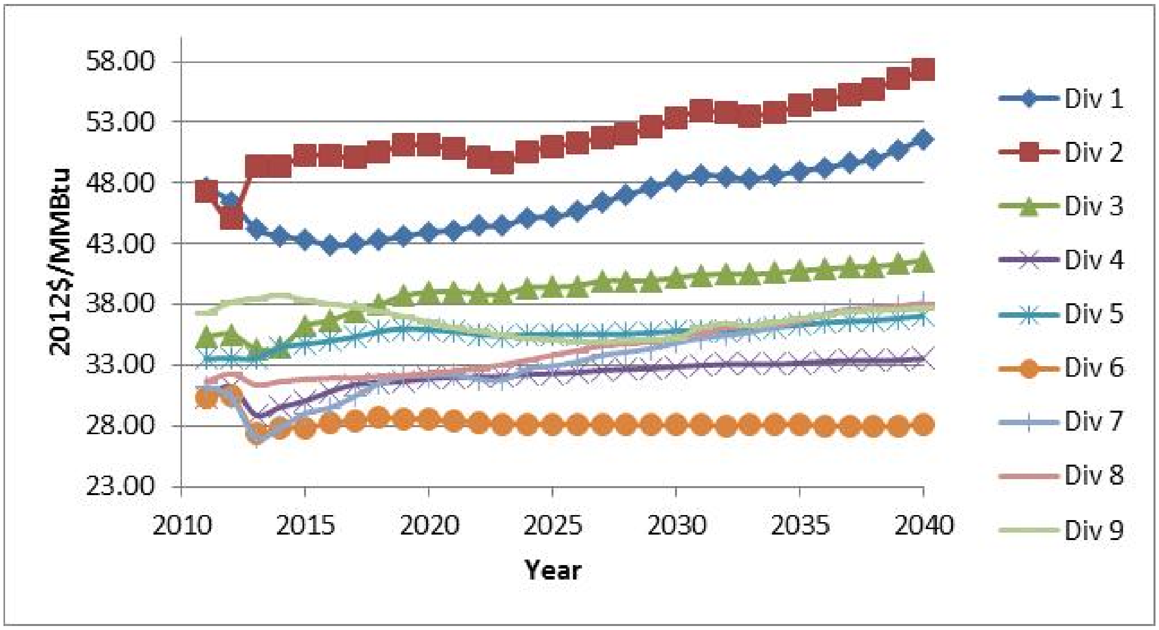

Figure 8E.6.2 Projected Residential Division Electricity Price Factors

Figure 8E.6.3 shows the residential national natural gas price factor trend.

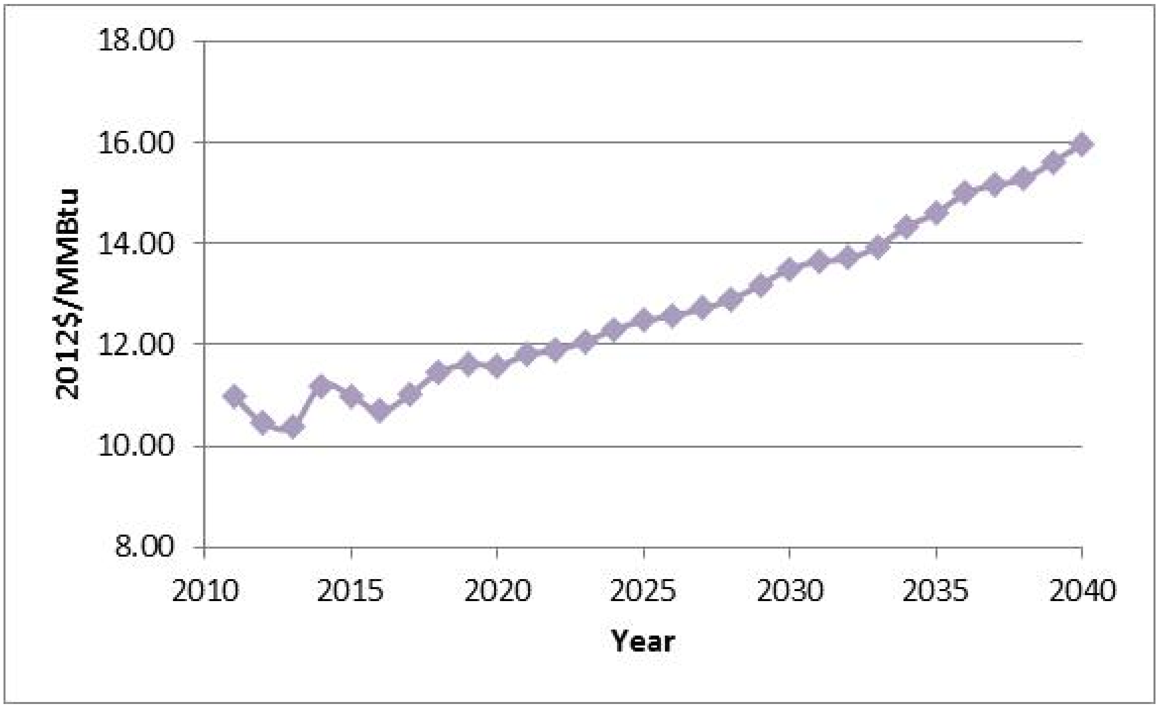

Figure 8E.6.3 Projected Residential National Natural Gas Price Factor

Figure 8E.6.4 shows the residential regional natural gas price factor trends, disaggregated by the nine census divisions.

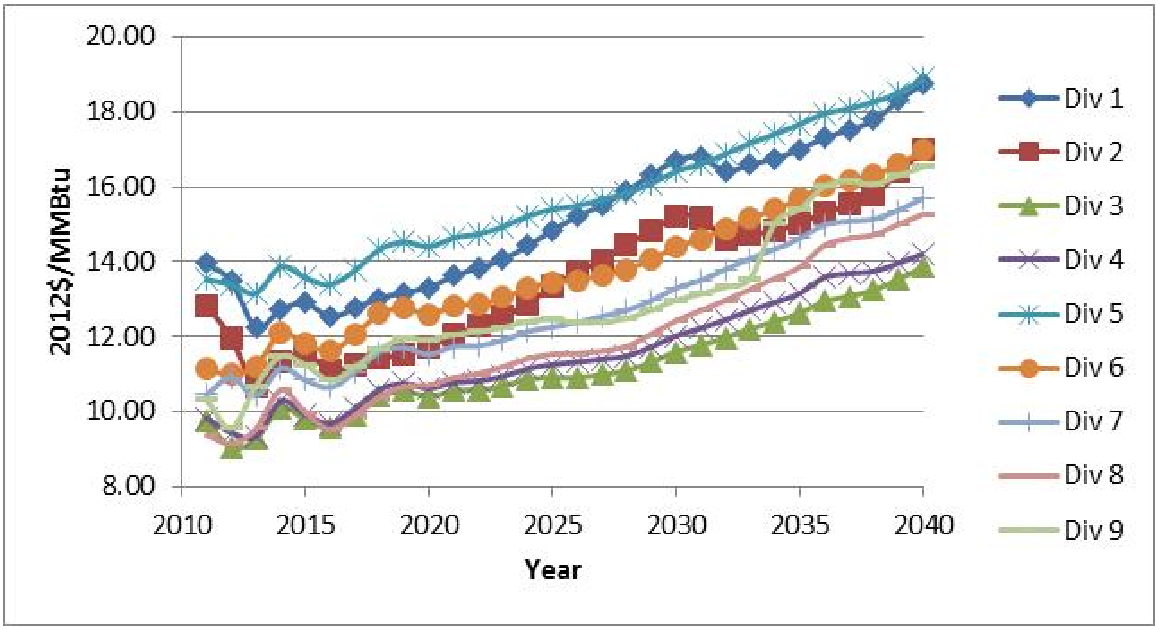

Figure 8E.6.4 Projected Residential Division Natural Gas Price Factors

Figure 8E.6.5 shows the residential national LPG price factor trend.

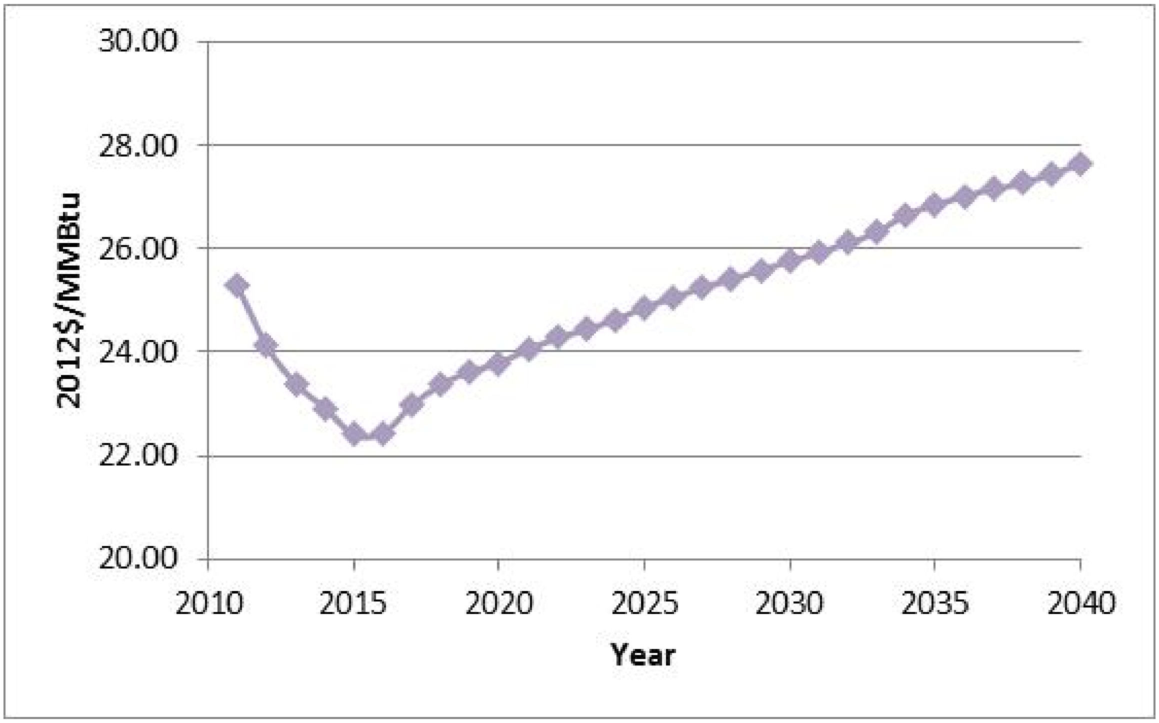

Figure 8E.6.5 Projected Residential National LPG Price Factor

Figure 8E.6.6 shows the residential regional LPG price factor trends, disaggregated by the nine census divisions.

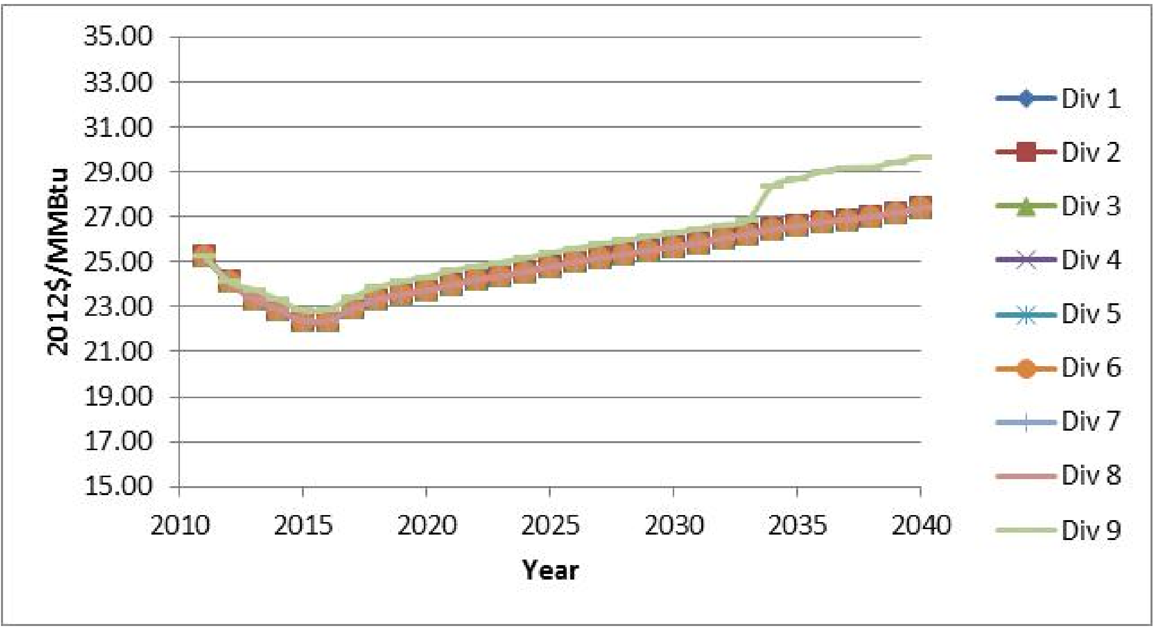

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Figure 8E.6.6 Projected Residential Division LPG Price Factors

8E.6.2 Commercial Energy Price Trends

DOE applied the same methodology to the projected energy price for each of the nine census divisions to each building in the commercial sample, based on the building's location.

To arrive at prices in future years, DOE multiplied the prices described in the preceding section by the forecast of annual average price changes in EIA's *AEO 2014.* DOE converted the forecasted energy prices into energy price factors, with 2012 as the base year. Figure 8E.6.7 shows the national commercial electricity price factor trend. To estimate the trend after 2040, DOE followed past guidelines provided to the Federal Energy Management Program (FEMP) by EIA and used the average rate of change during 2025–2040 for electricity, natural gas, and LPG.

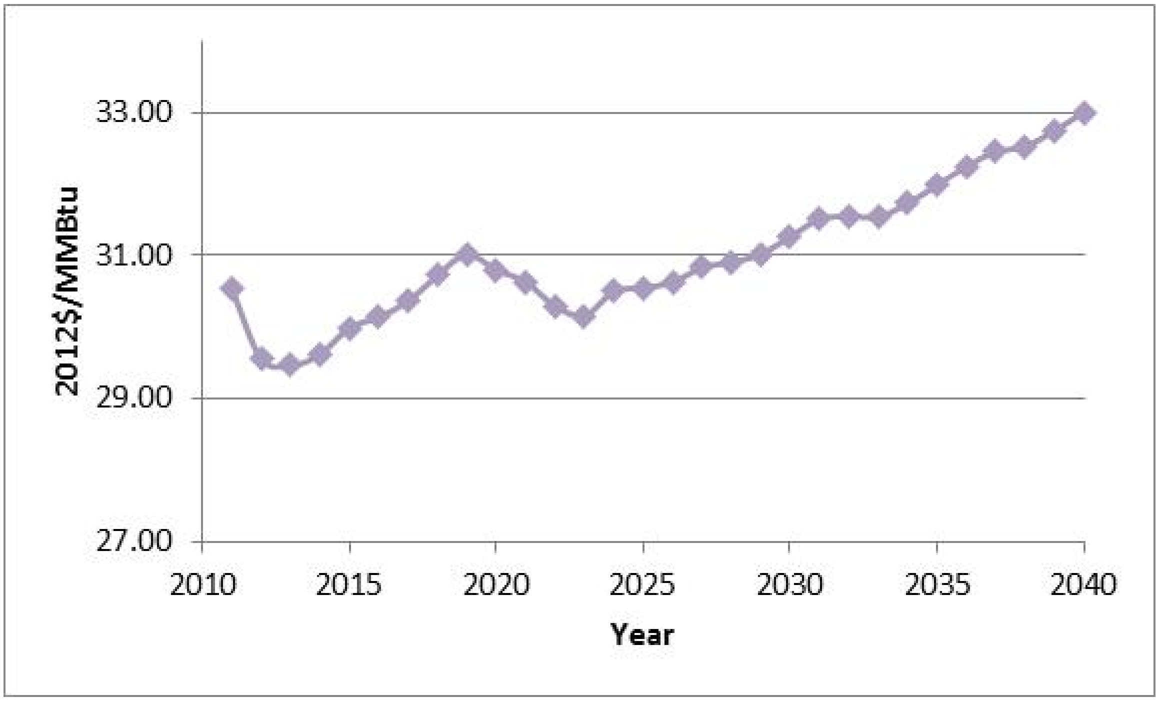

Figure 8E.6.7 Projected Commercial National Electricity Price Factor

Figure 8E.6.8 shows the commercial regional electricity price factor trends, disaggregated by the nine census divisions.

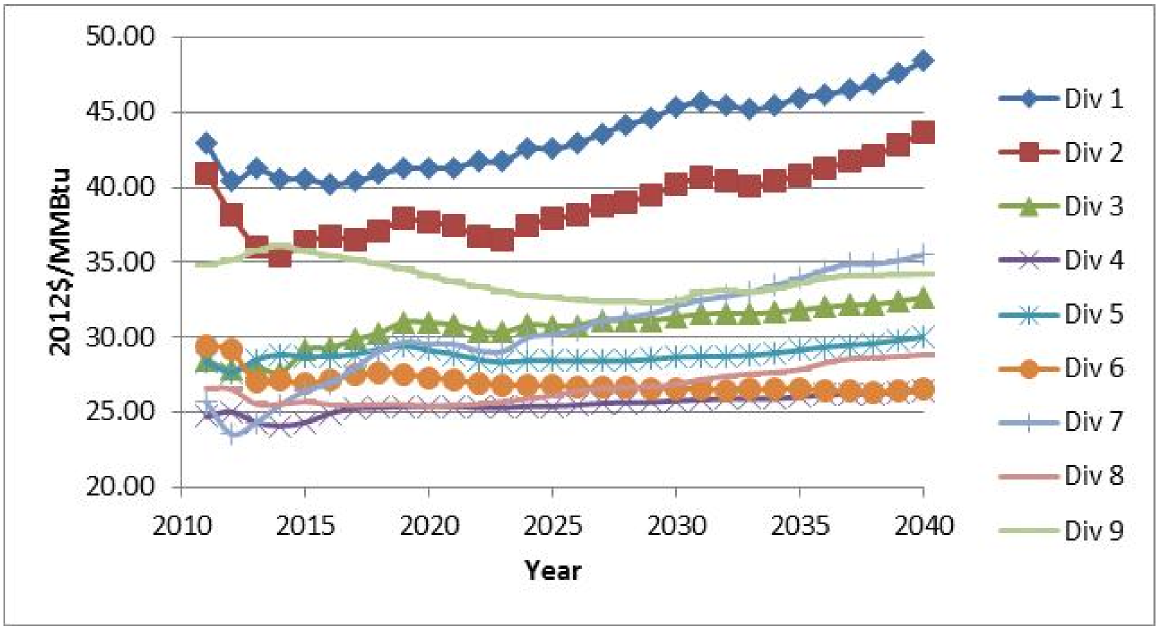

Figure 8E.6.8 Projected Commercial Division Electricity Price Factors

Figure 8E.6.9 shows the commercial national natural gas price factor trend.

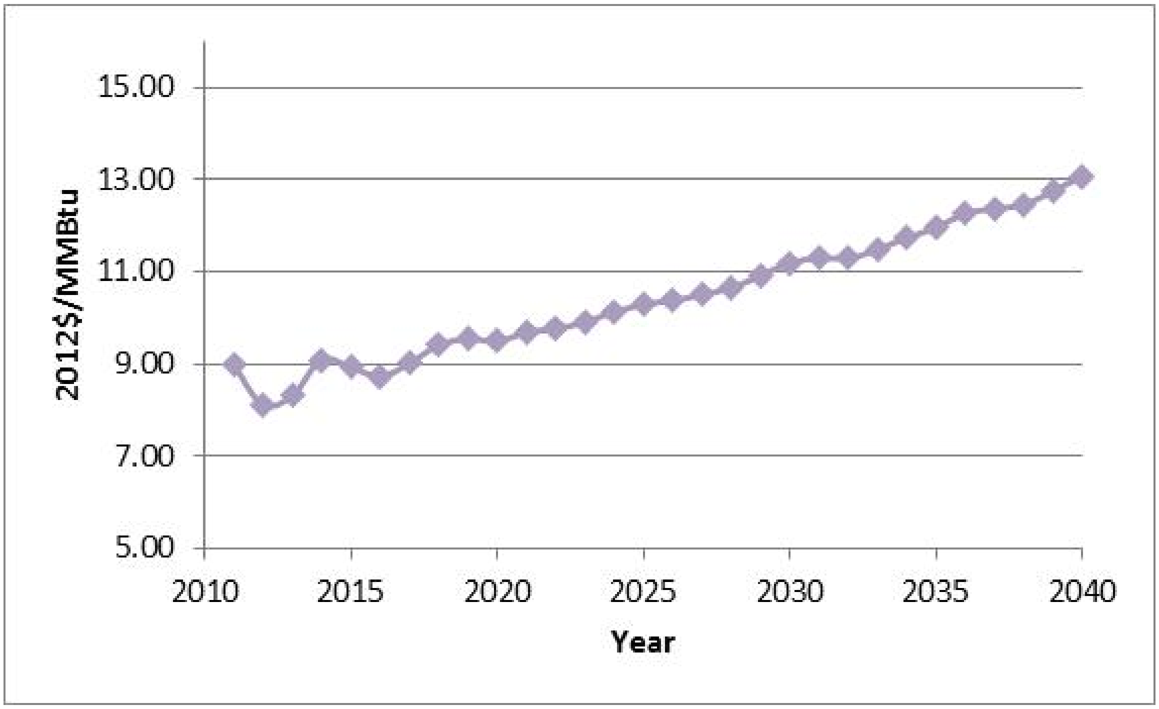

Figure 8E.6.9 Projected Commercial National Natural Gas Price Factor

Figure 8E.6.10 shows the commercial regional natural gas price factor trends, disaggregated by the nine census divisions.

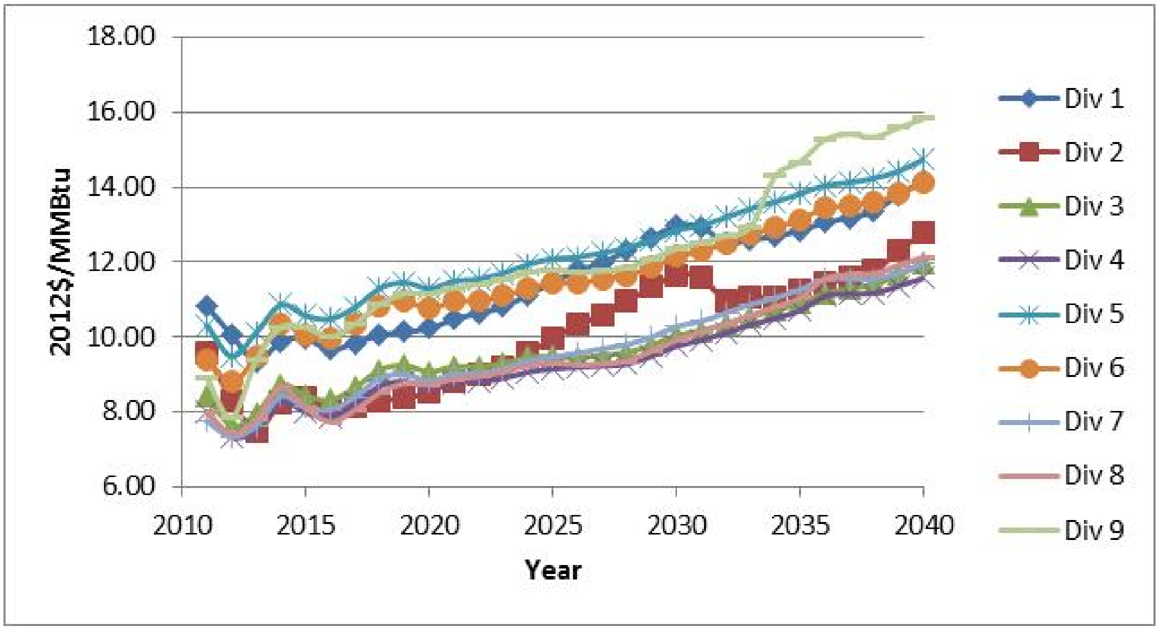

Figure 8E.6.10 Projected Commercial Division Natural Gas Price Factors

Figure 8E.6.11 shows the commercial national LPG price factor trend.

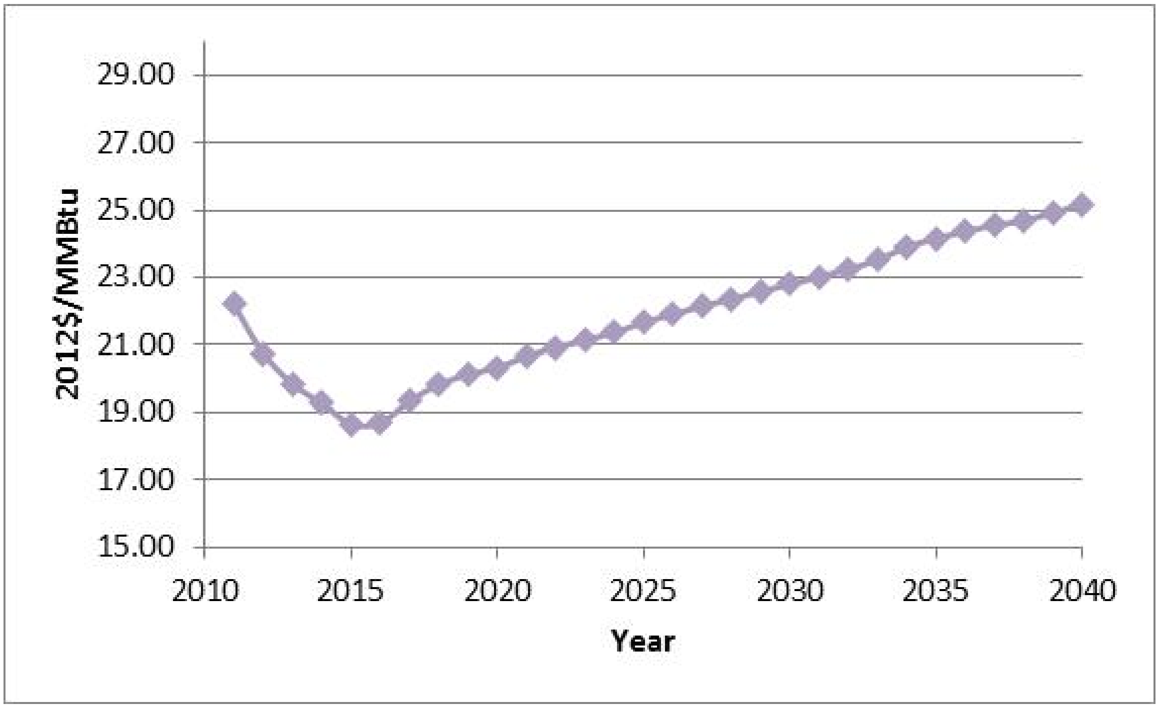

Figure 8E.6.11 Projected Commercial National LPG Price Factor

Figure 8E.6.12 shows the commercial regional LPG price factor trends, disaggregated by the nine census divisions.

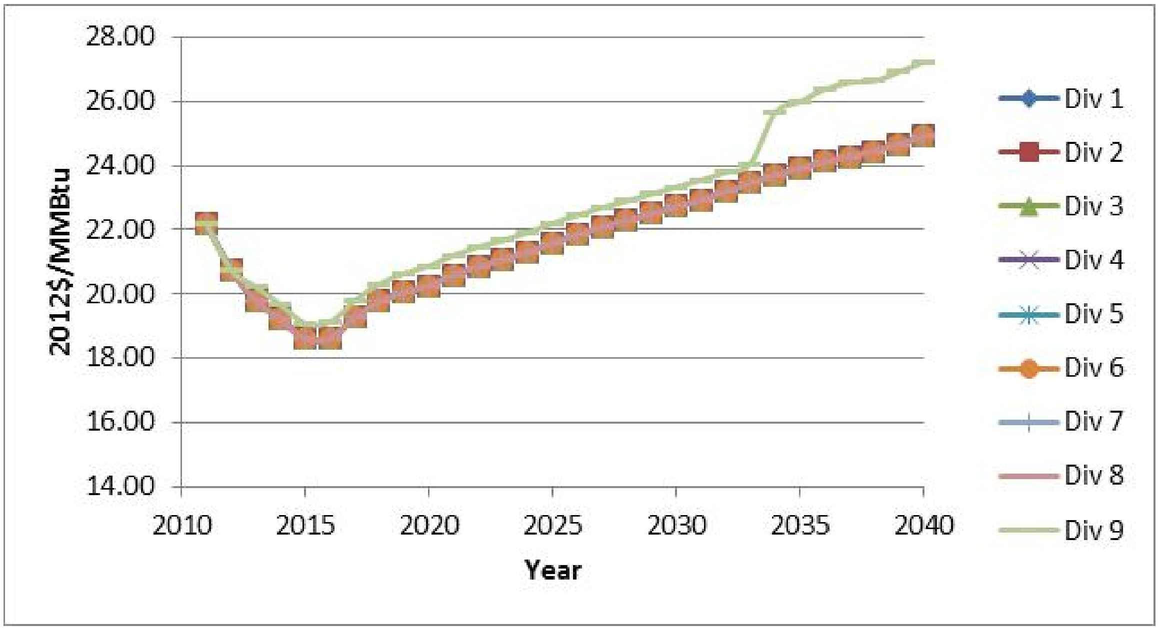

Figure 8E.6.12 Projected Commercial Division LPG Price Factors

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APPENDIX 8F. MAINTENANCE AND REPAIR COST DETERMINATION FOR RESIDENTIAL FURNACES

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8F.1 INTRODUCTION

This appendix provides further details about the derivation of maintenance and repair costs for non-weatherized gas furnaces (NWGFs) and mobile home gas furnaces (MHGFs).

The Department of Energy (DOE) estimated maintenance and repair costs for NWGFs and MHGFs based on RS Means, a well-known and respected construction cost estimation method, as well as manufacturer literature and information from expert consultants. Table 8F.1.1 offers an example of the cost calculation method. All labor costs are derived using the latest residential repair and remodeling 2013 RS Means labor costs by crew type.[1] Maintenance and repair cost tables include a trip charge, which is often charged by contractors and calculated to be equal to one half hour of labor per crew member. Labor hours (or person-hours) are based on RS Means data and expert data. Bare costs are all the costs without any markups. Material costs are based on RS Means data, expert data, or internet sources. The total includes overhead and profit (O&P), which is calculated using labor and material markups from RS Means. Values reported in this appendix are based on national average 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 tomore accurately estimate maintenance costs by region. Section 8F.4 describes the derivation of regional labor costs. DOE then applied the appropriate regional labor cost to each RECS sample household. The total costs include O&P.

Table 8F.1.1 Example Cost Table

Description	Crew	Labor Hours	Unit	Bare Costs *(2012$)*			Quantity	Total incl. O&P
				Material	Labor	Total		
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**

8F.2 MAINTENANCE COST FOR RESIDENTIAL FURNACES

The maintenance cost is the routine annual cost to the consumer of general maintenance for equipment operation. DOE estimated maintenance costs at each considered efficiency level using a variety of sources, including *2013 RS Means Facility Repair and Maintenance Data*,[2] manufacturer literature, and information from expert consultants. For AFUE standards analysis, DOE assumed that this maintenance cost is higher for condensing furnaces. DOE added additional maintenance requirements for condensing furnaces including additional inspection of condensate system and replacement of neutralizer filter. For standby and off mode standards, DOE assumed no additional maintenance costs for the baseline or higher efficiency design options. DOE accounted for regional differences in labor costs, as is discussed in section 8F.4.

The frequency with which the maintenance occurs was derived from RECS 2009 and CBECS 2003 data about how often furnace owners perform maintenance. Survey respondents identified whether they performed regular maintenance. The frequency with which the maintenance occurs was derived from a 2008 consumer survey[3] on the frequency with which owners of different types of furnaces perform maintenance. DOE assumed that regularly maintained furnaces reported in RECS or CBECS are maintained 62 percent of the time every year and 20 percent of the time every two years, and 18 percent of the time every 5 years, while furnaces that are not regularly maintained are assumed to not be maintained regularly (see Table 8F.2.1).

Table 8F.2.1 Maintenance Fractions based on 2008 American Home Comfort Survey

2008 American Home Comfort Survey Data		**DOE Analysis Assumptions**		
Frequency of Reported of Last Gas Furnace Maintenance	**Fraction of Households Furnace**	**Reported Regular Maintenance**	**Assumed Frequency for Analysis**	**Fraction of Households**
Within a year	62%	Yes	Annual	26%
Within two years	20%		Every Two Years	9%
Over 2 years	18%		Every 5 years	8%
		No	Never	58%

DOE assumed that labor hours required to perform the furnace maintenance tasks would be 1.495 hours as reported in RS Means in addition to a 0.5 hours for the trip charge.[2] For condensing furnaces, DOE assumed an additional 0.077 labor hours to check the condensate withdrawal system. DOE also assumed that the condensate neutralizer is cleaned every 3 years if present, which requires an additional 0.078 hours for each cleaning.

8F.3 REPAIR COST FOR RESIDENTIAL FURNACES

The repair cost is the cost to the consumer for replacing or repairing components in the furnace that have failed. DOE estimated repair costs at each considered efficiency level using a variety of sources, including *2013 RS Means Facility Repair and Maintenance Data*,[4] manufacturer literature, and information from expert consultants. DOE accounts for regional differences in labor costs, as discussed in appendix 8D.

Table 8F.3.1 and Table 8F.3.2 show repair rate and cost assumptions that DOE used in its analysis. The failure year distribution was assumed to be a Weibull function for each component.

Table 8F.3.1 Furnace Repair Rates

Repair Description	Mean Failure Year	Repair Rate
Ignition, Controls, Inducer Fan	10	25%
Mechanical Vent Damper or Power Vent Blower	14	25%

Table 8F.3.2 Furnace Repair Costs

Repair Description	Bare Material Cost (2013$)*	Total Labor Hours
Ignition, Controls, Gas Valve (Baseline)	$233.00	2.25
Ignition, Controls, Gas Valve (Condensing)	$291.25	2.75
Fan Blower	$274.00	3.43

*Does not include sales tax or markups by trade from RS Means.

8F.4 REGIONAL MATERIAL AND 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. DOE used the residential repair and remodeling labor cost from RS Means crew type Q1 (1 Plumber, 1 Plumber Apprentice) for all repair and maintenance labor cost calculations as shown in Table 8F.4.1.[1] 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 8F.4.2.

Table 8F.4.1 RS Means 2013 National Average Labor Costs by Crew

Crew Type	Crew Description	Laborers per Crew	Cost per Labor-Hour	
			Bare Costs	Incl. O&P*
2013 RS Means Labor Costs Data (Residential, Repair/Remodeling)				
Q1	1 Plumber, 1 Plumber Apprentice	2	$50.23	$78.15

* O&P includes markups in Table 8F.4.2

Table 8F.4.2 RS Means Labor Costs Markups by Trade

Trade	Workers Comp.	Aver Fixed Overhead	Overhead	Profit	Total
Plumber (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 U.S. To derive average labor cost values by state, DOE weighted the price factors by city or town population size using 2012 census data. DOE used the material and labor cost factors for cost associated with fire suppression, plumbing, and HVAC. See appendix 8D for more details.

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APPENDIX 8G. RESIDENTIAL FURNACE LIFETIME DETERMINATION

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8G.1 INTRODUCTION

DOE defines lifetime as the age when a product is retired from service. DOE notes that a large percentage of non-weatherized gas furnace and manufactured home gas furnace (NWGF and MHGF) equipment now on the market were not available 10 or more years ago and therefore comprehensive lifetime data is not yet available. Also, there is an ongoing evolution of the NWGF and MHGF component lifetime of which has not been thoroughly assessed yet.[1]

DOE used national survey data, along with manufacturer shipment data, to calculate the distribution of NWGF and MHGF lifetimes. DOE assumed that the lifetime of a NWGF or MHGF is the same at different efficiency levels. DOE assumed a median lifetime value of about 21.5 years for both NWGFs and MHGFs based on an updated literature review from that which was performed in the analysis for the 2014 residential furnace fans final rule.[2]

8G.2 LIFETIME LITERATURE REVIEW

To capture lifetime variances due to new furnace technologies, DOE performed a lifetime literature review. Table 8G.2.1 presents a range of product lifetimes and sources found by DOE. DOE used this information together with the methodology described in section 8G.3 to estimate the lifetime for NWGFs and MHGFs.

Table 8G.2.1 Non-Weatherized Gas Furnaces and Manufactured Home Gas Furnaces: Product Lifetime Estimates and Sources

Typical Lifetime or Range (years)	**Source**
Unspecified Fuel Type	
18	GRI (1994)[1]
15-20	National Association of House Builders (NAHB) (2007)[3]
20.3	American Home Comfort Survey (AHCS) (2004)[4]
20.1	AHCS (2006)[4]
20.2	AHCS (2008)[4]
19.6	AHCS (2013)[5]
15	RS Means 2013[6]
15	Old House Web[7]
Min = 10; Max = 25	National Energy Modeling System (NEMS)[8]
Gas	
20	Department of Community Affairs (DCA) (2011)[9]
Median = 22.61; Mean = 23.63	Lawrence Berkeley National Lab (LBNL) (2011)[10]
18*	Mid-Atlantic Technical Reference Manual (2011)[11]
18	Mid-Atlantic Technical Reference Manual (2011)[11]
18	Old House Web[7]
18	Building Owners and Managers Association (BOMA)[12]

* Condensing

8G.3 METHODOLOGY

DOE's lifetime methods are based on the approach described in "Using national survey data to estimate lifetimes of residential appliances" paper.[10]

Energy Information Administration (EIA)'s Residential Energy Consumption Survey (RECS) from 1990-2009[13] surveyed occupied primary housing units, noting the presence of a range of appliances and placing the age of each appliance into several-year bins. The U.S. Census's *American Housing Survey* (AHS) from 1974-2011[14] surveyed all housing, including vacant and second homes, noting the presence of a range of appliances. Using the AHS data allowed DOE to adjust the RECS data to reflect some appliance use outside of primary residences. AHS also has a larger sample size, with correspondingly smaller sampling error. By combining these survey results with the historical shipments data DOE estimated the fraction of appliances of a given age still in operation. The historical shipments data is described in more detail in appendix 9B.[a] This survival function, which DOE assumed has the form of a cumulative Weibull distribution, provides an estimate of the average and median appliance lifetime.

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[a] Since neither RECS or AHS distinguish between NWGFs and WGFs, DOE included WGF shipments to the shipments described in appendix 9B for NWGFs and MHGFs based on AHRI shipments data from 2004-2009.[15]

The Weibull distribution is a probability distribution function commonly used to measure failure rates.[16] 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:

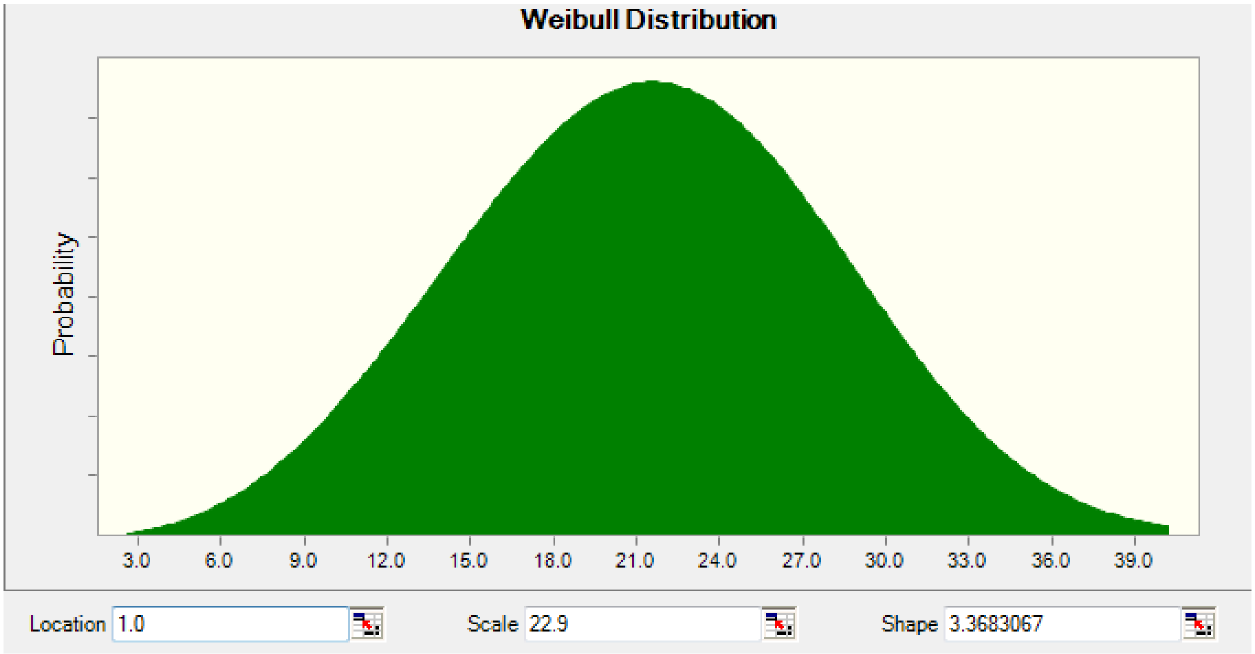
$$P(x) = e^{-\left(\frac{x-\theta}{\alpha}\right)^{\beta}} \text{ for } x > \theta \text{ and } P(x) = 1 \text{ for } x \leq \theta,$$

Eq. 8G.1

Where:

$P(x)$ = probability that the appliance is still in use at age x,
x = appliance 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 $\beta = 1$, the failure rate is constant over time, and this distribution takes the form of a cumulative exponential distribution. For the case of appliances, β is commonly greater than 1, which results from a rising failure rate as the appliance ages. A plot of a Weibull distribution (DOE's calculated furnace survival function) is shown as Figure 8G.3.1.



Location 1.0
Scale 22.9
Shape 3.3683067

Figure 8G.3.1 **Lifetime Distribution for Non-Weatherized Gas Furnaces and Manufactured Home Gas Furnaces**

The RECS survey is DOE's primary resource for furnace ages. For several appliances, including furnaces, the survey asks respondents to place the appliance's age into one of these bins:[b]

- less than 2 years;
- 2 to 4 years;
- 5 to 9 years;
- 10 to 19 years and
- more than 20 years.

The RECS survey has been conducted every 3 or 4 years for the last several decades. For this analysis, DOE used the RECS surveys conducted in 1990, 1993, 1997, 2001, 2005, and 2009.[13] DOE also used the biennial AHS surveys conducted from 1974 to 2011.[14] DOE used the AHS count of housing units with furnaces to scale the RECS data to better match the total installed stock. DOE used the surveys' household-level micro-data to count households with shared or multiple furnaces. Households that did not know the age of their appliances were allocated among the remaining age bins according to the distribution of respondents who did report their appliance age.

DOE used appliance age data derived from RECS, AHS total installed stock data, and the historical furnace shipments to generate an estimate of the survival function. For example, DOE summed the total shipments from 5 to 9 years prior to the RECS survey, and compared this number with the number of units of those ages still in use, to calculate one approximation of the surviving appliance fraction within that age bin. The AHS total stock acts as an "all ages" bin. By combining the age bins from five RECS surveys and nine AHS surveys with shipments data, DOE had enough data to build a fit to a Weibull distribution and find the parameters (α, β, θ) that best approximate the surviving units, using a least-squares method. Because the first two (youngest) RECS bin data tend to have a large scatter relative to the shipments in those years, DOE combined the RECS and shipments data in the first two bins. Generally, appliances do not tend to fail in large numbers during this period, so combining bins does not appreciably lower the accuracy of the shape of the distribution. DOE weighted each bin's contribution to the sum of squares by the inverse of the variance in the survey results, which controls for the changes in sample size between RECS bins, between RECS and AHS, and within each survey over time.[17] RECS and AHS have complicated error models; DOE used only the error due to finite sample size to determine the variance used to weight each data point's contribution. The error due to sampling is less than 1 percent for AHS survey data and is typically about 5 percent for RECS age bins. The equation for the sum of squares DOE minimized is therefore:

---

[b] For RECS 2009 the 10 to 19 year bin is split into two bins (10 to 14 years and 15 to 19 years).

$$\sum_i \frac{\left(\boldsymbol{RECS}_i - \boldsymbol{Surv}_i\right)^2}{\sigma^2_{i,RECS}} + \sum_j \frac{\left(\boldsymbol{AHS}_j - \boldsymbol{Surv}_j\right)^2}{\sigma^2_{j,AHS}}$$

Eq. 8G.2

Where:

i = the identifier for a bin from a single RECS,
j = the identifier for a single AHS survey,
$RECS_i$ = the number of appliances reported by RECS in bin i,
AHS_j = the number of appliances reported by AHS in survey year j,
$Surv_i$ = the number of surviving appliances in bin i predicted by the Weibull distribution applied to the number of appliances shipped (a function of α, β, and θ),
$\sigma_{i,RECS}$ = the standard error (square root of the variance) of the RECS data point for bin i, and
$\sigma_{j,AHS}$ = the standard error (square root of the variance) of the AHS data point for year j.

DOE adjusted the RECS and AHS survey data in several ways to align the timing of the survey data with the historical shipment data. In particular, DOE adjusted for the fact that the RECS survey is scaled to July of its reference year, the AHS survey is conducted in the middle portion of the year, and shipment data is provided for each calendar year. Adjustments included:

- DOE modeled the additional retirement of older appliances and their replacement by new ones that took place in the latter half of the survey year (after a given respondent had been surveyed), using the survival function. This had the effect of moving households from the older RECS age bins to the youngest age bin.
- For appliances installed directly in new construction, such as furnaces, DOE added units to the youngest RECS age bin and to the AHS total stock to represent half of the new construction for the final year of the survey, which were known to have installed the appliance type in question, using data from the U.S. Census for new construction starts.

8G.3.1 Assumptions

DOE's lifetime-calculation technique depends on several assumptions:

- Appliance lifetime can be modeled by a survival function. In particular, a Weibull distribution is an appropriate survival function.
- The appliance survival function does not change over time.
- The survival function is independent of other household factors (such as household size, region, etc.) as well as product class (within furnaces).
- The age bin for the appliance as reported by the RECS respondent is correct.
- The historical shipment data is correct.
- The Weibull delay parameter, θ, is limited to between 1 and 5 years.

Three of these assumptions are of particular importance. The first is the assumption that a Weibull distribution is the correct distribution to use for appliance retirement rates. This distribution is the standard distribution for use in lifetime analysis, but it is not guaranteed to reflect actual consumer behavior. The second assumption is that consumer behavior and mechanical appliance lifetime have not changed over time. This assumption required DOE to treat all data from different RECS surveys on an equal footing. Using only recent surveys (to potentially better reflect recent consumer behavior and appliance lifetime) would result in attempted least-squares fits using a small number of data points, leading to large statistical uncertainty.

DOE limited 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 $\theta > 5$ also commonly show nonsensical behavior with sharp changes in consumer behavior or appliance survival immediately following the "delay" period.

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APPENDIX 8H. DISTRIBUTIONS USED FOR DISCOUNT RATES

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APPENDIX 8H. DISTRIBUTIONS USED FOR DISCOUNT RATES

8H.1 INTRODUCTION

The Department of Energy (DOE) estimated discount rate distributions by consumer type: residential and commercial consumers. This appendix describes the distributions used.

8H.2 DISTRIBUTIONS USED FOR RESIDENTIAL CONSUMER DISCOUNT RATES

The Department of Energy (DOE) derived consumer discount rates for the life-cycle cost (LCC) analysis using data on interest or return rates for various types of debt and equity to calculate a real effective discount rate for each household in the Federal Reserve Board's *Survey of Consumer Finances* (*SCF*) in 1995, 1998, 2001, 2004, 2007, and 2010.[1] To account for variation among households in rates for each of the types, DOE sampled a rate for each household in its building sample from a distribution of discount rates for each of six income groups. This appendix describes the distributions used.

8H.2.1 Distribution of Rates for Debt Classes

Figure 8H.2.1 through Figure 8H.2.6 show the distribution of real interest rates for different types of household debt. The data source for the interest rates for mortgages, home equity loans, credit cards, installment loans, other residence loans, and other lines of credit is the Federal Reserve Board's *SCF* in 1995, 1998, 2001, 2004, 2007, and 2010.[1] DOE adjusted the nominal rates to real rates using the annual inflation rate in each year.

Using the appropriate *SCF* data for each year, DOE adjusted the nominal mortgage interest rate and the nominal home equity loan interest rate for each relevant household in the *SCF* for mortgage tax deduction and inflation. In cases where the effective interest rate is equal to or below the inflation rate (resulting in a negative real interest rate), DOE set the real effective interest rate to zero.

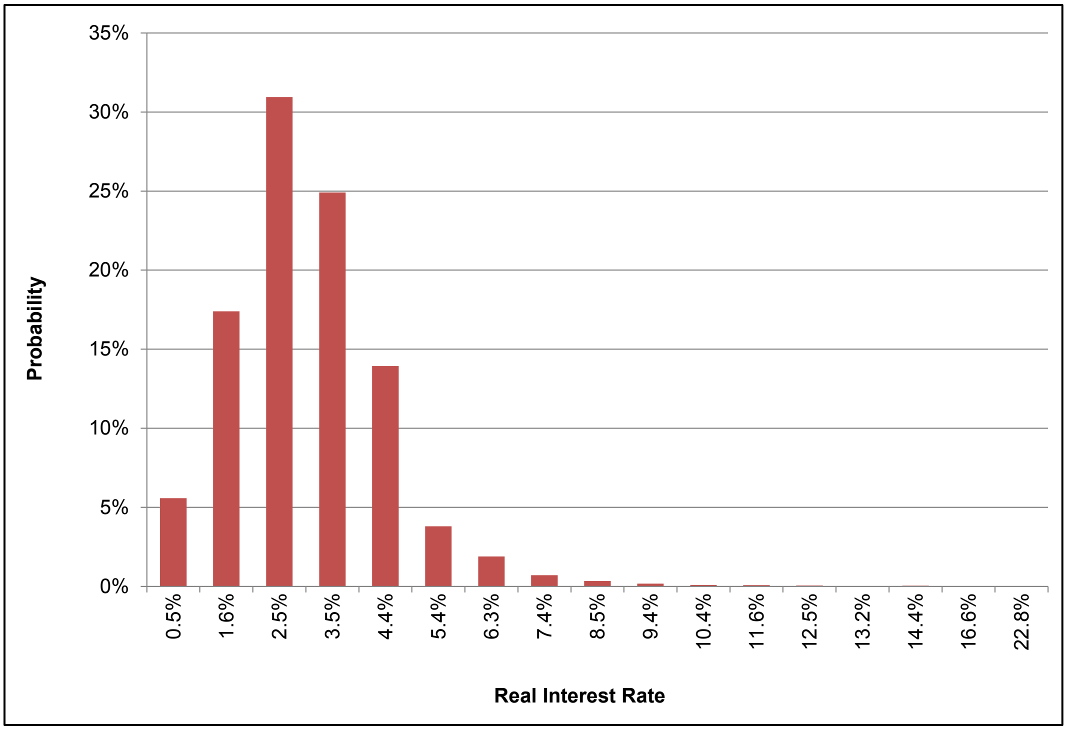

Figure 8H.2.1 Distribution of Mortgage Interest Rates

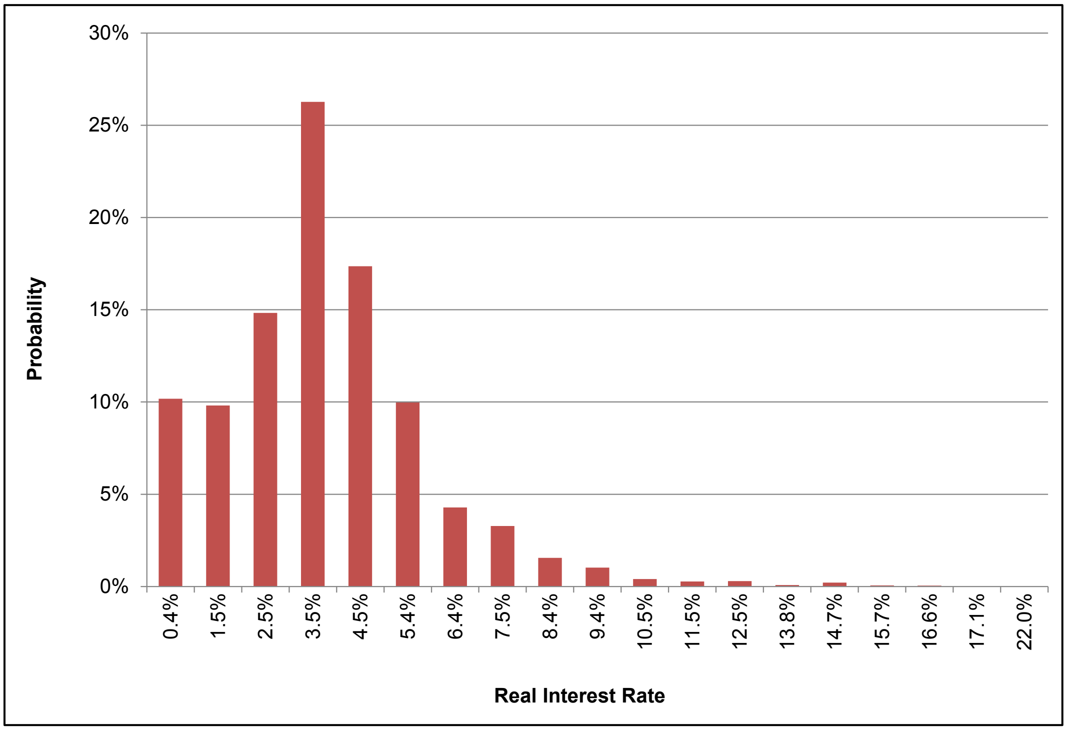

Figure 8H.2.2 Distribution of Home Equity Loan Interest Rates

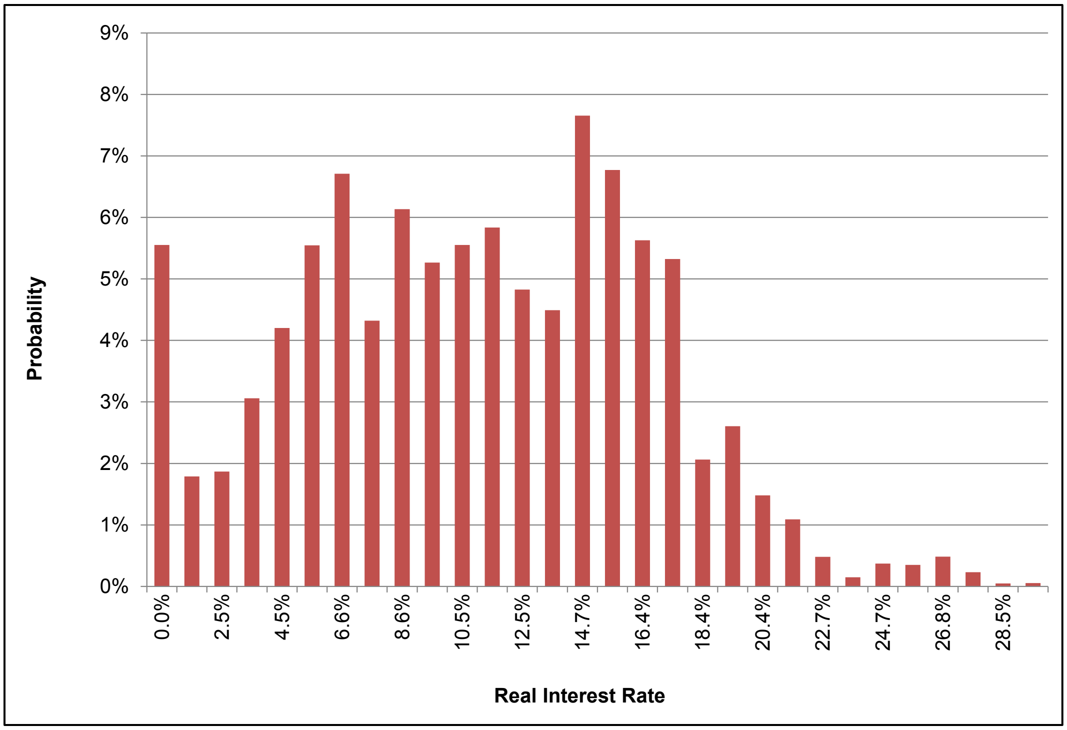

Figure 8H.2.3 **Distribution of Credit Card Interest Rates**

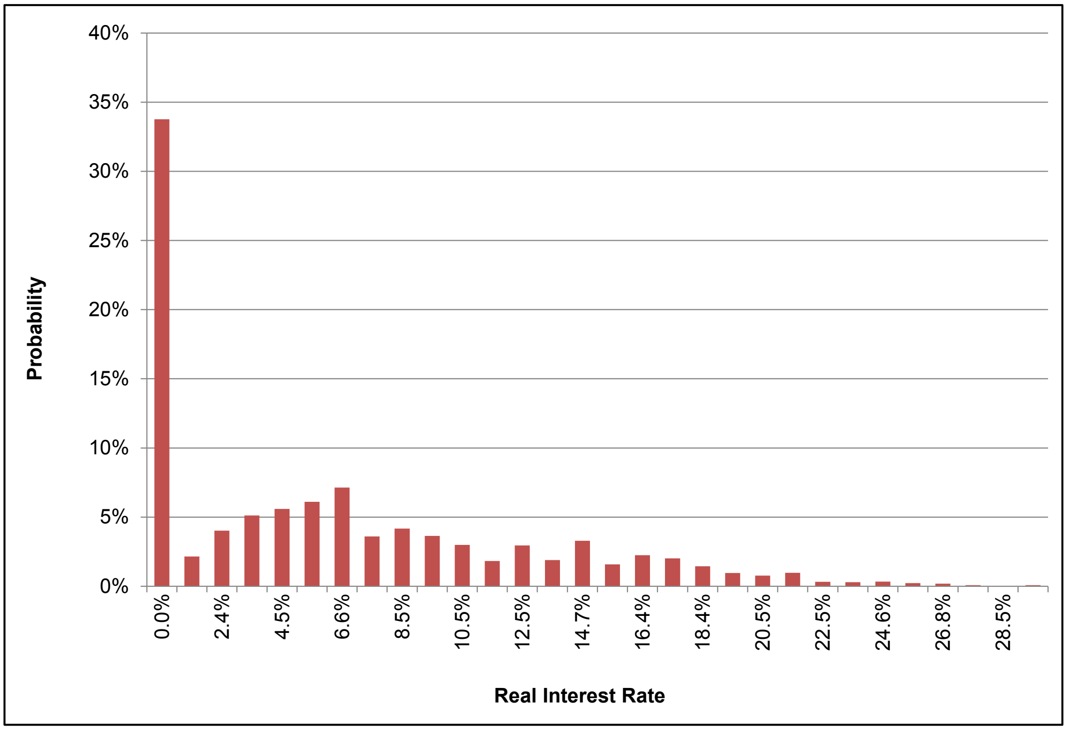

Figure 8H.2.4 **Distribution of Installment Loan Interest Rates**

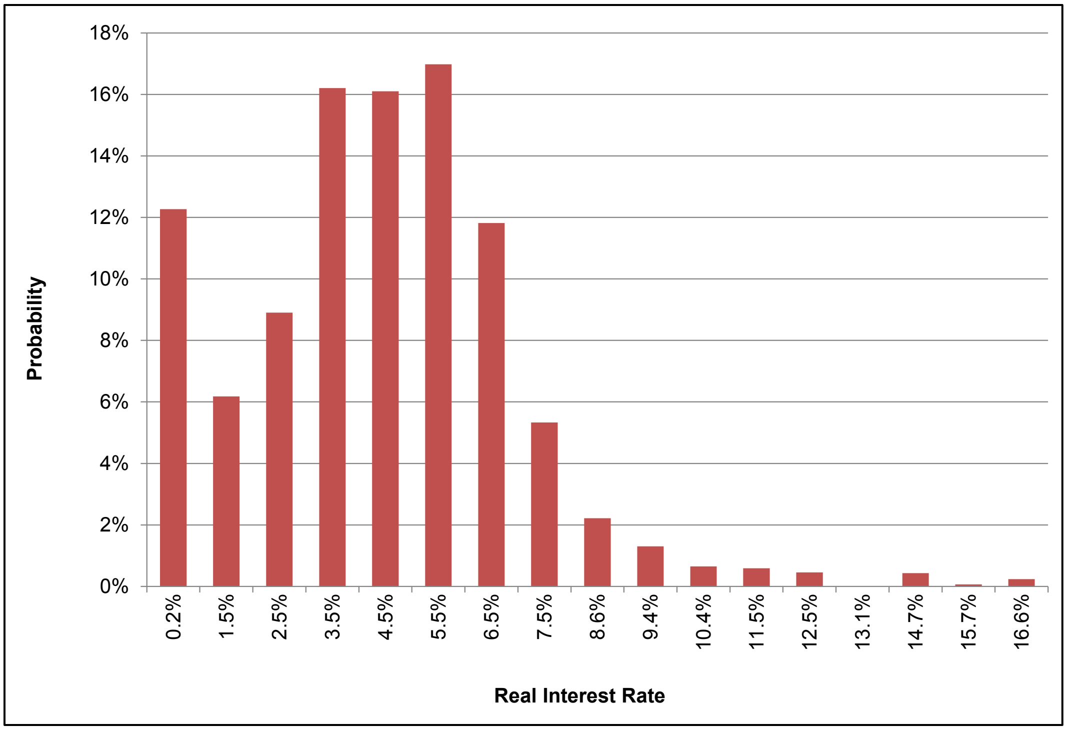

Figure 8H.2.5 Distribution of Other Residence Loan Interest Rates

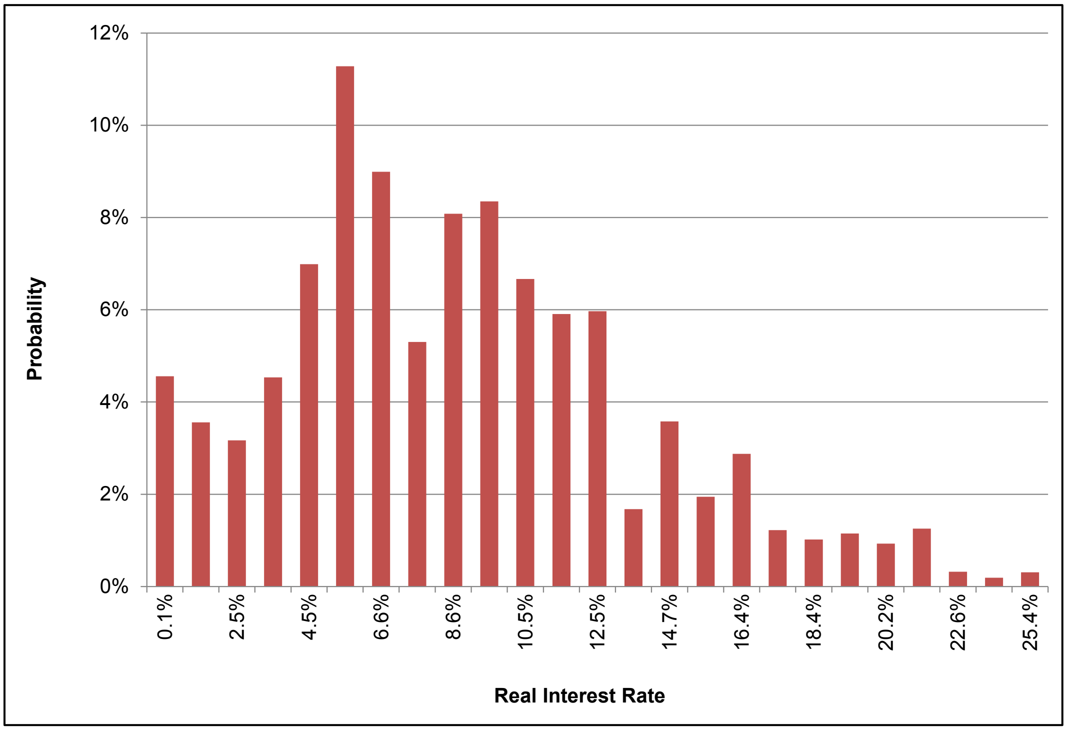

Figure 8H.2.6 Distribution of Other Lines of Credit Loan Interest Rates

8H.2.2 Distribution of Rates for Equity Classes

Figure 8H.2.7 through Figure 8H.2.13 show the distribution of real interest rates for different types of equity. Data for equity classes are not available from the Federal Reserve Board's *SCF*, so DOE derived data for these classes from national-level historical data (1984-2013). The interest rates associated with certificates of deposit (CDs),[2] savings bonds,[3] and AAA corporate bonds[4] are from Federal Reserve Board time-series data. DOE assumed rates on checking accounts to be zero. Rates on savings and money market accounts are from Cost of Savings Index data.[5] The rates for stocks are the annual returns on the Standard and Poor's (S&P) 500.[6] The mutual fund rates are a weighted average of the stock rates (two-thirds weight) and the bond rates (one-third weight) in each year. DOE adjusted the nominal rates to real rates using the annual inflation rate in each year.

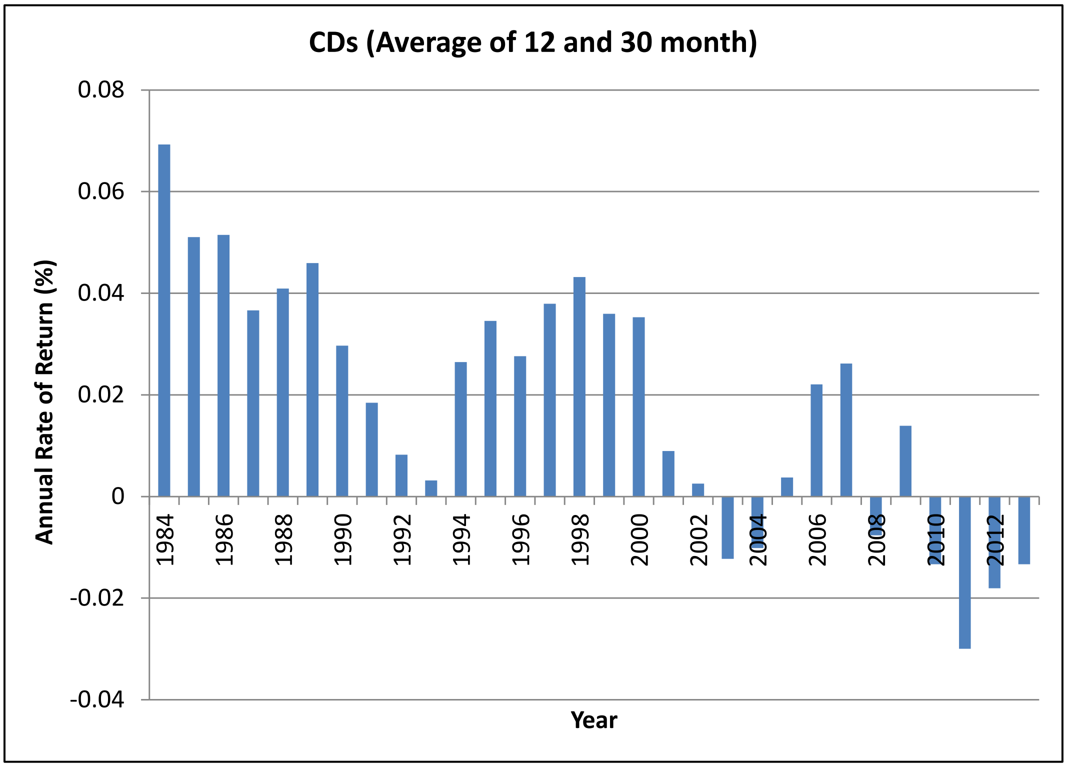

Figure 8H.2.7 Distribution of Annual Rate of Return on CDs

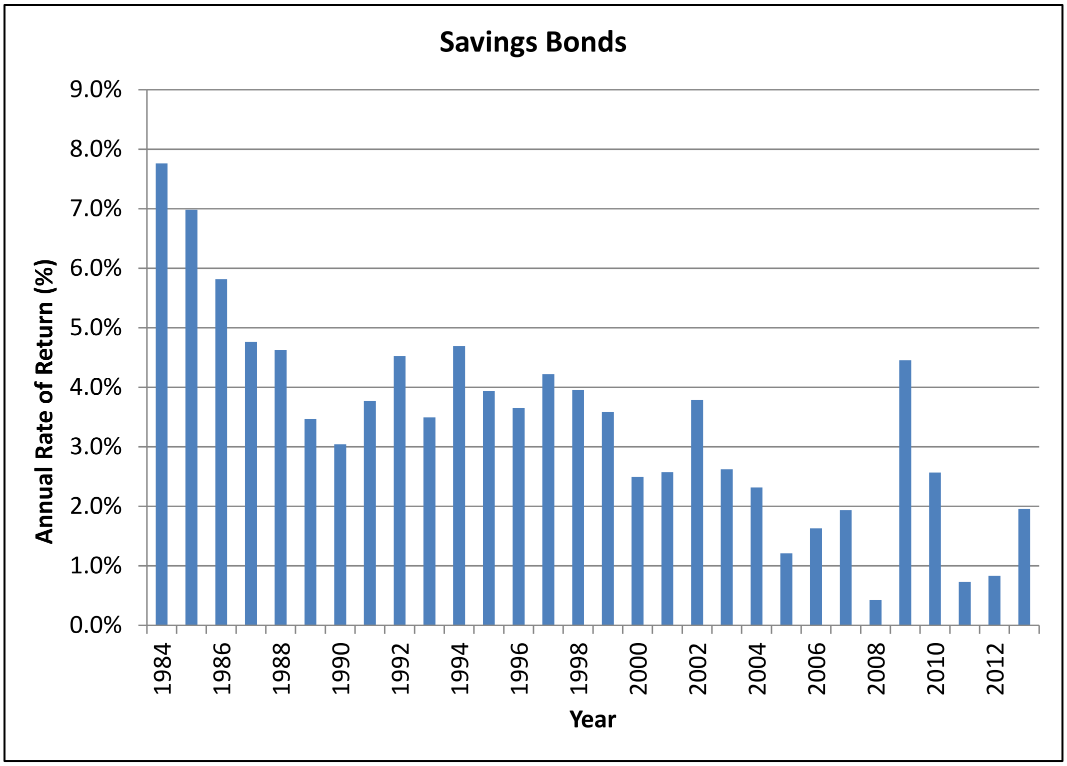

Figure 8H.2.8 Distribution of Annual Rate of Return on Savings Bonds

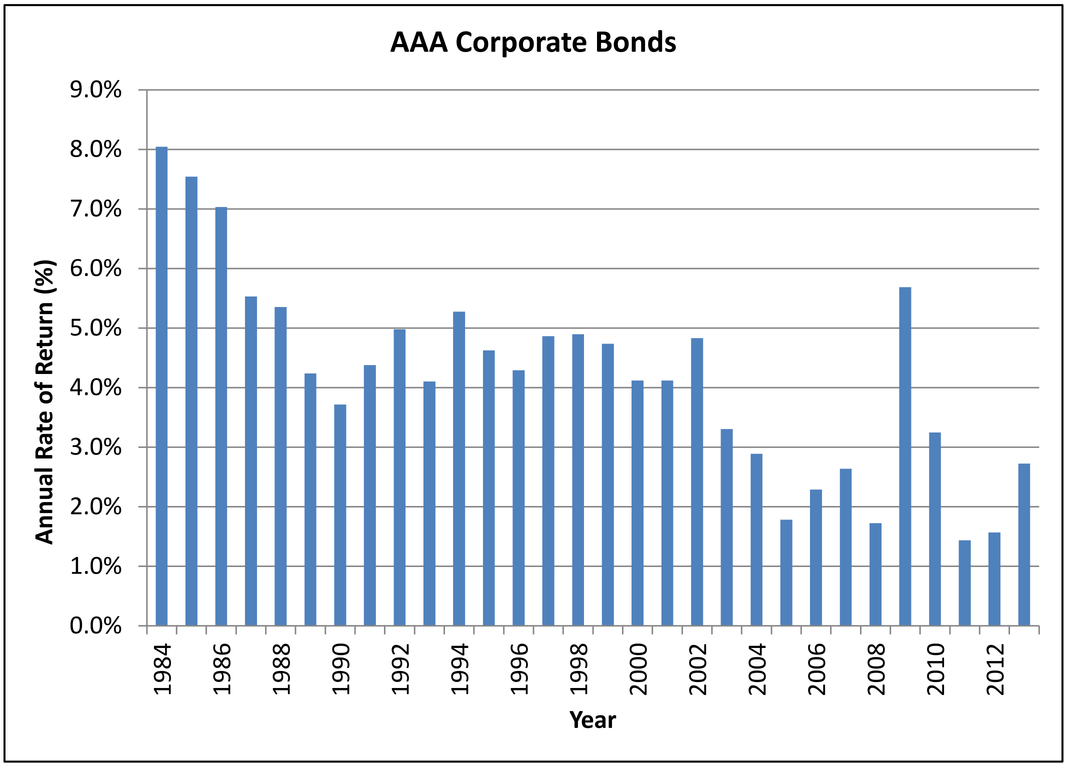

Figure 8H.2.9 Distribution of Annual Rate of Return on Corporate AAA Bonds

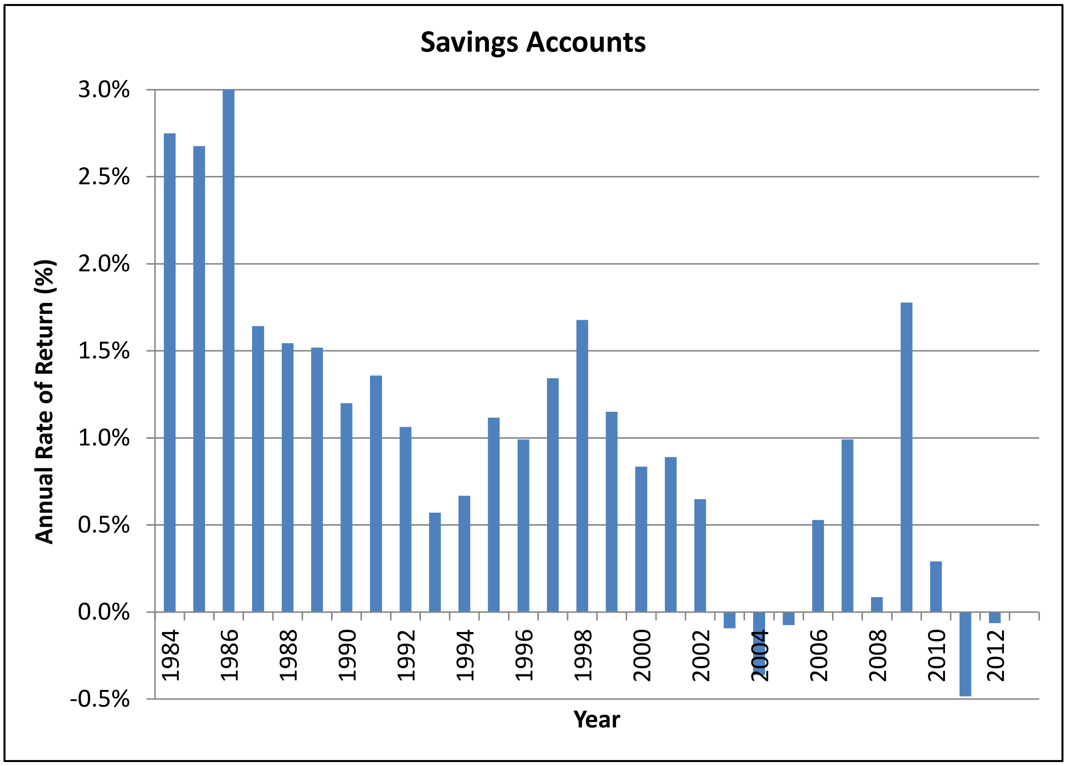

Figure 8H.2.10 Distribution of Annual Rate of Savings Accounts

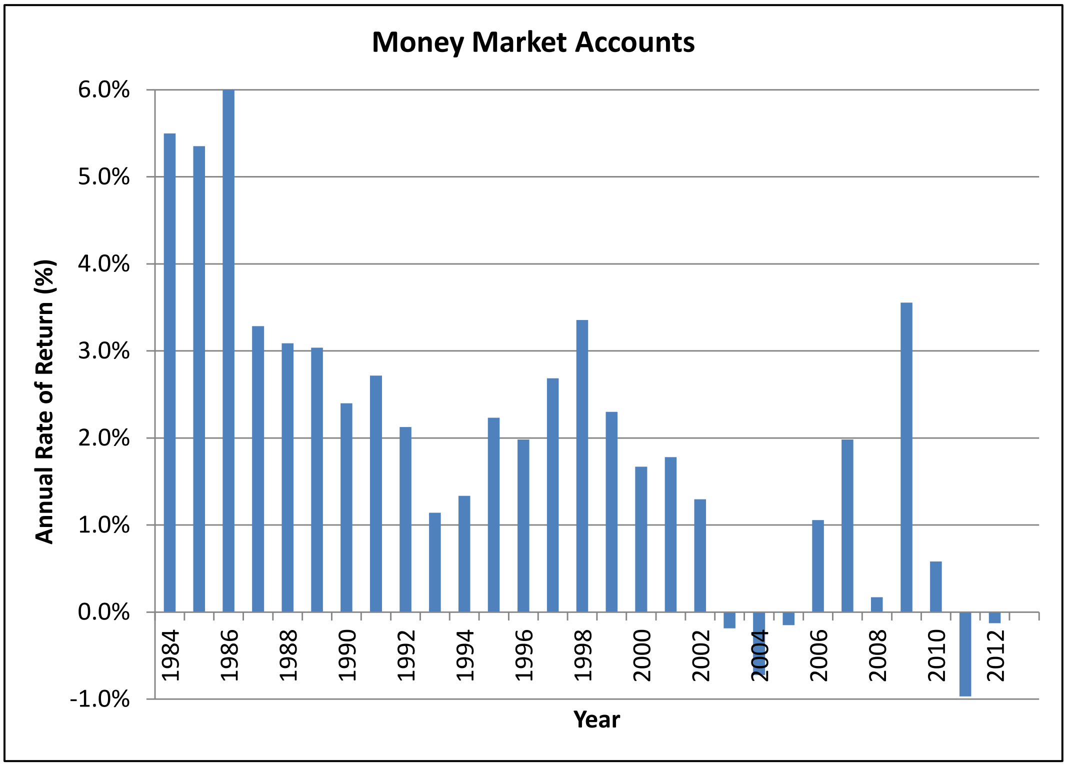

Figure 8H.2.11 Distribution of Annual Rate of Money Market Accounts

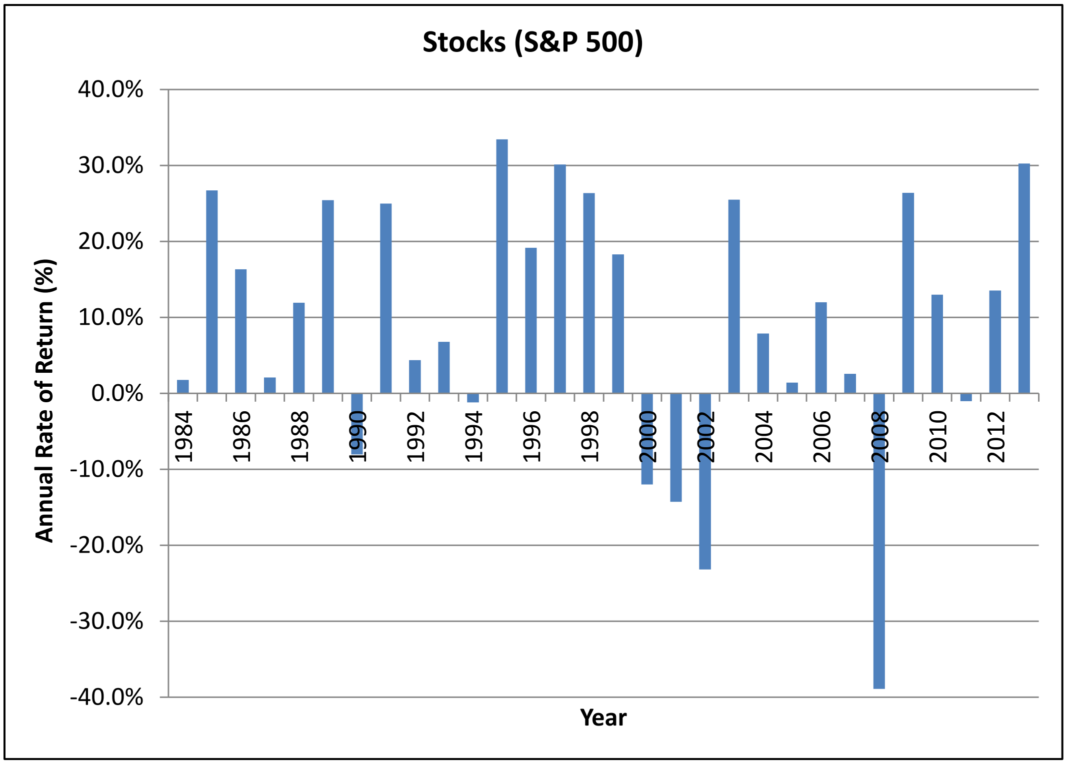

Figure 8H.2.12 Distribution of Annual Rate of Return on S&P 500

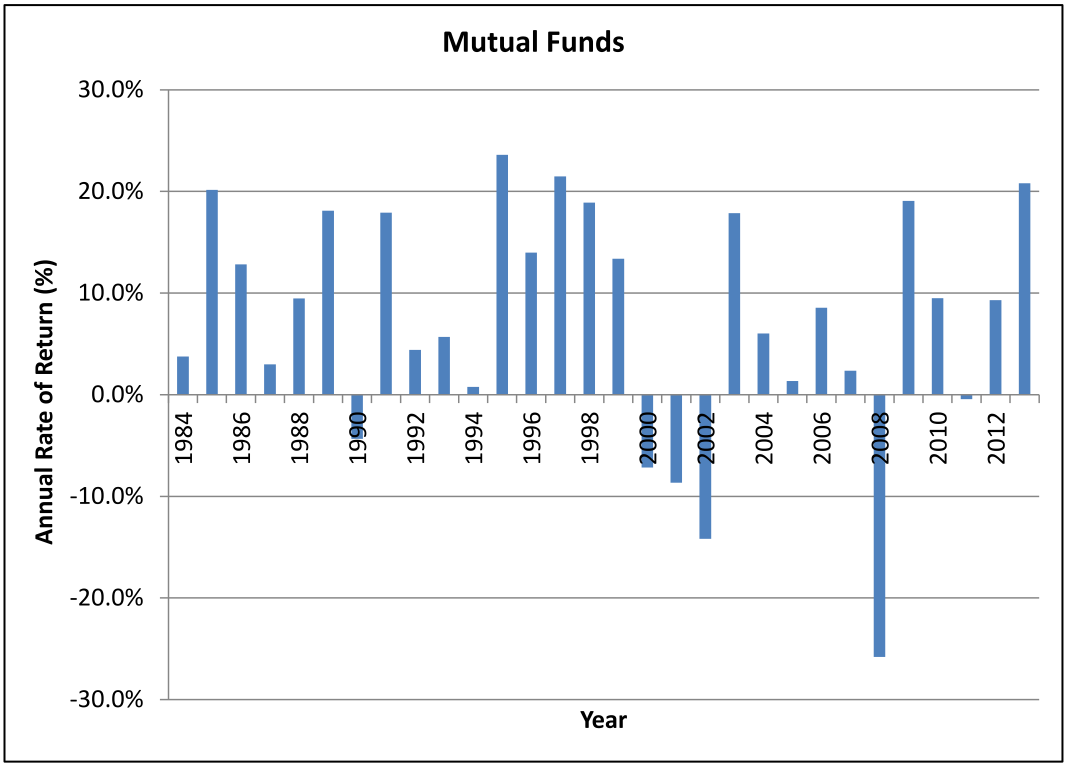

Figure 8H.2.13 Distribution of Annual Rate of Return on Mutual Funds

8H.3 DISTRIBUTION OF REAL EFFECTIVE DISCOUNT RATES BY INCOME GROUP

Figure 8H.3.1 and Table 8H.3.1 present the distributions of real discount rates for each income group.

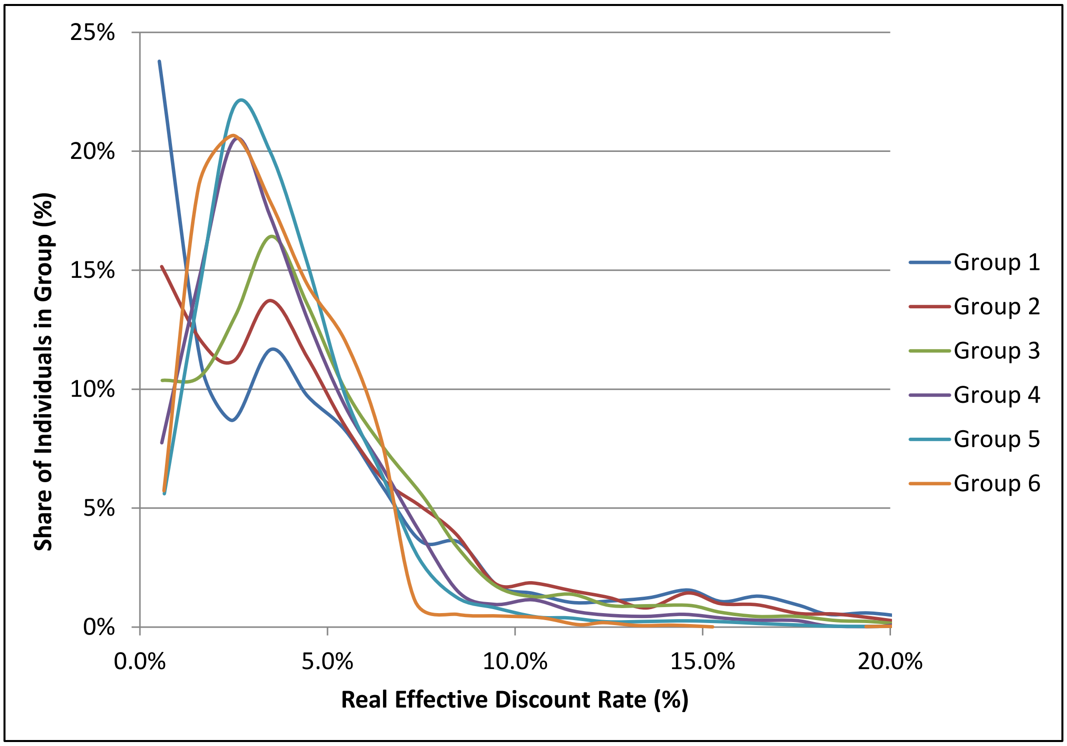

Figure 8H.3.1 Distribution of Real Discount Rates by Income Group

Table 8H.3.1 Distribution of Real Discount Rates by Income Group

DR Bin	Income Group 1 (1-20 percentile)		Income Group 2 (21-40 percentile)		Income Group 3 (41-60 percentile)		Income Group 4 (61-80 percentile)		Income Group 5 (81-90 percentile)		Income Group 6 (90-99 percentile)	
	rate	weight	rate	weight	rate	weight	rate	weight	rate	weight	rate	weight
0-1	0.5%	0.238	0.6%	0.152	0.6%	0.104	0.6%	0.077	0.6%	0.056	0.6%	0.057
1-2	1.6%	0.110	1.6%	0.120	1.6%	0.105	1.6%	0.146	1.6%	0.142	1.6%	0.185
2-3	2.5%	0.087	2.5%	0.112	2.6%	0.131	2.5%	0.205	2.5%	0.219	2.5%	0.207
3-4	3.5%	0.117	3.5%	0.137	3.5%	0.164	3.5%	0.173	3.5%	0.200	3.5%	0.178
4-5	4.5%	0.097	4.5%	0.113	4.5%	0.136	4.5%	0.129	4.5%	0.153	4.5%	0.144
5-6	5.5%	0.083	5.5%	0.084	5.5%	0.100	5.5%	0.093	5.5%	0.098	5.5%	0.120
6-7	6.5%	0.058	6.5%	0.062	6.5%	0.075	6.5%	0.067	6.5%	0.063	6.4%	0.079
7-8	7.5%	0.036	7.5%	0.051	7.6%	0.054	7.4%	0.041	7.4%	0.029	7.3%	0.011
8-9	8.5%	0.036	8.4%	0.039	8.4%	0.034	8.5%	0.015	8.4%	0.012	8.5%	0.005
9-10	9.5%	0.017	9.5%	0.018	9.5%	0.017	9.5%	0.010	9.5%	0.008	9.6%	0.005
10-11	10.5%	0.014	10.5%	0.019	10.5%	0.013	10.5%	0.011	10.6%	0.004	10.7%	0.004
11-12	11.5%	0.010	11.5%	0.015	11.5%	0.014	11.5%	0.007	11.4%	0.004	11.7%	0.001
12-13	12.5%	0.011	12.5%	0.012	12.5%	0.009	12.4%	0.005	12.4%	0.002	12.4%	0.002
13-14	13.6%	0.012	13.5%	0.008	13.5%	0.009	13.5%	0.004	13.5%	0.002	13.3%	0.001
14-15	14.6%	0.016	14.6%	0.014	14.6%	0.009	14.5%	0.005	14.6%	0.003	14.2%	0.001
15-16	15.5%	0.011	15.5%	0.010	15.5%	0.006	15.6%	0.004	15.6%	0.002	15.3%	0.000
16-17	16.5%	0.013	16.5%	0.009	16.5%	0.004	16.5%	0.003	16.5%	0.001	0.0%	0.000
17-18	17.5%	0.009	17.6%	0.006	17.5%	0.005	17.5%	0.003	17.6%	0.001	17.7%	0.001
18-19	18.4%	0.005	18.5%	0.005	18.6%	0.003	18.4%	0.001	18.2%	0.000	0.0%	0.000
19-20	19.4%	0.006	19.4%	0.004	19.4%	0.002	19.7%	0.000	19.7%	0.000	19.4%	0.000
20-21	20.6%	0.004	20.4%	0.002	20.5%	0.001	20.3%	0.001	20.5%	0.000	20.3%	0.000
21-22	21.4%	0.003	21.4%	0.002	21.4%	0.001	21.5%	0.001	0.0%	0.000	21.4%	0.000
22-23	22.5%	0.002	22.4%	0.001	22.6%	0.001	22.9%	0.000	22.8%	0.000	22.3%	0.000
23-24	23.6%	0.001	23.4%	0.001	23.6%	0.001	0.0%	0.000	0.0%	0.000	24.0%	0.000
24-25	24.6%	0.001	24.5%	0.000	24.6%	0.000	24.1%	0.000	24.3%	0.000	0.0%	0.000
25-26	25.4%	0.001	25.4%	0.001	25.5%	0.000	0.0%	0.000	0.0%	0.000	0.0%	0.000
26-27	26.5%	0.001	26.5%	0.000	26.4%	0.000	0.0%	0.000	0.0%	0.000	0.0%	0.000
27-28	27.8%	0.000	27.6%	0.000	27.8%	0.000	0.0%	0.000	0.0%	0.000	0.0%	0.000
28-29	28.2%	0.000	0.0%	0.000	0.0%	0.000	0.0%	0.000	0.0%	0.000	0.0%	0.000
29-23	29.9%	0.000	29.3%	0.000	0.0%	0.000	0.0%	0.000	0.0%	0.000	0.0%	0.000
>30	59.1%	0.001	142.7%	0.002	0.0%	0.000	53.3%	0.000	0.0%	0.000	0.0%	0.000

8H.4 DISTRIBUTIONS USED FOR COMMERCIAL DISCOUNT RATES

DOE derived commercial discount rates (*i.e.*, weighted average cost of capital) for the life-cycle cost (LCC) analysis using the capital asset pricing model and firm-level data provided by Damodaran Online.[7] State and local government discount rates were estimated using the rate of return on 20-year municipal bonds, as provided by the Federal Reserve Board.[3] Separate distributions were constructed for each major industry. Figure 8H.4.1 through Figure 8H.4.10 show the probability distributions of commercial discount rates by industry.

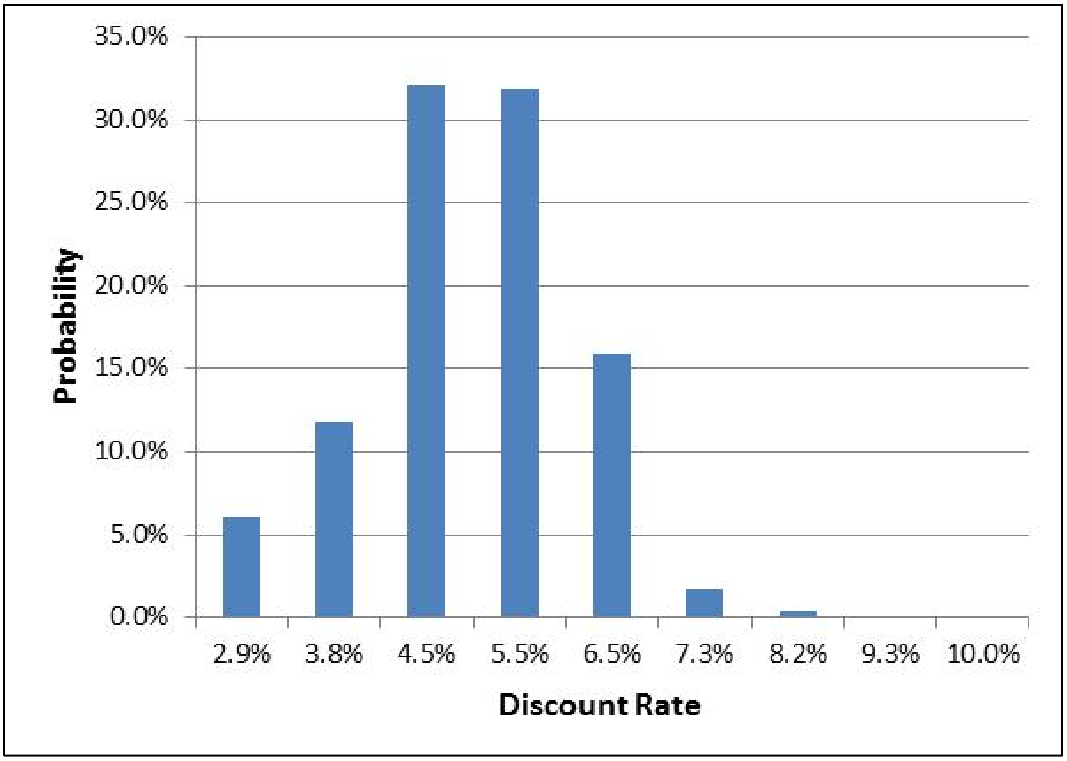

Figure 8H.4.1 Distribution of Commercial Discount Rates: Retail

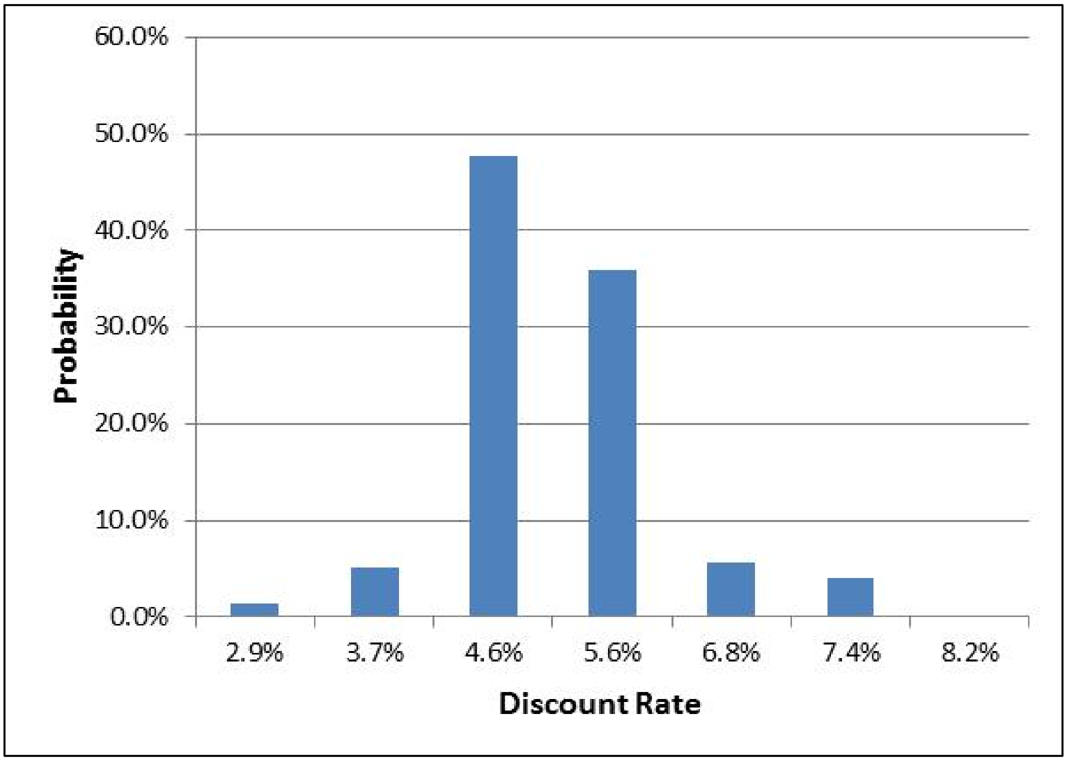

Figure 8H.4.2 Distribution of Commercial Discount Rates: Property

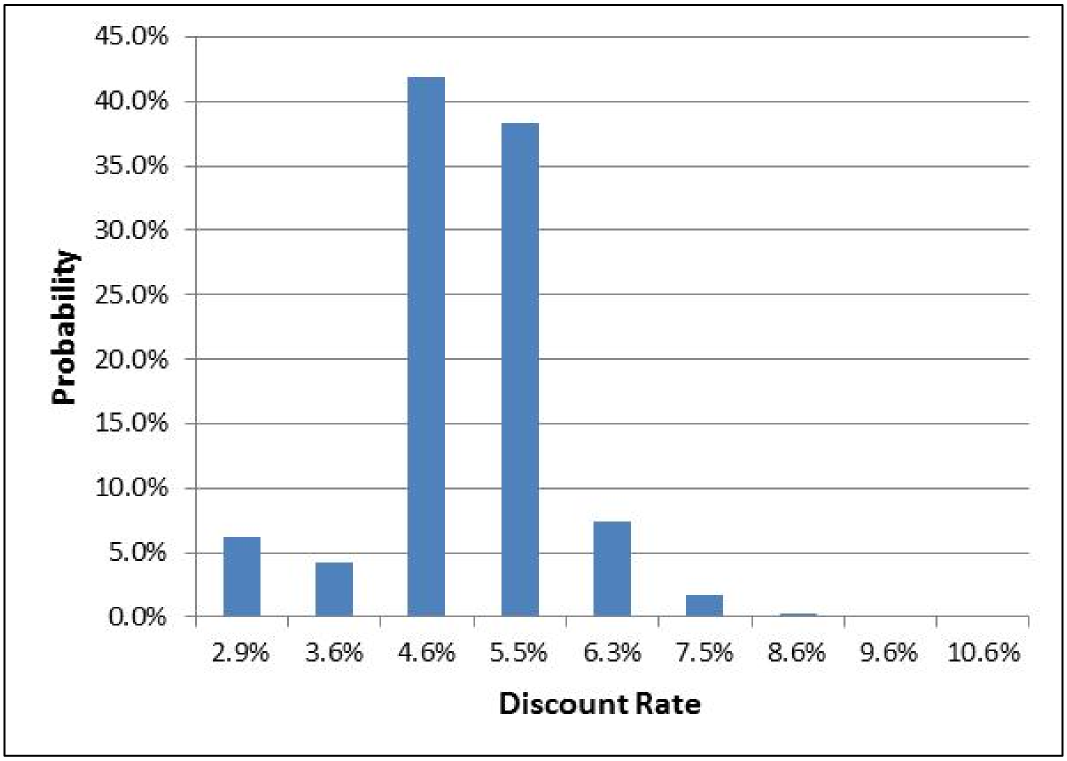

Figure 8H.4.3 Distribution of Commercial Discount Rates: Medical

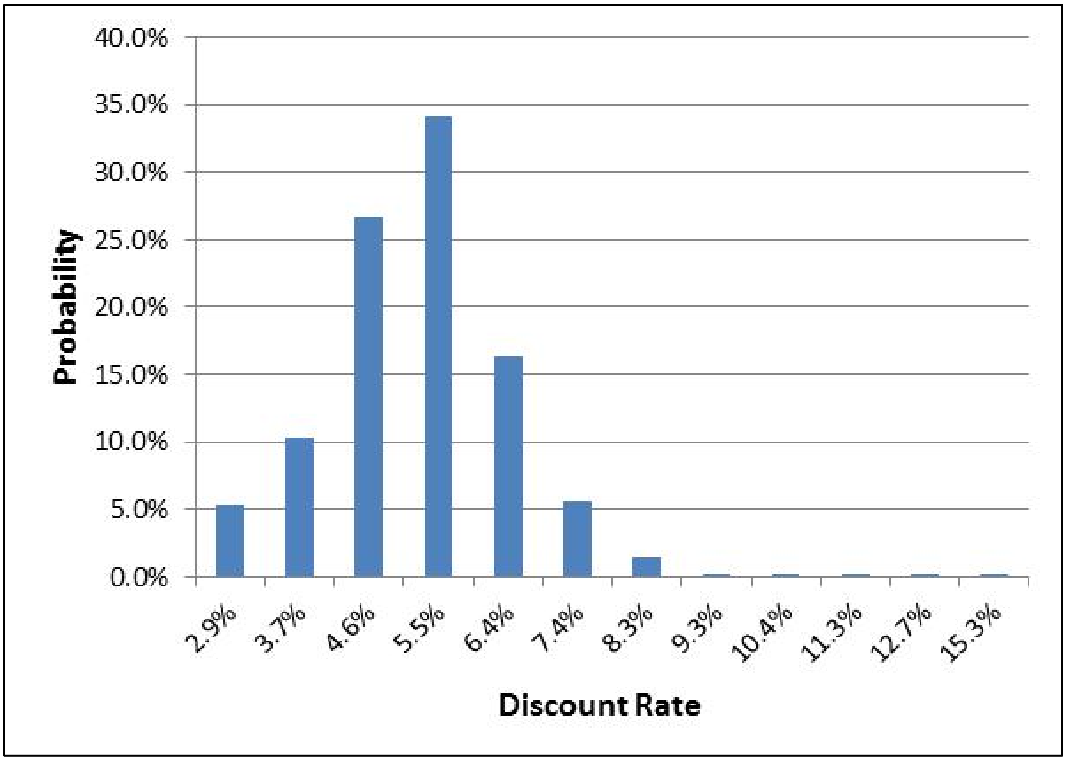

Figure 8H.4.4 Distribution of Commercial Discount Rates: Industrial

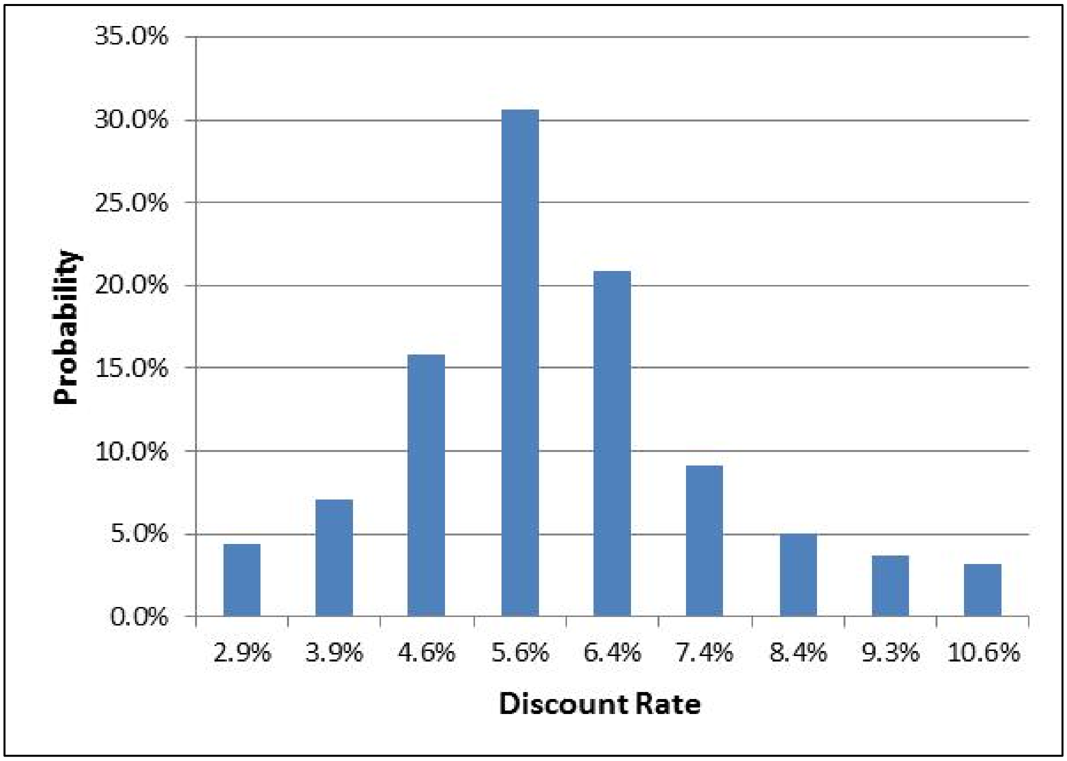

Figure 8H.4.5 Distribution of Commercial Discount Rates: Lodging

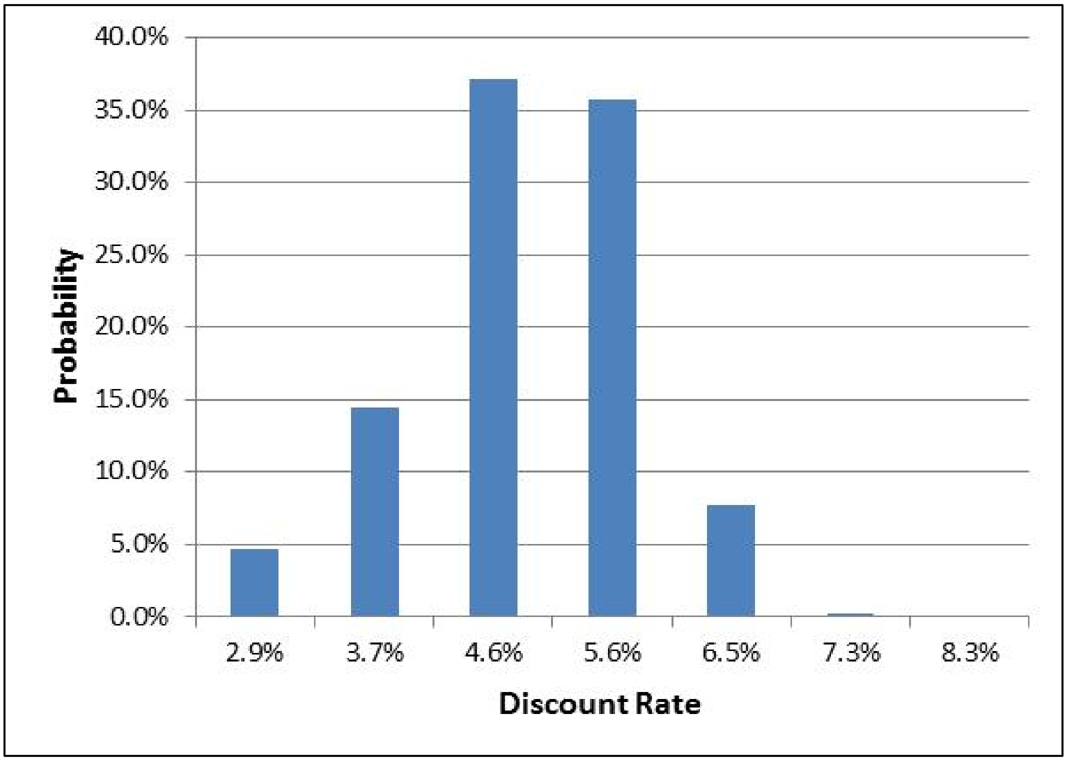

Figure 8H.4.6 Distribution of Commercial Discount Rates: Food Service

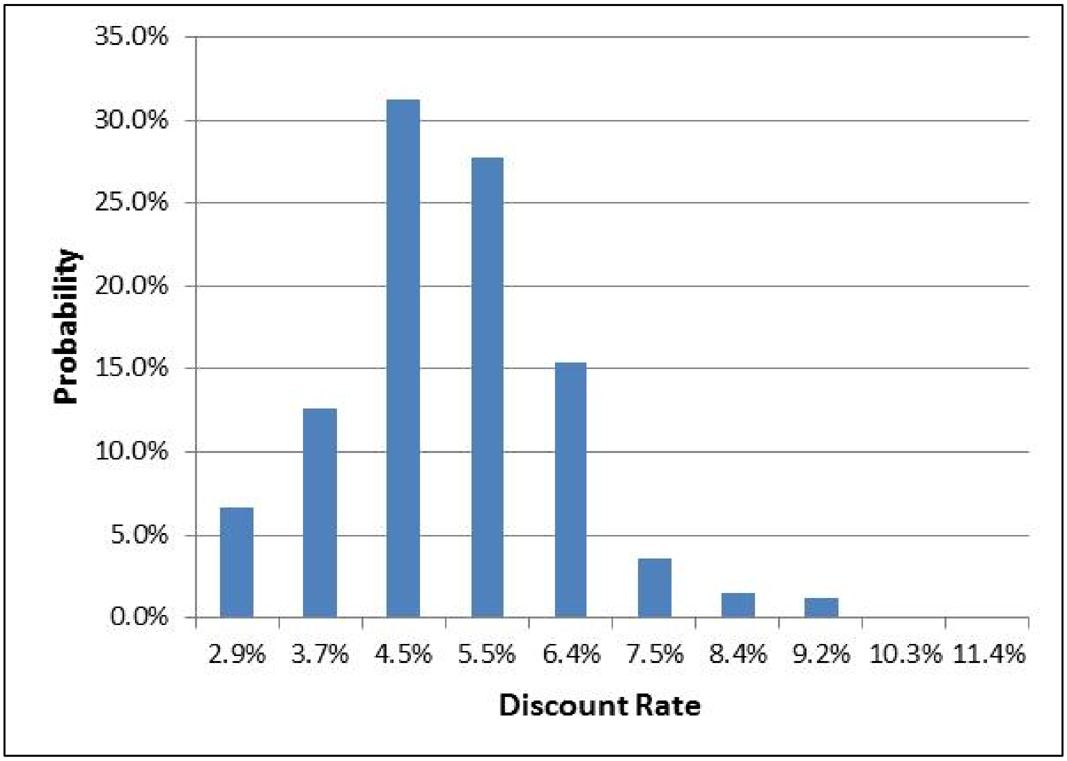

Figure 8H.4.7 Distribution of Commercial Discount Rates: Office

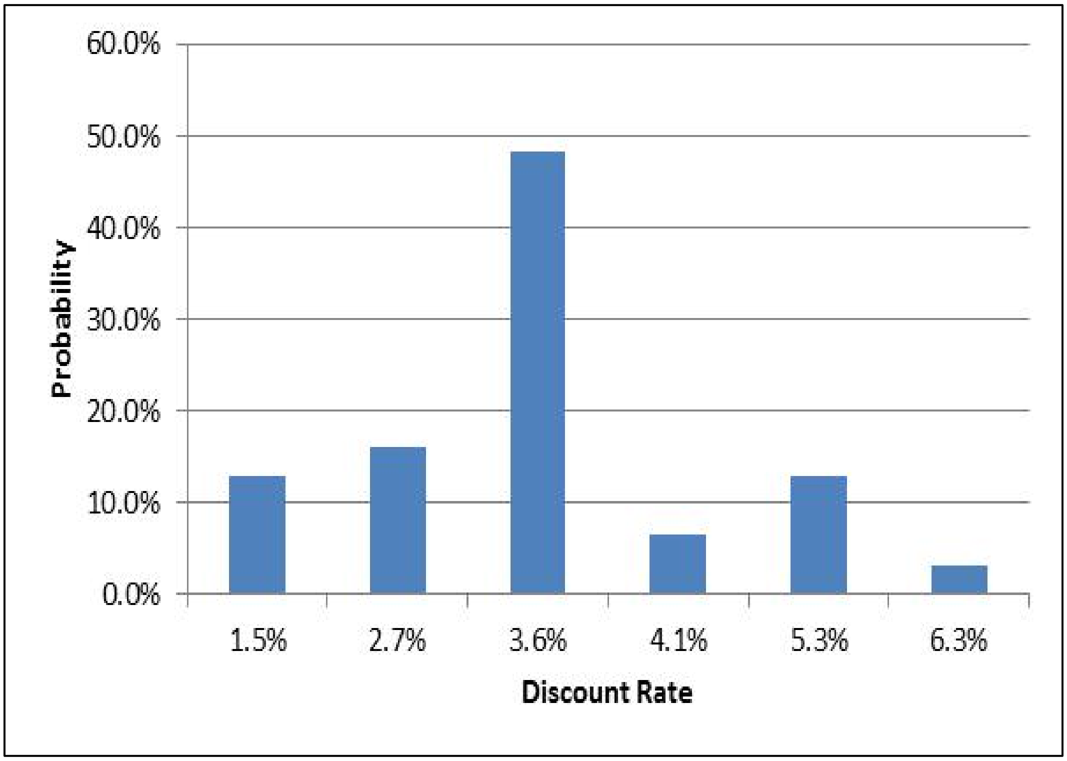

Figure 8H.4.8 Distribution of Commercial Discount Rates: State and Local Government

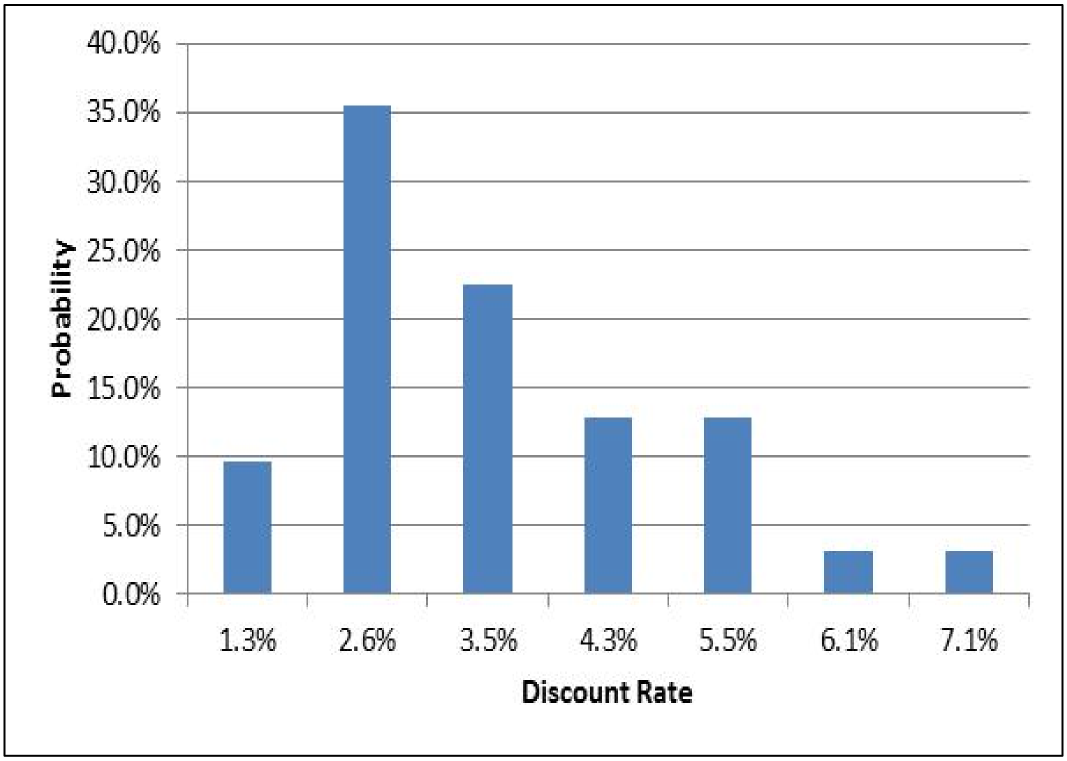

Figure 8H.4.9 Distribution of Commercial Discount Rates: Federal Government

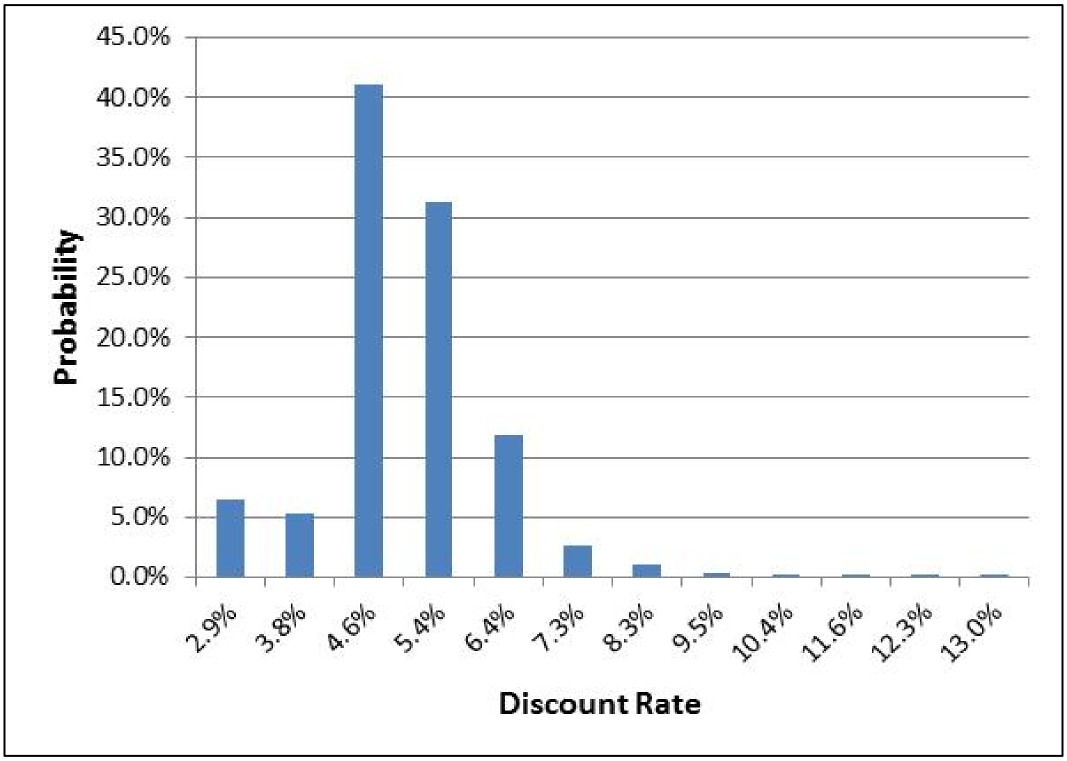

Figure 8H.4.10 Distribution of Commercial Discount Rates: Other

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APPENDIX 8I. BASE CASE DISTRIBUTION OF EFFICIENCY LEVELS

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APPENDIX 8I. BASE CASE DISTRIBUTION OF EFFICIENCY LEVELS

8I.1 INTRODUCTION

To estimate the share of consumers affected by a potential standard at a particular efficiency level, The Department of Energy's (DOE) LCC and PBP analysis considers the projected distribution (*i.e.*, market shares) of product efficiencies that consumers will purchase in the first compliance year, without amended energy conservation standards (base case). DOE derived base case efficiency distributions of efficiency levels by product class, recognizing that consumers already purchasing products at efficiencies greater than or equal to a prospective standard level are not impacted by the standard. This appendix describes the distributions used.

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 Annual Fuel Utilization Efficiency (AFUE) efficiency levels for each of the two considered residential furnace product classes: non-weatherized gas furnaces (NWGFs) and mobile home gas furnaces (MHGFs). The development of these distributions was based on the following key data inputs:

- Number of shipments disaggregated by non-condensing and condensing gas furnaces from the Air Conditioning, Heating, and Refrigeration Institute (AHRI);
- AHRI Directory of Certified Product Performance, which allowed review of specific efficiencies sold into the market for each product class; and
- ENERGY STAR® unit shipments for NWGFs from 2009-2012.

8I.2 HISTORICAL EFFICIENCY DISTRIBUTIONS

DOE used historical shipment data for NWGFs and MHGFs provided by AHRI. DOE reviewed AHRI[a] data from 1978 to 1992 detailing the market shares of non-condensing (80 percent AFUE)[b] and condensing (90 percent AFUE and greater) gas furnaces[c] by State.[1, 2] DOE also reviewed combined NWGF and MHGF shipment data from AHRI disaggregated by non-condensing and condensing furnaces from 1992 to 2009 by North and Rest of Country regions.[3] DOE also compiled data on the national shipments of condensing gas furnaces from 2009 to

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[a] Previously known as Gas Appliance Manufacturers Association (GAMA).

[b] The market share of furnaces with AFUE between 80 and 90 percent is well below 1 percent due to the very high installed cost of 81-percent AFUE furnaces, compared with condensing designs, and concerns about safety of operation.

[c] Combined NWGF and MHGF shipments.

2012 from the ENERGY STAR program.[d,4] With these data, DOE derived historic trends for the North and Rest of Country regions. Figure 8I.2.1 shows the historical fraction of condensing NWGFs and MHGFs by region based on these shipment data.

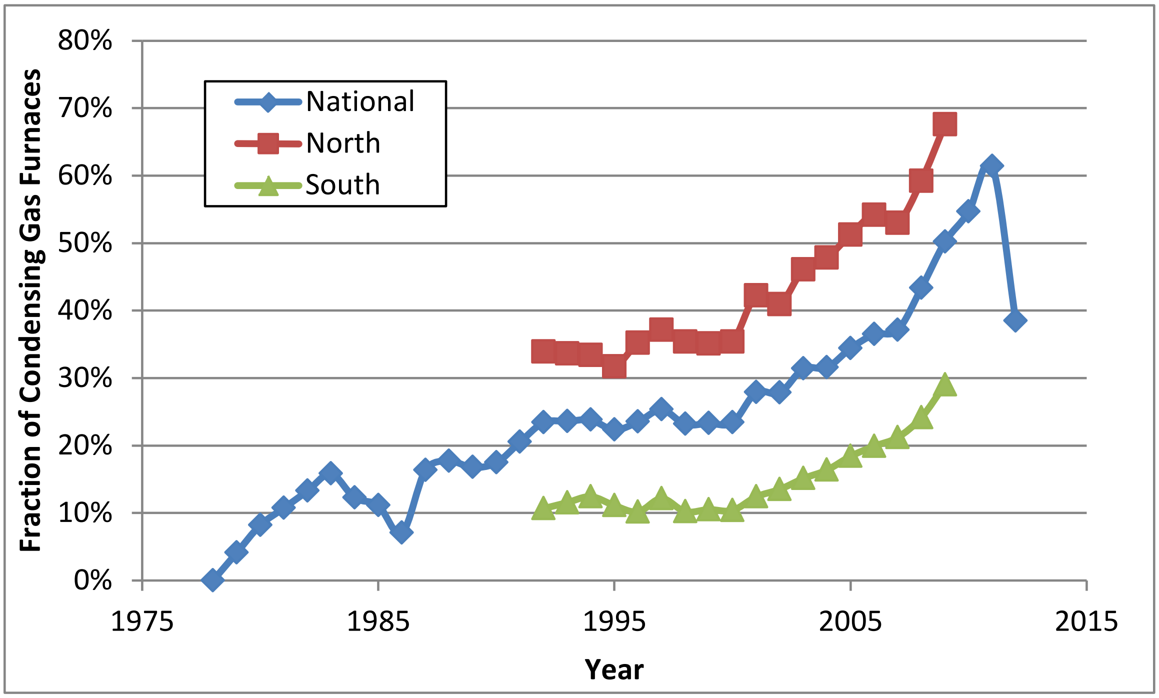

Figure 8I.2.1 Fraction of Condensing NWGF and MHGF Shipments from 1978 to 2012 by Region

8I.3 DERIVATION OF EFFICIENCY DISTRIBUTIONS IN 2013 BY PRODUCT CLASS AND EFFICIENCY LEVEL

DOE used data on the distribution of models in the February 2013 AHRI Directory of Certified Product Performance[5] to disaggregate the shipments of condensing NWGFs and MHGFs by AFUE, as shown in Table 8I.3.1. See appendix 7D for a full description on the development of the reduced set of models DOE used.

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[d] The ENERGY STAR criteria changed from 2009 to2013. From 2009-2011, all condensing furnaces met the ENERGY STAR criteria of 90-percentAFUE or above. Beginning in February 1, 2012 (Specification Version 3), DOE required 95-percent AFUE and above for North states and 90-percent and above for the Rest of Country. In addition, all ENERGY STAR furnaces needed to meet furnace fan efficiency (e) metric criteria of ≤ 2.0 percent. Beginning in February 1, 2013, an additional requirement was added that ENERGY STAR furnaces needed to meet the Air Leakage (Q_{leak}) metric value of ≤ 2.0 percent. For 2012-2013, ENERGY STAR provided to DOE all shipments above 90-percent AFUE that met the additional criteria, but only reports shipments of 95-percent AFUE and above in the unit shipments reports.

Table 8I.3.1 Fraction of Non-Weatherized Gas Furnace and Mobile Home Gas Furnace Models in February 2013 AHRI Directory by AFUE

Efficiency (% AFUE)	NWGF	MHGF
75		4.3%
76		
77		
78	0.1%	
79	0.1%	
80	41.5%	17.1%
81		2.9%
82		
83		
84		
85		
86		
87		
88		
89		
90	3.3%	
91	0.6%	
92	11.3%	14.3%
93	2.2%	
94	0.7%	
95	17.8%	37.1%
96	15.0%	24.3%
97	6.5%	
98	0.8%	
99		

To create the fractions of NWGFs by efficiency levels, DOE used the following criteria to process the AHRI model directory data:

1. The 80-percent AFUE bin of NWGFs includes 80-percent to 81-percent AFUE models
2. The 90-percent AFUE bin of NWGFs includes 90-percent to 91-percent AFUE models
3. The 92-percent AFUE bin of NWGFs includes 92-percent to 94-percent AFUE models
4. The 95-percent AFUE bin of NWGF includes 95-percent to 97-percent AFUE models
5. The 98-percent AFUE bin of NWGFs includes 98-percent to 99-percent AFUE models

To create the fractions of MHGFs by efficiency levels, DOE used the following criteria to process the AHRI model directory data:

6. The 80-percent AFUE bin of MHGFs includes 78-percent to 80-percent AFUE models[e]
7. The 90-percent AFUE bin of MHGFs includes 90-percent to 91-percent AFUE models
8. The 92-percent AFUE bin of MHGFs includes 92-percent to 94-percent AFUE models
9. The 95-percent AFUE bin of MHGFs includes 95-percent to 96-percent AFUE models
10. The 97-percent AFUE bin of MHGFs includes 97-percent to 99-percent AFUE models

DOE used data from Table 8I.3.1 and the AFUE binning criteria to disaggregate the shipments of condensing NWGFs and MHGFs by efficiency levels, as shown in Table 8I.3.2.

Table 8I.3.2 Fraction of Condensing Non-Weatherized Gas Furnace and Mobile Home Gas Furnace Models in February 2013 AHRI Directory by AFUE

EL	AFUE	Fraction of Models
NWGF		
1	90%	6.7%
2	92%	24.4%
3	95%	67.5%
4	98%	1.4%
MHGF		
1	92%	18.9%
2	95%	81.1%
3	97%	0.0%

Based on stakeholder input, DOE assumed that for furnace replacements, the fraction of 95-percent AFUE and above shipments in the replacement market would be double the fraction in the new construction market. DOE also assumed that the fraction of 95-percent AFUE and above shipments would be higher (three times more) in the North compared to the Rest of Country because the ENERGY STAR level in the North is 95-percent AFUE, compared to 90 percent in the Rest of Country. Therefore, NWGF and MHGF replacements in the North were assumed to have the same distribution of efficiencies among the condensing units as in the February 2013 AHRI Directory. Replacements in the Rest of Country at the higher efficiency levels (AFUE of 95 percent and 98 percent) were assumed to have one third as much of the market share as in North replacement market, and the remaining two thirds was distributed to the lower efficiency levels (AFUE of 90 percent and 92 percent). NWGFs and MHGFs at higher efficiency levels (AFUE of 95 percent or 98 percent) in new construction in the North were assumed to have one half as much of the market share as in North replacement market, and that the remaining half is distributed to the lower efficiency levels (AFUE of 90 percent and 92 percent). NWGFs and MHGFs at higher efficiency levels (AFUE of 95 percent and 98 percent) in new construction in the Rest of Country were assumed to have one half as much of the market share as in replacement Rest of Country market, and that the remaining half is distributed to the lower efficiency levels (AFUE of 90 percent and 92 percent).

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[e] Note that by 2015 the minimum efficiency of both NWGFs and MHGFs is 80-percent AFUE.

Table 8I.3.3 shows the resulting market shares of condensing NWGFs and MHGFs.

Table 8I.3.3 Estimated AFUE Distribution for Condensing Non-Weatherized Gas Furnaces and Mobile Home Gas Furnaces in 2013

Efficiency, AFUE	2013 Estimated Market Share			
	North, Repl	North, New	South, Repl	South, New
NWGF				
90%	6.7%	14.1%	16.6%	19.0%
92%	24.4%	51.5%	60.5%	69.5%
95%	67.5%	33.7%	22.5%	11.2%
98%	1.4%	0.7%	0.5%	0.2%
MHGF				
92%	18.7%	59.3%	72.9%	86.4%
95%	80.3%	40.2%	26.8%	13.4%
97%*	1.0%	0.5%	0.3%	0.2%

* 1-percent market share was added to the North replacement market because there are several models at 96.5-percent AFUE.

Based on historical shipments of condensing furnaces from 1994-2004,[f] DOE estimated that in 2013, the condensing NWGF market share is 39 percent nationally, 58 percent in the North and 19 percent in the Rest of Country. DOE assumed that the fraction of condensing MHGFs was exactly half that of NWGFs. Non-condensing NWGFs and MHGFs comprise the rest of the market. DOE assumed that all non-condensing units will have an AFUE of 80 percent.

8I.4 DERIVATION OF EFFICIENCY DISTRIBUTIONS IN 2021 BY PRODUCT CLASS

Based on historical shipments of condensing furnaces from 1994-2004, DOE estimated the 2021 condensing NWGF market share. See section 8I.5 for more details. DOE used the efficiency distribution in 2013 and the projections of base case market shares of condensing NWGFs and MHGFs from 2013 to 2021 to project the efficiency distributions in 2021. The base case distributions of condensing NWGFs and MHGFs in 2021 are calculated by multiplying the market shares in 2013 with a factor to account for the increase in market shares of condensing NWGFs and MHGFs from 2013 to 2021. Table 8I.4.1 through Table 8I.4.6 shows the distributions by region and market used in the analysis.

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[f] There was no data on the condensing market share in 2013. DOE used 1994-2004 trend to estimate the 2013 condensing market share. See section 8-I.5 for more details.

Table 8I.4.1 Base-Case AFUE Distribution for Non-Weatherized Gas Furnaces in 2021, Residential Replacements

Region	Distributions				
	80%	**90%**	**92%**	**95%**	**98%**
CT, ME, NH, RI, VT	5%	6%	23%	64%	1%
Massachusetts	5%	6%	23%	64%	1%
New York	41%	4%	14%	40%	1%
New Jersey	31%	5%	17%	47%	1%
Pennsylvania	11%	6%	22%	60%	1%
Illinois	49%	3%	12%	35%	1%
Indiana, Ohio	25%	5%	18%	51%	1%
Michigan	30%	5%	17%	48%	1%
Wisconsin	5%	6%	23%	64%	1%
IA, MN, ND, SD	5%	6%	23%	64%	1%
Kansas, Nebraska	52%	3%	12%	33%	1%
Missouri	41%	4%	14%	40%	1%
Virginia	25%	12%	45%	17%	0%
DE, DC, MD, WV	45%	9%	33%	12%	0%
Georgia	88%	2%	7%	3%	0%
NC, SC	27%	12%	44%	16%	0%
Florida	97%	1%	2%	1%	0%
AL, KY, MS	57%	7%	26%	10%	0%
Tennessee	57%	7%	26%	10%	0%
AR, LA, OK	93%	1%	4%	2%	0%
Texas	97%	1%	2%	1%	0%
Colorado	66%	2%	8%	23%	0%
ID, MT, UT, WY	57%	3%	10%	29%	1%
Arizona	71%	5%	18%	7%	0%
NV, NM	87%	2%	8%	3%	0%
California	85%	3%	9%	3%	0%
OR, WA	54%	3%	11%	31%	1%
Alaska	59%	3%	10%	27%	1%
Hawaii	11%	15%	54%	20%	0%
West Virginia	5%	6%	23%	64%	1%

Table 8I.4.2 Base-Case AFUE Distribution for Non-Weatherized Gas Furnaces in 2021, Residential New Construction

Region	Distributions				
	80%	**90%**	**92%**	**95%**	**98%**
CT, ME, NH, RI, VT	5%	13%	49%	32%	1%
Massachusetts	5%	13%	49%	32%	1%
New York	41%	8%	30%	20%	0%
New Jersey	31%	10%	36%	23%	1%
Pennsylvania	11%	12%	46%	30%	1%
Illinois	49%	7%	26%	17%	0%
Indiana, Ohio	25%	11%	39%	25%	1%
Michigan	30%	10%	36%	24%	1%
Wisconsin	5%	13%	49%	32%	1%
IA, MN, ND, SD	5%	13%	49%	32%	1%
Kansas, Nebraska	52%	7%	25%	16%	0%
Missouri	41%	8%	31%	20%	0%
Virginia	25%	14%	52%	8%	0%
DE, DC, MD, WV	45%	10%	38%	6%	0%
Georgia	88%	2%	8%	1%	0%
NC, SC	27%	14%	51%	8%	0%
Florida	97%	1%	2%	0%	0%
AL, KY, MS	57%	8%	30%	5%	0%
Tennessee	57%	8%	30%	5%	0%
AR, LA, OK	93%	1%	5%	1%	0%
Texas	97%	1%	2%	0%	0%
Colorado	66%	5%	17%	11%	0%
ID, MT, UT, WY	57%	6%	22%	14%	0%
Arizona	71%	6%	20%	3%	0%
NV, NM	87%	3%	9%	1%	0%
California	85%	3%	11%	2%	0%
OR, WA	54%	6%	24%	16%	0%
Alaska	59%	6%	21%	14%	0%
Hawaii	11%	17%	62%	10%	0%
West Virginia	5%	13%	49%	32%	1%

Table 8I.4.3 Base-Case AFUE Distribution for Non-Weatherized Gas Furnaces in 2021, Commercial Replacements

Region	Distributions				
	80%	**90%**	**92%**	**95%**	**98%**
New England	5%	6%	23%	64%	1%
Middle Atlantic	27%	5%	18%	50%	1%
East North Central	29%	5%	17%	48%	1%
West North Central	28%	5%	18%	49%	1%
South Atlantic	54%	8%	28%	10%	0%
East South Central	57%	7%	26%	10%	0%
West South Central	95%	1%	3%	1%	0%
Mountain	68%	4%	13%	14%	0%
Pacific	77%	3%	10%	10%	0%

Table 8I.4.4 Base-Case AFUE Distribution for Non-Weatherized Gas Furnaces in 2021, Commercial New Construction

Region	Distributions				
	80%	**90%**	**92%**	**95%**	**98%**
New England	5%	13%	49%	32%	1%
Middle Atlantic	27%	10%	38%	25%	1%
East North Central	29%	10%	36%	24%	1%
West North Central	28%	10%	37%	24%	1%
South Atlantic	54%	9%	32%	5%	0%
East South Central	57%	8%	30%	5%	0%
West South Central	95%	1%	3%	1%	0%
Mountain	68%	5%	19%	7%	0%
Pacific	77%	4%	14%	5%	0%

Table 8I.4.5 Base-Case AFUE Distribution for Mobile Home Gas Furnaces in 2021, Residential Replacements

Region	Distributions			
	80%	**92%**	**95%**	**97%**
CT, ME, NH, RI, VT	53%	9%	38%	0%
Massachusetts	53%	9%	38%	0%
New York	71%	5%	24%	0%
New Jersey	65%	6%	28%	0%
Pennsylvania	56%	8%	36%	0%
Illinois	74%	5%	21%	0%
Indiana, Ohio	62%	7%	30%	0%
Michigan	65%	7%	28%	0%
Wisconsin	53%	9%	38%	0%
IA, MN, ND, SD	53%	9%	38%	0%
Kansas, Nebraska	76%	5%	19%	0%
Missouri	70%	6%	24%	0%
Virginia	63%	27%	10%	0%
DE, DC, MD, WV	73%	20%	7%	0%
Georgia	94%	4%	2%	0%
NC, SC	63%	27%	10%	0%
Florida	98%	1%	0%	0%
AL, KY, MS	78%	16%	6%	0%
Tennessee	78%	16%	6%	0%
AR, LA, OK	96%	3%	1%	0%
Texas	98%	1%	0%	0%
Colorado	83%	3%	14%	0%
ID, MT, UT, WY	79%	4%	17%	0%
Arizona	85%	11%	4%	0%
NV, NM	93%	5%	2%	0%
California	92%	6%	2%	0%
OR, WA	77%	4%	18%	0%
Alaska	80%	4%	16%	0%
Hawaii	55%	33%	12%	0%
West Virginia	53%	9%	38%	0%

Table 8I.4.6 Base-Case AFUE Distribution for Mobile Home Gas Furnaces in 2021, Residential New Construction

Region	Distributions			
	80%	**92%**	**95%**	**97%**
CT, ME, NH, RI, VT	53%	28%	19%	0%
Massachusetts	53%	28%	19%	0%
New York	71%	17%	12%	0%
New Jersey	65%	21%	14%	0%
Pennsylvania	56%	26%	18%	0%
Illinois	74%	15%	10%	0%
Indiana, Ohio	62%	22%	15%	0%
Michigan	65%	21%	14%	0%
Wisconsin	53%	28%	19%	0%
IA, MN, ND, SD	53%	28%	19%	0%
Kansas, Nebraska	76%	14%	10%	0%
Missouri	70%	18%	12%	0%
Virginia	63%	32%	5%	0%
DE, DC, MD, WV	73%	24%	4%	0%
Georgia	94%	5%	1%	0%
NC, SC	63%	32%	5%	0%
Florida	98%	1%	0%	0%
AL, KY, MS	78%	19%	3%	0%
Tennessee	78%	19%	3%	0%
AR, LA, OK	96%	3%	0%	0%
Texas	98%	1%	0%	0%
Colorado	83%	10%	7%	0%
ID, MT, UT, WY	79%	13%	9%	0%
Arizona	85%	13%	2%	0%
NV, NM	93%	6%	1%	0%
California	92%	7%	1%	0%
OR, WA	77%	14%	9%	0%
Alaska	80%	12%	8%	0%
Hawaii	55%	39%	6%	0%
West Virginia	53%	28%	19%	0%

Table 8I.4.7 and Table 8I.4.8 show the regional base-case efficiency distributions in 2021 for NWGFs and MHGFs, respectively.

Table 8I.4.7 Base-Case AFUE Distribution for Non-Weatherized Gas Furnaces in 2021

Efficiency, AFUE	2021 Market share in percent				
	National	**North, Repl**	**North, New**	**South, Repl**	**South, New**
80%	53.4%	33.0%	34.7%	77.6%	70.4%
90%	5.2%	5.5%	8.8%	3.4%	5.5%
92%	17.9%	15.8%	32.4%	13.9%	20.2%
95%	23.0%	44.9%	23.6%	4.9%	3.8%
98%	0.5%	0.8%	0.6%	0.1%	0.2%

Table 8I.4.8 Base-Case AFUE Distribution for Mobile Home Gas Furnaces in 2021

Efficiency, AFUE	2021 Market share in percent				
	National	**North, Repl**	**North, New**	**South, Repl**	**South, New**
80%	73.9%	65.8%	64.3%	87.2%	89.2%
92%	12.1%	6.1%	21.2%	9.6%	9.6%
95%	13.8%	27.7%	14.3%	3.2%	1.2%
97%	0.2%	0.4%	0.2%	0.0%	0.0%

8I.5 DERIVATION OF BASE CASE EFFICIENCY DISTRIBUTIONS FROM 2013 TO 2050 BY PRODUCT CLASS

DOE considered incentives and other market forces that have increased the sales of high-efficiency furnaces to estimate base case efficiency distributions for the considered product classes. To project efficiency trends from 2013 to 2050, DOE only used shipment data from 1994 to 2004 because from 2005 to 2011, there was a sharp increase in the share of condensing furnaces primarily due to Federal tax credits. DOE determined that excluding these years provides a more reasonable projection of NWGF and MHGF efficiency distributions. The maximum share of condensing shipments for each region is assumed to be 95 percent. In other words, at least five percent of NWGF and MHGF furnace shipments will be non-condensing.

In the case of replacement units, DOE estimated that there would be growth in the overall market share of condensing NWGFs from 67.6 percent in 2021 to 88.0 percent in 2050 in the North, and from 23.5 percent in 2021 to 34.8 percent in 2050 in the Rest of Country (Figure 8I.5.1). Similarly, DOE estimated that there would be growth in the overall market share of condensing MHGFs from 33.8 percent in 2021 to 44.0 percent in 2050 in the North, and from 11.8 percent in 2021 to 17.4 percent in 2050 in the Rest of the Country (Figure 8I.5.2).

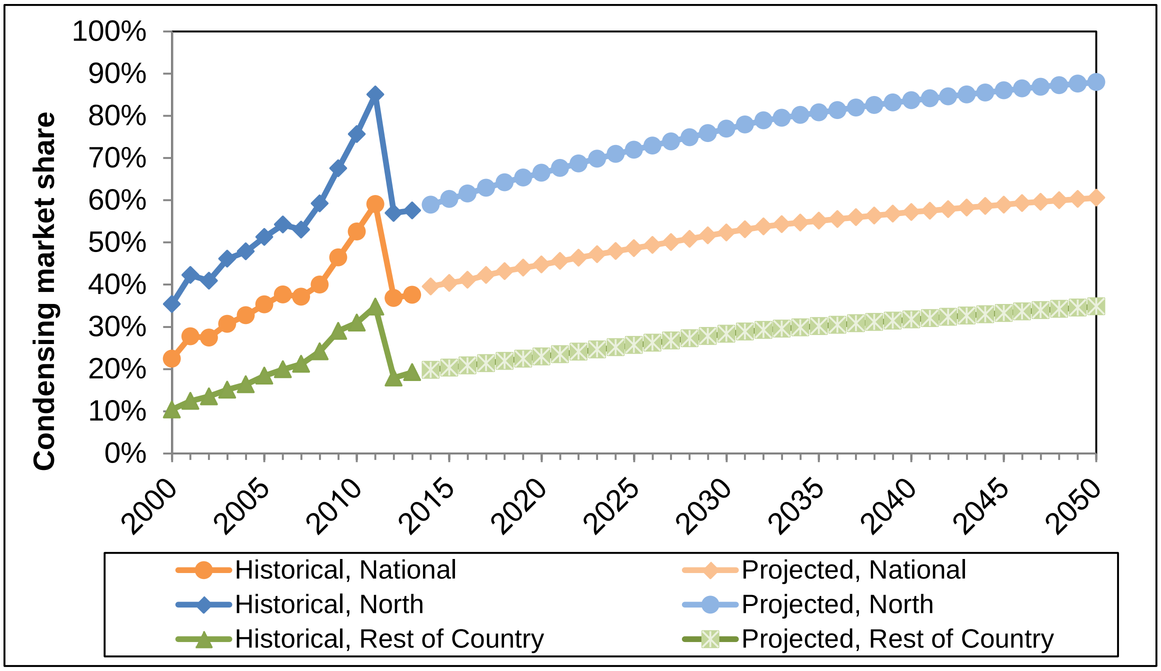

Figure 8I.5.1 **Projection of Base Case Market Share of Condensing Non-Weatherized Gas Furnaces by Region**

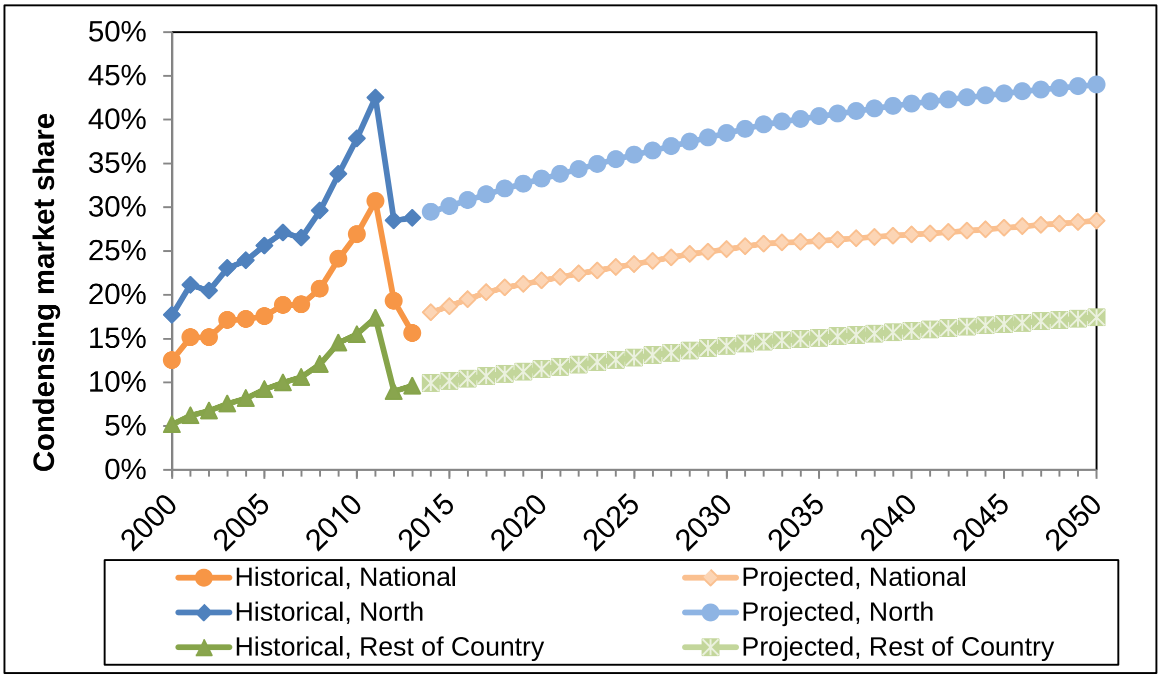

Figure 8I.5.2 **Projection of Base Case Market Share of Condensing Mobile Home Gas Furnaces by Region**

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APPENDIX 8J. PRODUCT SWITCHING METHODOLOGY

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APPENDIX 8J. PRODUCT SWITCHING METHODOLOGY

8J.1 INTRODUCTION

As described in chapter 8, DOE considered the possibility that some households would switch from a non-weatherized gas furnace (NWGF) to an electric furnace (EF) or electric heat pump (HP) due to more stringent NWGF standards. In addition, DOE also considered the possibility of switching from a gas storage water heater (GSWH) to electric storage water heater (ESWH).

8J.2 PRODUCT SWITCHING METHODOLOGY

Because consumers are sensitive to the cost of heating products, a standard level that significantly increases the purchase price may induce some consumers to switch to a different heating system rather than purchase a NWGF. The decision to switch is affected by the total installed cost and operating costs, including the energy use and energy prices for alternative products.

DOE developed a consumer choice model to estimate the response of builders and home owners to potential amended NWGF Annual Fuel Utilization Efficiency (AFUE) standards.[a] The model considers three space heating options available to each sample household or building, which are to purchase and install: (1) the NWGF that meets a particular standard level, (2) a heat pump, or (3) an electric furnace. In addition, for some households or buildings, installation of a condensing NWGF would leave an "orphaned" gas storage water heater that would require expensive resizing of the vent system.[b] DOE allowed for the possibility that households with an orphaned water heater might choose to purchase an electric water heater rather than resize the vent system when they choose any of the three space heating options. For option 2, purchase a heat pump, DOE also took into consideration the age of the existing central air conditioner (CAC) if present; if the air conditioner is not very old, it is unlikely that the consumer would opt to install a heat pump to provide both heating and cooling.

The consumer choice model used the total installed cost and operating costs of each option, as estimated for each sample household or building, taking into account the space heating load, water heating load, and energy prices over the lifetime of the available product options. DOE also accounted for the cooling load of each household or building that might switch from a NWGF and CAC to a heat pump.

The decision criteria in the model are based on proprietary data from Decision Analysts, who identified for a representative sample of consumers their willingness to purchase more-efficient space-conditioning systems. From these data, DOE deduced that consumers would

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[a] DOE did not analyze switching for MHGFs because the installation cost differential is small between condensing and non-condensing products, so the incentive for switching is insignificant.

[b] An orphaned water heater is a water heater that was commonly vented with a non-condensing NWGF prior to replacing the non-condensing NWGF with a condensing NWGF. After the installation of a condensing NWGF, the water heater must be vented independently.

expect a payback period of 3.5 years or less for a more-expensive but more-efficient product. This reflects that in general, consumers place a relatively high importance on the first cost differences. For each household, the model calculates the PBP for a NWGF that meets each particular efficiency level and each product switching option. The model rejects any option that has a PBP greater than 3.5 years, and selects the option with the lowest PBP.

8J.2.1 Determination of Product Switching Options

DOE used the Energy Information Administration's (EIA) 2009 Residential Energy Consumption Survey (RECS 2009)[1] and 2003 Commercial Building Energy Consumption Survey (CBECS 2003)[2] to determine what product options are available to consumers. The switching model includes potential switching from a NWGF to an EF and from a NWGF with a CAC to an air handler or electric furnace with a heat pump. In addition, DOE considered switching from an orphaned GSWH (described in appendix 8D) to an ESWH. Figure 8J.2.1 shows the different product switching scenarios available to consumers depending on the existing product combination. Using RECS 2009 or CBECS 2003 sample data, DOE determined whether the household or building had a commonly-vented GSWH and/or space cooling system (CAC or HP). For each household or building, DOE analyzed product switching scenarios that represent all available combinations of space conditioning and water heating products that could be used in the case of a condensing NWGF energy efficiency standard.

The color scheme used in Figure 8J.2.1 is as follows:

- *Green diamonds*: criteria for determining the existing space conditioning and water heating combination in each sample household or building;
- *Purple rectangles*: existing product combinations, labeled by ID number;
- *Blue rectangles*: existing products that do not switch to an alternative product; and
- *Orange rectangles*: existing products that switch to an alternative product.

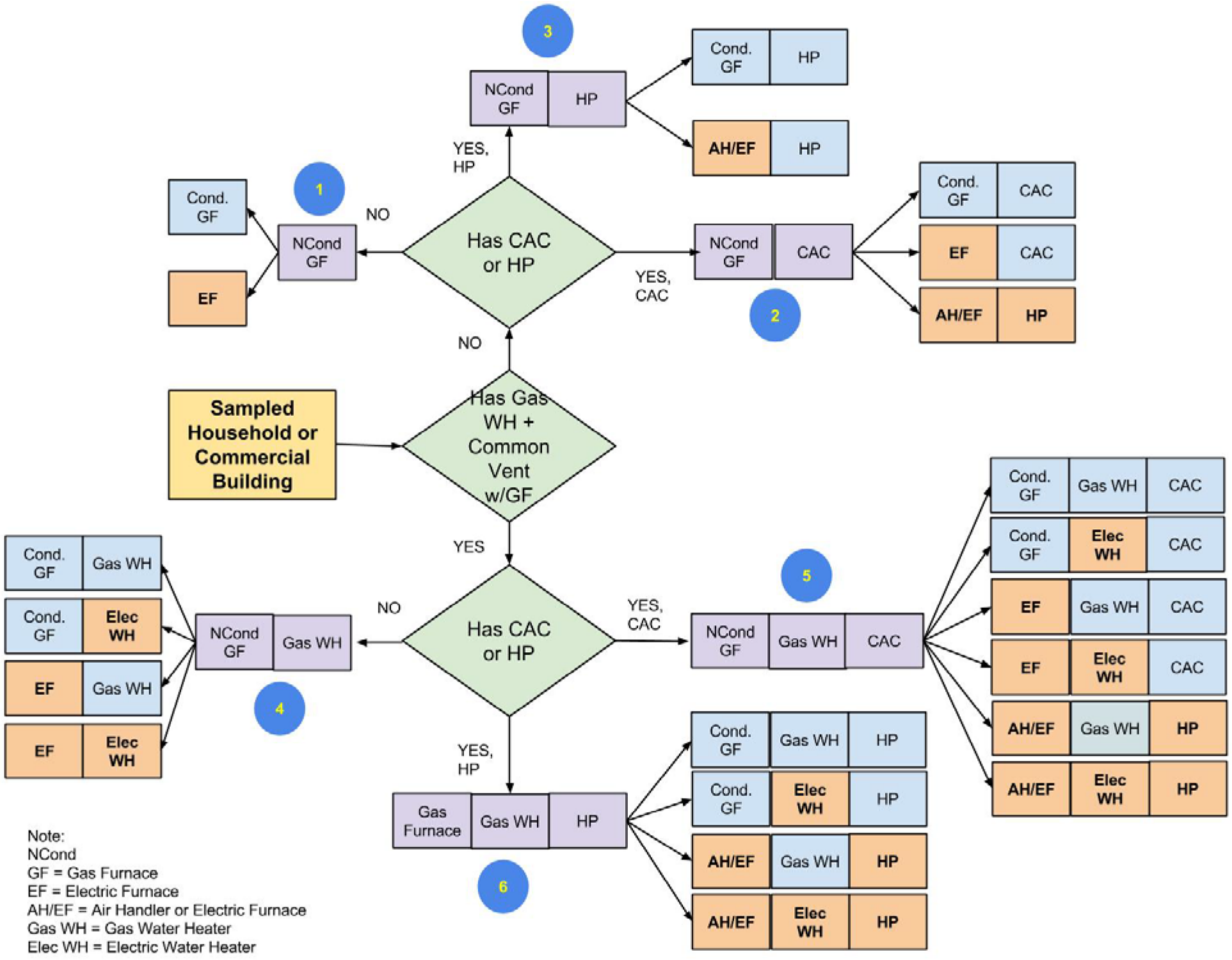

Figure 8J.2.1 Product Switching Scenarios for NWGF installations

Table 8J.2.1 shows the different existing and available combinations of space heating, water heating, and space cooling products by the product switching scenarios that were considered in the analysis, as shown in Figure 8J.2.1. Table 8J.2.2 shows the fraction of installations of each existing product combination from Figure 8J.2.1.

Table 8J.2.1 Product Switching Scenarios

ID	Existing Product Combination	New Space Heating	New Water Heating	Cooling
1	(1) Non-Cond. NWGF	Condensing NWGF	N/A	N/A
2		EF	N/A	N/A
3	(2) Non-Cond. NWGF + CAC	Condensing NWGF	N/A	CAC
4		EF	N/A	CAC
5		AH/EF	N/A	HP
6	(3) Non-Cond. NWGF + HP	Condensing NWGF	N/A	HP
7		AH/EF	N/A	HP
8	(4) Non-Cond. NWGF + GSWH	Condensing NWGF	GSWH	N/A
9		Condensing NWGF	ESWH	N/A
10		EF	GSWH	N/A
11		EF	ESWH	N/A
12	(5) Non-Cond. NWGF + GSWH + CAC	Condensing NWGF	GSWH	CAC
13		Condensing NWGF	ESWH	CAC
14		EF	GSWH	CAC
15		EF	ESWH	CAC
16		AH/EF	GSWH	HP
17		AH/EF	ESWH	HP
18	(6) Non-cond. NWGF + GSWH + HP	Condensing NWGF	GSWH	HP
19		Condensing NWGF	ESWH	HP
20		AH/EF	GSWH	HP
21		AH/EF	ESWH	HP

N/A = Not applicable

Table 8J.2.2 Fraction of Installations of Product Combinations in 2021

	Existing Product Combination	Replacement			New Construction		
		National	North	Rest of Country	National	North	Rest of Country
1	Non-Cond. NWGF	2.6%	4.0%	1.7%	2.7%	4.2%	1.7%
2	Non-Cond. NWGF + CAC	10.2%	7.0%	12.3%	10.8%	12.4%	9.8%
3	Non-Cond. NWGF + HP	1.0%	0.2%	1.5%	0.9%	0.2%	1.4%
4	Non-Cond. NWGF + GSWH	17.2%	27.3%	10.8%	7.4%	9.5%	6.0%
5	Non-Cond. NWGF + GSWH + CAC	65.9%	59.5%	70.0%	72.7%	68.9%	75.2%
6	Non-cond. NWGF + GSWH + HP	3.1%	2.1%	3.7%	5.5%	4.9%	5.8%

8J.2.2 Decision Algorithm

To estimate the likelihood of product switching, DOE created a product switching model based on proprietary data from Decision Analysts, who identified the willingness of a representative sample of consumers to purchase more-efficient space-conditioning systems.[3] From these data and RECS 2009 billing data, DOE determined the average length of the payback period (PBP) for a more-efficient NWGF that the consumer will require before switching to either a heat pump or electric furnace for space heating, a heat pump for space cooling, or an ESWH for water heating.

Figure 8J.2.2 illustrates the methodology used to determine the fraction of households that would switch to a heat pump, electric furnace, or ESWH should a condensing standard for NWGFs be adopted.

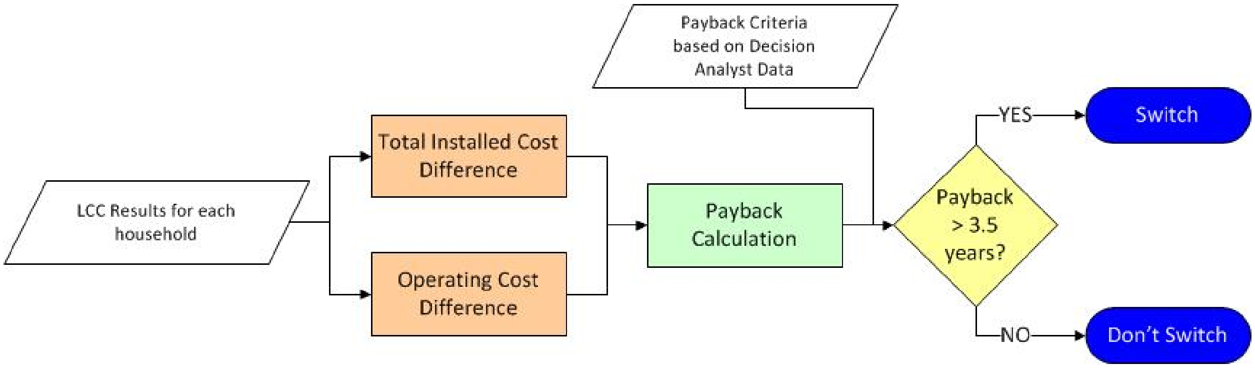

Figure 8J.2.2 Product Switching Methodology Flowchart

As discussed in chapter 8, DOE used results for the total installed cost and lifetime operating cost to determine the PBP of a more-efficient NWGF for each household relative to the baseline. To model the consumer decision for each household, DOE calculated the PBP of the potential switching options relative to the NWGF at the specified EL. From Decision Analysts data, DOE determined that consumers would expect a PBP of 3.5 years or less to justify the purchase of a more-expensive but more-efficient NWGF. If the PBP of installing a more-efficient NWGF exceeded 3.5 years, DOE forecasted that the consumer would switch to either a heat pump or an electric furnace. In the case of the heat pump option, the PBP is relative to that of the combination of a NWGF at the specified EL and a CAC.

The PBP criterion of 3.5 years was determined using data from the 2006, 2008, 2010, and 2013 American Home Comfort Survey (AHCS)[4, 5, 6, 7] (Table 8J.2.3) and average space conditioning energy cost determined from RECS 2001, RECS 2005, and RECS 2009 (Table 8J.2.4).[8, 9] The AHCS asked respondents the maximum price they would be willing to pay for a product that was 25 percent more efficient than their existing product, which DOE assumed is equivalent to a 25-percent decrease in annual energy costs.

Table 8J.2.3 Maximum Product Price Consumers would Pay to Purchase Higher-Efficiency Products Based on AHCS (2006-2013)

Year	Average Cost Consumers are Willing to Pay for 25% Higher Efficiency	
	Nominal $	2013$
2006	$720	$ 831.99
2008	$832	$ 900.74
2010	$817	$ 872.83
2013	$564	$ 564.00
Average		$ 792.39

Table 8J.2.4 Average Space Conditioning Energy Cost (Heating and Cooling) from RECS 2001, 2005, and 2009

Year	Average Space Conditioning Energy Cost	
	Nominal $	2013$
2001	$667	$877.38
2005	$792	$944.93
2009	$825	$896.05
Average		$906.12

The PBP criterion was calculated as follows:

$$\frac{Price_{\ More-Efficient\ Product}}{25\%\ of\ Space\ Conditioning\ Energy\ Cost} = \frac{\$792}{25\% \times \$906/year} = 3.5\ years$$

8J.3 INPUTS

The total installed cost and operating cost inputs for NWGFs are described in chapter 8. Sections 8J.3.1 and 8J.3.2 describe the inputs for determining the LCC costs and savings and the PBP for alternative electric space conditioning and water heating options.

8J.3.1 Total Installed Cost

8J.3.1.1 Manufacturer Costs

For CACs and HPs, DOE used manufacturer production costs (MPC) from the 2011 CAC and HP direct final rule (DFR) as shown in Table 8J.3.1.[10] DOE selected the efficiency level that meets the minimum efficiency in 2015. For GSWHs and ESWHs, DOE used the MPCs from the 2010 heating products final rule as shown in Table 8J.3.2.[11] DOE selected the efficiency level that meets the minimum efficiency by rated storage volume in 2015. Low-nitrogen oxide (NO_X) GSWHs are required for a fraction of consumers in California. The prices were converted from 2009$ to 2013$ using the implicit price deflator for gross domestic product (equal to a 4.0-percent increase).[c] For EFs, based on RS Means 2013 product price data, DOE determined that the MPC of an EF is $101.75 less than that of a non-condensing NWGF for all input capacities.[12]

Table 8J.3.1 Manufacturer Production Cost for CAC and HP by Representative Capacity

Product	Manufacturer Production Cost (2009$)		
	2-Ton	3-Ton	5-Ton
13 SEER* CAC (North)	$573.87	$642.12	$894.62
14 SEER CAC (Rest of Country)	$633.96	$705.76	$984.85
14 SEER HP (HP, Indoor Unit)	$900.47	$1,075.56	$1,352.70

* SEER = Seasonal Energy Efficiency Ratio

Table 8J.3.2 Manufacturer Production Cost for Gas and Electric Storage Water Heaters by Rated Storage Volume

Product	Manufacturer Product Cost (2009$)				
	30 gal	40 gal	50 gal	66 gal	75/80 gal
	EF = 0.63*	*EF = 0.62*	*EF = 0.60*	*EF = 0.75*	*EF = 0.73*
GSWH - Default	$172.00	$187.00	$200.00	$537.00	$565.00
GSWH - Ultra Low NO_X	$273.00	$290.00	$303.00	$631.00	$659.00
	EF = 0.95	*EF = 0.95*	*EF = 0.95*	*EF = 1.98*	*EF = 1.97*
ESWH	$142.00	$159.00	$170.00	$569.00	$592.00

*EF = energy factor

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[c] See www.bea.gov/national/pdf/dpga.pdf.

8J.3.1.2 Transportation Costs

The MPC of CAC, HP, GSWH, and ESWH products derived above is considered to be a price that does not include the cost of shipping the product to the distributor. Based on the physical attributes of these products (product dimensions and shipping) and the requirements for maximum weight and dimensions of a standard 53-ft trailer, DOE determined that manufacturers were likely to run out of volume inside the shipping trailer before reaching the maximum weight for a truckload. The additional cost of transporting a product to the local distribution point depends mainly on its volume, which was calculated for each product class at each efficiency level. Shipping cost was calculated as a function of size and weight, which vary by representative capacity for all CAC and HP products and by rated storage volume for water heaters. For EFs, DOE used the same shipping costs as for NWGFs.

Table 8J.3.3 Shipping Costs for CACs and HPs by Representative Capacity

Product	Shipping Cost (2009$)		
	2-Ton	3-Ton	5-Ton
13 SEER CAC	$16.02	$20.51	$28.42
14 SEER CAC	$20.30	$24.83	$29.50
14 SEER HP (HP, Indoor Unit)	$25.45	$30.54	$38.42

Table 8J.3.4 Shipping Costs for Gas and Electric Water Heaters by Rated Storage Volume

Product	Shipping Cost (2009$)				
	30 gal	40 gal	50 gal	66 gal	75/80 gal
GSWH - Default	\$17.00	\$20.00	\$40.00	\$56.00	\$61.00
GSWH - Ultra Low NO_X	\$20.00	\$26.00	\$54.00	\$56.00	\$61.00
ESWH	\$21.00	\$21.00	\$56.00	\$64.00	\$67.00

8J.3.1.3 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 by the baseline markup to arrive at the price paid by the consumer. DOE used the same markups and distribution channels derived for NWGFs (see chapter 6) for CACs, HPs, GSWHs, and ESWHs. DOE used a baseline manufacturer markup of 1.34 from the 2011 CAC and HP DFR, and a baseline manufacturer markup of 1.31 for GSWHs and 1.28 for ESWHs from the 2010 heating products final rule. For EFs, DOE used the same manufacturer markup as for NWGFs of 1.34.

8J.3.1.4 Total Consumer Cost

The total consumer cost is the sum of the manufacturer and transportation costs multiplied by the appropriate distribution channel markups and sales tax. See chapter 8 for details on the methodology used for calculating the total consumer cost.

8J.3.1.5 Future Product Prices

DOE used a decreasing price trend for CAC and HP similar to the one used for the 2011 CAC and HP DFR, with the latest data available. DOE used a constant price trend for gas and electric storage water heaters, which was also used in the analysis for the 2010 heating products final rule.

The decreasing price trend for CAC and HP was derived based on the experience curve method, in which the real cost of production is related to the cumulative production or "experience" with a manufactured product. This experience is usually measured in terms of cumulative production. DOE obtained historical Producer Price Index (PPI) data for unitary air conditioners from the Bureau of Labor Statistics' (BLS). Because PPI data specific to air-source heat pumps were not available prior to 2008, DOE used PPI data for unitary air conditioners as representative of both unitary air conditioner and heat pump prices. Inflation-adjusted price indices for unitary air conditioners and heat pumps were calculated by dividing the PPI series by the Consumer Price Index (CPI) "all items" index for the same years. In addition, DOE also assembled a time-series of annual shipments for unitary air conditioners during the period of

1953-2009 from AHRI and the Gas Appliance Manufacturers Association as a proxy for production. Heat pump shipments data were also available but were not utilized in this analysis due to the unavailability of PPI data.

To estimate a learning rate parameter, a least-squares power-law fit was performed on the normalized price index versus cumulative shipments.

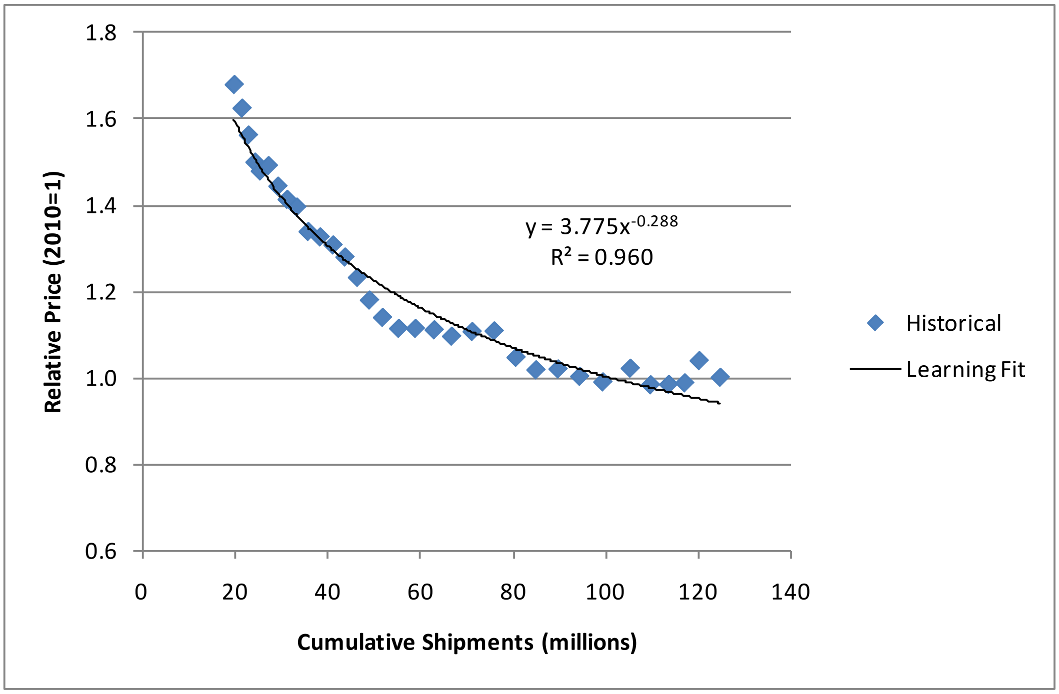

Figure 8J.3.1 **Relative Price Versus Cumulative Shipments of Unitary Air Conditioners, with Power Law Fit**

The form of the fitting equation is:

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

where the two parameters, b (the learning rate parameter) and P_o (the price or cost of the first unit of production), are obtained by fitting the model to the data. DOE notes that the cumulative shipments on the right hand side of the equation can have a dependence on price, so there is an issue with simultaneity where the independent variable is not truly independent. DOE's use of a simple least squares fit is equivalent to an assumption of no significant first price elasticity effects in the cumulative shipments variable.

The parameter values obtained are:

$P_o = 3.77^{+0.34}_{-0.31}$ (95% confidence), and
b = 0.288±0.021 (95% confidence).

As a result, the estimated learning rate is $18.1^{+1.2}_{-1.2}\%$ (95% confidence). Projected heat pump prices were based on the learning rate derived for unitary air conditioners.

In the LCC and PBP analysis, DOE derived a price factor index to project prices in 2021, the compliance year. The index value in a given year is a function of the LR and the cumulative production forecast through that year. DOE applied the same value to project prices for each product class at each considered efficiency level.

8J.3.1.6 Installation Cost

The installation cost of an alternative conditioning option is the cost to the consumer of installing the alternative space conditioning product. The cost of installation covers all labor and material costs associated with the delivery of the new product, removal of the existing NWGF, and any applicable permit fees. DOE also considered the installation costs of potential water heater product switching. DOE’s analysis of installation costs estimated specific installation costs for each sample household or building based on building characteristics given in RECS 2009 or CBECS 2003.

DOE estimated the installation costs at each considered efficiency level using a variety of sources, including RS Means 2013 *Residential Cost Data*,[12] manufacturer literature, and information from expert consultants. DOE’s analysis of installation costs accounts for regional differences in labor costs.

For alternative space conditioning and water heating products, DOE estimated basic installation costs. These costs, which apply to all products, include a trip charge, installation of the new product, startup and check of the product, electrical hookup for the thermostat, permit, removal or disposal fees, and, when applicable, additional labor hours for an attic installation, which are the same as for NWGFs (see appendix 8D). The NWGF removal and product installation labor hours are based on the input capacity of the NWGF that the household would otherwise install without switching. In addition, DOE included one hour of labor for switching costs, which including additional labor to cancel flue venting, cancel gas piping, and adjust duct work fittings.

Replacing a NWGF with electric space heating incurs substantial costs because of the complexity involved in modifying the installation. DOE determined that it would be unlikely for a fraction of households to switch from a NWGF to electric space heating primarily because installing an electric circuit capable of serving an electric space heating system is prohibitively expensive for these households. For a household with a NWGF to switch to electric space heating, a separate circuit up to 100 amps would be needed, depending on the house heating design requirements, as shown in Table 8J.3.5. The cost to install a circuit would vary from approximately $279 to $599 based on estimates using RS Means 2013 Residential Cost Data and average national labor rates. The installation costs for added a 50- or 100-amp electrical outlet for an electric furnace, which would be required for a fraction of households, would cost an additional $1,392 to $1,748 using average national labor rates.

DOE assumed the following to determine when to apply the electrical charges:

For replacement situations:

1) New electrical circuit: For NWGFs that have an input capacity of 70 kBtu/h or less, a new 50-amp circuit is required for all households. For NWGFs that have an input capacity greater than 70 kBtu/h, a new 100-amp circuit is required for all households.
2) New panel: For houses built before 1970, 75 percent require new panel in the North and 50 percent in the Rest of Country. For houses built in 1970 or later, 50 percent require a new vent panel in the North and 25 percent in the Rest of Country. For NWGFs that have an input capacity of 70 kBtu/h or less a new 150-amp panel is required. For NWGFs that have an input capacity greater than 70 kBtu/h, a new 200-amp is required.

For new construction situations:

1) New electrical circuit: The differential between the NWGF circuit required and the 50-amp circuit or 100-amp circuit required for an EF or HP.
2) New panel: The difference between a 100-amp circuit and a 150-amp circuit is used for NWGFs that are 70 kBtu/h or less. The difference between a 150-amp circuit and a 200-amp circuit is used for NWGFs that are at 70 kBtu/h or more.

Table 8J.3.5 Common Residential Electric Furnace (Single Phase) Sizes and Single Circuit Heater Amps, Compared to Equivalent NWGF Shipments by Input Capacity

Electric Furnace*			Non-Weatherized Gas Furnaces	
Input Capacity		Heat Amps (230V)	Comparable Input Capacity Range (kBtu/h)	Furnace Shipments (GAMA, 2001)
(kW at 240V)	(kBtu/h)			
3	10.2	12		
5	17.1	20		
8	27.3	32		
9	30.7	36		
10	34.1	40	40-55	9.4%
15	51.2	60	55-70	8.6%
20	68.2	80	70-90	38.5%
24	81.9	96	90-110	23.2%
30	102.4	120	>110	20.4%

* Source: Bryant Model Series FH4C[13] and GAMA historical furnace shipments by input capacity.[14]

In addition, many households that would be potentially interested in switching due to high installation costs from a condensing NWGF standard may still face high installation costs for an alternative product combination. Adding an electric furnace or heat pump would not preclude having to pay the installation costs associated with an orphaned water heater, a problem that can be encountered when switching from a non-condensing to a condensing furnace. In 18 percent of all NWGF installations, contractors encounter an orphaned water heater, which adds on average $501 to the installation cost.

8J.3.2 Operating Cost

8J.3.2.1 Product Energy Efficiency

For electric furnaces, DOE used an efficiency of 98-percent AFUE, which was derived from the DOE residential furnace and boiler test procedure. (10 CFR 430, appendix N to subpart B)

For heat pumps and CACs, DOE used efficiencies for models that meet the energy conservation standards due to take effect on January 1, 2015. (10 CFR 430.32(c)(3)) For HPs operating in heating mode, DOE used a Heating Seasonal Performance Factor (HSPF) of 8.2. DOE adjusted the HSPF ($HSPF_{Adj}$) to account for regional climate differences as follows:[15]

$$HSPF_{Adj} = 8.2 - \left(8.2 * \left(0.1392 + (-0.00846 * ODT_{Heat}) + \left(-0.0001074 * ODT_{Heat}{}^{2}\right) + (0.0228 * 8.2)\right)\right)$$

Eq. 8J.1

Where:

8.2 = national average HSPF for heat pumps, and
ODT_{Heat} = heating outdoor design temperature.

Table 8J.3.6 shows the cooling efficiencies used for new CACs and HPs. For CACs and HPs operating in cooling mode, DOE adjusted the rated SEER to account for regional differences in climate.

Table 8J.3.6 CAC and HP Space Cooling Efficiency

Product	Region	Rated SEER	SEER Climate Adjustment
CAC	North	13	$13-(-0.5655+0.005414*ODT_{Cooling}+0.01039*13)$
CAC	Rest of Country	14	$14-(-0.5864+0.005668*ODT_{Cooling}+0.01029*14)$
HP	National	14	$14-(-0.5864+0.005668*ODT_{Cooling}+0.01029*14)$

To determine the efficiency of the existing CAC, DOE used data provided by the Air Conditioning and Refrigeration Institute (ARI) from 1976 to 1989, excluding 1986, and the Air Conditioning, Heating and Refrigeration Institute (AHRI) from 1990 to 2009, as shown in Table 8J.3.7.[d] For 1986, DOE calculated the average of the historical SEER in 1985 and 1987.

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[d] In 2007, ARI and the Gas Appliance Manufacturers Association (GAMA) merged to become AHRI.

Table 8J.3.7 Historical CAC and HP Efficiency

Year	Split A/C	Split HP
	SEER	***SEER***
1976	7.16	6.84
1977	7.18	6.95
1978	7.42	7.26
1979	7.45	7.32
1980	7.51	7.47
1981	7.73	7.71
1982	8.25	7.94
1983	8.39	8.23
1984	8.65	8.42
1985	8.78	8.53
1986	8.84	8.70
1987	8.90	8.87
1988	9.05	9.06
1989	9.18	9.20
1990	9.24	9.43
1991	9.43	9.75
1992	10.49	10.61
1993	10.54	10.85
1994	10.59	10.92
1995	10.66	10.95
1996	10.65	10.97
1997	10.63	10.96
1998	10.24	10.54
1999	10.88	11.24
2000	10.97	11.24
2001	11.08	11.32
2002	11.07	11.33
2003	11.24	11.51
2004	11.34	11.61
2005	11.35	11.72
2006	13.16	13.45
2007	13.72	13.86
2008	13.77	13.99
2009	13.90	14.25

🟩	Data provided by AHRI[16]
🟦	ARI Data 1995[17]
🟥	No data. Average of 1985 and 1987.

Table 8J.3.8 shows the efficiencies used for gas and electric storage water heaters by rated storage volume. For new water heaters, DOE used efficiencies for models that meet the standards due to take effect on April 16, 2015. (10 CFR 430.32(d)) The efficiency standards enacted in 1990 and 2004 were used to determine the efficiency of the existing GSWH if commonly vented with the existing NWGF. (42 U.S.C. 6295(e)(1)–(4)), 66 FR 4474)

Table 8J.3.8 Water Heater Efficiencies by Rated Storage Volume

Standard	Application	Energy Factor				
		30 gal	*40 gal*	*50 gal*	*66 gal*	*80 gal*
1990 Standard (GSWH)	GSWH installed before 2004	0.56	0.54	0.53	0.49	-
2004 Standard (GSWH)	GSWH installed after 2004	0.61	0.59	0.58	0.54	-
2015 Standard (GSWH)	New GSWH	0.63	0.62	0.60	0.75	-
2015 Standard (ESWH)	New ESWH	0.95	0.95	0.95	1.98	1.97

8J.3.2.2 Energy Use

Product Sizing. As explained in appendix 7B, the CAC and HP sizing was developed to match AHRI shipments data from 2004-2013[18] by representative capacity in tons, as shown in Table 8J.3.9, using adjusted household square footage percentiles. The average CAC and HP representative capacity using this method for all households is 3.13 tons.

Table 8J.3.9 Fraction of CAC and HP Shipments by Representative Capacity (AHRI 2004-2013)

Representative Capacity (Tons)	Fraction of Shipments
2	36.9%
3	46.0%
5	17.1%

To account for the potentially larger heating requirements of households that could switch from a NWGF and CAC to a HP, DOE assumed that a household with a 60 kBtu/h or less NWGF would require at least a 2-ton CAC unit; with a 100 kBtu/h or less NWGF, at least a 3-ton CAC unit; and with a 100 kBtu/h or greater NWGF, a 5-ton CAC unit. The average representative capacity using this method for households switching to HPs is 3.45 tons for all households.

GSWHs are sized based on RECS 2009 variables that assign the size of the household's water heater (30 gallon, 40 gallon, or 50+ gallon). Based on historical shipments from AHRI, DOE assigned 10 percent of 50+ gallon water heaters to 66 gallons and 90 percent to 50 gallons.[19] If switching to an ESWH, some households will choose a larger ESWH because ESWHs produce hot water more slowly than GSWHs. To account for this, DOE assumed that 50 percent of the time, ESWH would be 10 gallons more (or one bin size higher) than the GSWH. In other words, if the household has a 30 gallon, then 50 percent of the time it would switch to a 30 gallon ESWH and 50 percent of the time it would switch to a 40 gallon ESWH.

Space Heating Energy Use – Electric Furnace/Heat Pump. The electricity use of the electric furnace during the heating season is determined by:

$$ElecUse_{Switch,ElecF} = \frac{BHL_{Furnace}}{AFUE_{ElecF} \times 3.412} + BlowerMotorElecUse_{ElecF}$$

Eq. 8J.2

Where:

$BHL_{Furnace}$ = building heating load served by a single furnace (kBtu/yr) (see chapter 7),
$AFUE_{ElecF}$ = AFUE of electric furnace, assumed to be 98-percent AFUE (section 8J.3.2.1),
3.412 = conversion factor to convert kBtu/yr to kWh/yr, and
$BlowerMotorElecUse_{ElecF}$ = total electrical energy consumption by the circulating blower of the electric furnace (kWh/yr).

The electricity use of the heat pump during the heating season is determined by:

$$ElecUse_{Switch,HP} = \frac{BHL_{Furnace}}{HSPF_{Adjusted}}$$

Eq. 8J.3

Where:

$BHL_{Furnace}$ = building heating load served by a single furnace (kBtu/yr) as determined above, and
$HSPF_{Adjusted}$ = HSPF of heat pump adjusted to climate conditions of sampled household (Btu/Wh) (Eq. 8J.1).

For the heat pump option, DOE also accounted for the cooling energy use of each relevant household that might switch from NWGF and CAC to a heat pump. The electricity use during the cooling season for both CAC and heat pump is determined by:

$$ElecUse_{Switch,cooling} = \frac{BCL_{CAC}}{SEER_{new}}$$

Eq. 8J.4

Where:

BCL_{CAC} = building cooling load served by a single central air conditioner or heat pump (kBtu/yr), and
$SEER_{new}$ = seasonal energy efficiency ratio (SEER) of the new central air conditioner or heat pump (Btu/Wh).

The annual building cooling load (BCL_{CAC}) is the total amount of heat output from the central air conditioner or heat pump that the house or building needs during the cooling season.[e] This includes heat from the burner as well as other electrical components. DOE determined BHL_{CAC} for each sampled housing unit or building, based on the efficiency of the assigned existing central air conditioner or heat pump, using the following calculation:

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[e] BCL is the load served by a single central air conditioner or heat pump. DOE assumed that some of the building structures would be served by multiple residentially-sized central air conditioners based on RECS 2009 data and that some central air conditioners serve multiple building structures.

$$BCL_{Furnace} = \frac{\left(Q_{YR} \times \frac{SEER_{ex}}{3.412}\right) \times Adj_{Factor(s)}}{CAC\ Count} \times NumberofUnitsServed$$

Eq. 8J.5

Where:

Q_{YR} = annual fuel consumption for heating based on RECS 2009 or CBECS 2003 (kBtu/yr),
$SEER_{ex}$ = seasonal energy efficiency ratio (SEER) of the existing central air conditioner or heat pump equipment (Btu/Wh),
3.412 = conversion factor to convert Wh to Btu,
$Adj_{Factor(s)}$ = adjustment factors for changes in building shell efficiency, historical average climate conditions, and future climate trends, (see chapter 7),
CAC Count = number of central air conditioners or heat pumps used to fulfill the building heating load, and
NumberofUnitsServed = number of housing units served by a single central air conditioner or heat pump.

Space Cooling Energy Use – Heat Pump. For the North region, there is a difference in cooling energy use when switching to HP from a CAC. The HP minimum efficiency in 2015 is 14 SEER, while for CAC the minimum efficiency is 13 SEER. This efficiency difference is taken into account when calculating the cooling energy use in equation Eq. 8J.4.

Water Heating Product Switching. Non-condensing NWGFs are often commonly vented with GSWHs. If a condensing NWGF is installed in commonly vented installation, the GSWH will be orphaned, which could result in high installation costs because the vent system will need to be resized. In this situation, the owner might elect to install an ESWH instead of paying the high cost of resizing the vent system. To calculate the water heating energy use, DOE calculated the fuel use for the GSWH based on the following equation:

$$FuelUse_{WH} = \frac{WHL}{EF_{new}}$$

Eq. 8J.6

Where:

WHL = water heating energy use based on RECS 2009 or CBECS 2003, and
EF_{new} = energy factor of the new water heater (see Table 8J.3.8).

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

$$WHL = \left(Q_{YR,HW} \times (EF_{ex})\right)$$

Eq. 8J.7

Where:

$Q_{YR,HW}$ = annual fuel consumption for water heating based on RECS 2009 or CBECS 2003 (kBtu/yr), and
EF_{ex} = energy factor of the existing GSWH (see Table 8J.3.8).

8J.3.2.3 Energy Prices

DOE used marginal monthly energy prices by region to determine both the fraction of product switching and the LCC and PBP impacts of households that switched. See appendix 8E for more details.

8J.3.2.4 Repair

The repair cost is the cost to the consumer for replacing or repairing components in the product that have failed. DOE estimated repair costs at each considered efficiency level using a variety of sources, including *2013 RS Means Facility Repair and Maintenance Data*,[20] manufacturer literature, and information from expert consultants. DOE accounted for regional differences in labor costs, as discussed in appendix 8D.

Table 8J.3.10 through Table 8J.3.12 show repair cost assumptions that DOE used in its analysis for alternative space conditioning and water heating products. The failure year distribution for each component was assumed to be a Weibull function.

Table 8J.3.10 Electric Furnace and Air Handler Repair Costs

Repair Description	Mean Failure Year	Repair Rate	Bare Material Cost (2013$)*	Total Labor Hours
Controls, Electrical Element	10	25%	$50.00	1.50

*Does not include sales tax or markups.

Table 8J.3.11 Central Air Conditioner and Heat Pump Repair Costs

Repair Description	Mean Failure Year	Repair Rate	Bare Material Cost (2013$)*	Total Labor Hours
Controls, Refrigerant Change	10	25%	$120.08	1.90
Compressor	14.3	12.5%	$455.00	7.93

*Does not include sales tax or markups.

Table 8J.3.12 Water Heater Repair Costs

Repair Description	Mean Failure Year	Repair Rate	Bare Material Cost (2013$)*	Total Labor Hours
Ignition, Controls, Gas Valve (GSWH)	10	12.5%	$50.00	2.50
Electric Elements (ESWH)	10	12.5%	$20.00	1.50

*Does not include sales tax or markups.

8J.3.2.5 Maintenance

The maintenance cost is the routine annual cost to the consumer of general maintenance for product operation. DOE used data from RS Means to calculate the maintenance cost for alternative space conditioning and water heating products. DOE accounted for regional differences in labor costs, as discussed in appendix 8D.

DOE used the same maintenance frequency and labor costs for electric furnaces, air handlers, central air conditioners, and heat pumps as it used for NWGFs (see appendix 8F). For water heaters, DOE assumed that 2.5 percent are maintained every 5 years, while the remaining 97.5 percent are not maintained or maintained without the use of a contractor. The labor cost of maintenance for these alternative products is the same as for NWGFs, but labor hours vary by product as shown in Table 8J.3.13.

Table 8J.3.13 Labor Hours for Maintenance of Alternative Products

Product	Total Labor Hours
Electric Furnace/Air Handler	1.35
Heat Pump	1.17
Central Air Conditioner	1.11
Gas Storage Water Heater	1.20
Electric Storage Water Heater	0.93

8J.3.2.6 Lifetime

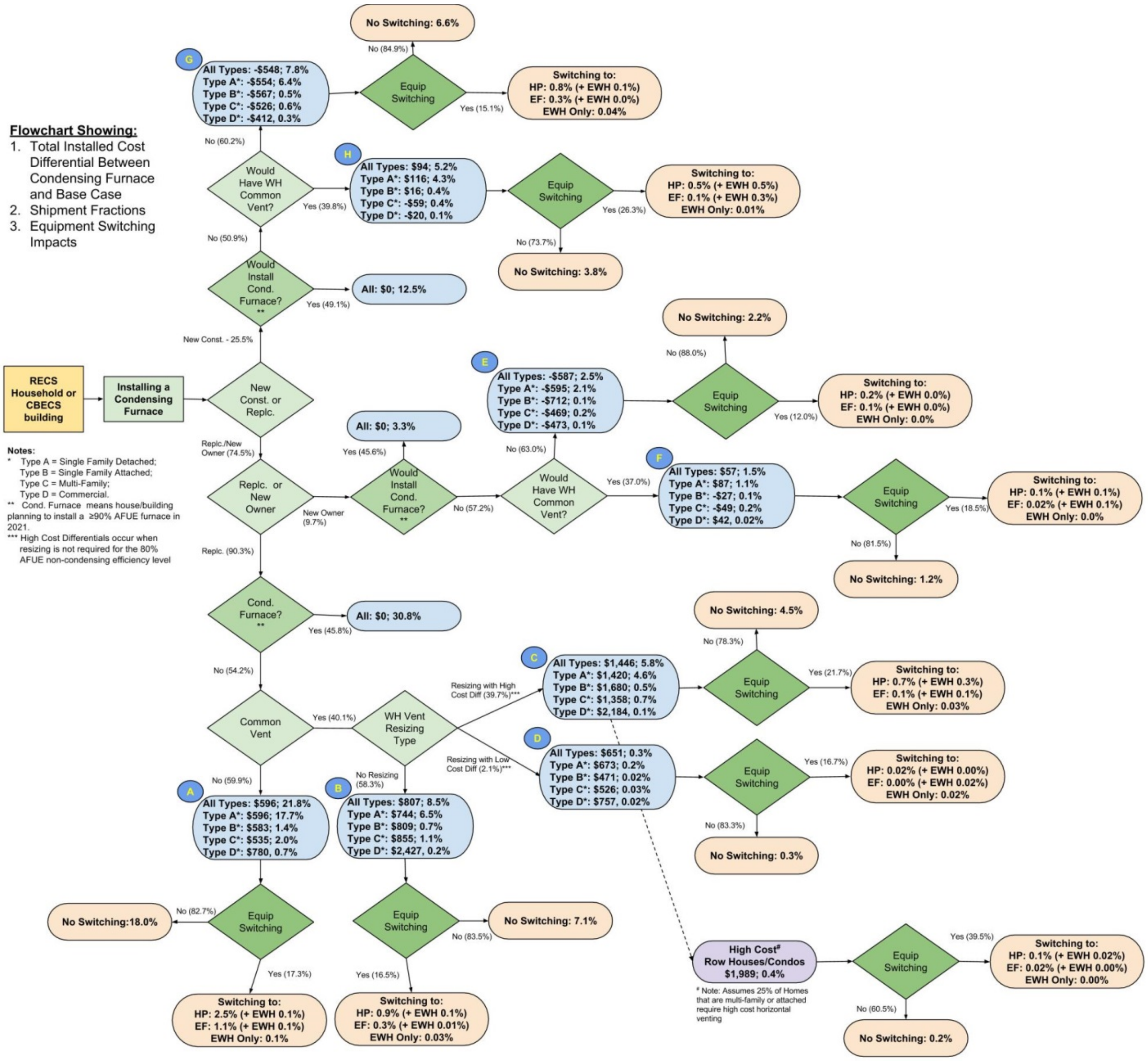
Electric furnaces are estimated to have the same lifetime as NWGFs. CACs and heat pumps have an estimated average lifetime of 19 years,[21] which is 2.5 years less than the estimated average lifetime of NWGFs (21.5 years). For GSWHs and ESWHs, the lifetime average is assumed to be 12.3 years.[11] To ensure comparable accounting, DOE annualized the installed cost of a second heat pump and multiplied the annualized cost by the difference in years between the heat pump and a NWGF in a particular switching situation.

8J.4 PRODUCT SWITCHING ANALYSIS RESULTS

The results presented in chapter 8include product switching as described in this appendix.

Figure 8J.4.1 shows a flowchart of how the installation methodology is applied in the product switching decision model. For illustrative purposes, the flowchart shows the average difference in installation cost between the base case and standards case at 90-percent AFUE, as well as the fraction of total NWGF shipments for different housing types AFUE. Note that negative installation costs indicate lower costs on average under the standards case.

Beginning with the sample household or building, DOE determined in which market the NWGF would be installed (new construction, replacement, or new owner). Then, DOE determined whether the household already has a condensing NWGF. For households that already have a condensing NWGF, DOE assumed that there is no difference in total installed cost between the base case and standards case. For households that have a non-condensing NWGF, DOE determined whether the household commonly vented the existing NWGF with the water heater based on a 1991 GTI Water Heater Survey,[22] and whether vent resizing would be required to accommodate an orphaned water heater. For the new construction and new owner markets, DOE determined which households would have otherwise installed a non-condensing NWGF with a commonly vented water heater in the base case (Cases F and H). Finally, DOE determined whether the household would switch to an alternative space-conditioning or water-heating product. The tan bubbles show the fraction of total NWGF shipments to each product combination.



Notes:
* Type A = Single Family Detached; Type B = Single Family Attached; Type C = Multi-Family; Type D = Commercial.
** Cond. Furnace means house/building planning to install a ≥90% AFUE furnace in 2021.
*** High Cost Differentials occur when resizing is not required for the 80% AFUE non-condensing efficiency level

\# Note: Assumes 25% of Homes that are multi-family or attached require high cost horizontal venting

Figure 8J.4.1 Product Switching Methodology and Results

Table 8J.4.1 through Table 8J.4.2 show the difference in energy use and cost between baseline NWGFs (80-percent AFUE) and other products in the residential sector in the North and Rest of Country regions for both replacement and new construction installations.

80% NWGF to EF: Represents the energy use and cost differentials between the households that switched from 80-percent AFUE NWGF to an electric furnace (EF) compared to the no-switching scenario for each NWGF efficiency level. The results show that the households that switched had lower total installed, maintenance, and repair costs as a result of switching. Also, fuel use decreases, while electricity use increases significantly.

80% NWGF to HP: Represents the energy use and cost differentials between the households that switched from 80-percent AFUE NWGF to a heat pump compared to the no-switching scenario for each NWGF efficiency level. The results show that the households that switched had lower total installed and maintenance and repair costs as a result of switching. Also, fuel use decreases, while electricity use increases significantly.

GSWH to ESWH: Represents the energy use and cost differentials between the households that switched from gas storage water heater (GSWH) to an electric storage water heater (ESWH) for each NWGF efficiency level. The results show that the households that switched had lower maintenance and repair costs as a result of switching. For some ELs and markets, the total installed costs are higher, but because these are associated with EF and HPs, the overall installation cost would be lower. Also, fuel use decreases, while electricity use increases significantly.

Table 8J.4.1 Replacement and New Owner Units in Residential Sector

Type of Switching	**NWGF EL**	**Fuel Use** *MMBtu/yr*		**Electricity Use** *kWh/yr*		**Total Installed Cost** *(2013$)*		**Annualized Maint & Repair** *(2013$)*	
	AFUE	*North*	*Rest of Country*	*North*	*Rest of Country*	*North*	*Rest of Country*	*North*	*Rest of Country*
80% NWGF to EF	90%	-31.57	-15.83	8636	4294	-$430	-$450	-$12	-$17
	92%	-29.81	-15.61	8331	4329	-$467	-$463	-$10	-$17
	95%	-28.33	-16.22	8175	4655	-$589	-$585	-$13	-$15
	98%	-27.31	-14.45	8132	4277	-$742	-$765	-$13	-$15
80% NWGF to HP	90%	-30.63	-20.90	4745	2699	-$693	-$442	-$9	-$7
	92%	-29.86	-20.10	4731	2642	-$714	-$450	-$9	-$6
	95%	-30.17	-19.91	4920	2637	-$783	-$463	-$10	-$6
	98%	-30.18	-19.81	4991	2638	-$875	-$527	-$10	-$6
GSWH to ESWH	90%	-15.07	-12.76	2518	2395	$307	$42	-$5	-$5
	92%	-16.61	-12.64	2682	2374	$327	$47	-$6	-$5
	95%	-17.88	-14.06	2871	2647	$392	$74	-$6	-$4
	98%	-20.37	-16.15	3251	3049	$395	$117	-$5	-$4

Table 8J.4.2 New Construction Units in Residential Sector

Type of Switching	NWGF EL	Fuel Use *MMBtu/yr*		Electricity Use *kWh/yr*		Total Installed Cost *(2013$)*		Annualized Maint & Repair *(2013$)*	
	AFUE	*North*	*Rest of Country*	*North*	*Rest of Country*	*North*	*Rest of Country*	*North*	*Rest of Country*
80% NWGF to EF	90%	-34.75	-11.01	9514	2987	-$289	-$404	-$14	-$19
	92%	-34.75	-10.78	9725	2989	-$310	-$423	-$13	-$18
	95%	-35.11	-11.12	10150	3189	-$380	-$544	-$13	-$15
	98%	-33.28	-13.76	9944	4083	-$519	-$622	-$15	-$13
80% NWGF to HP	90%	-31.19	-16.07	5095	2118	-$500	-$340	-$8	-$4
	92%	-30.10	-15.33	4994	2026	-$513	-$338	-$8	-$4
	95%	-29.75	-15.47	4973	2135	-$522	-$423	-$9	-$4
	98%	-29.24	-15.59	4927	2122	-$629	-$508	-$8	-$4
GSWH to ESWH	90%	-19.96	-10.32	3179	1840	$355	-$54	-$5	-$4
	92%	-19.97	-10.28	3180	1834	$362	-$53	-$4	-$4
	95%	-20.46	-10.69	3260	1903	$345	-$17	-$4	-$4
	98%	-23.16	-12.13	3656	2172	$347	$26	-$4	-$4

Table 8J.4.3 and Table 8J.4.4 show the fraction of switching by region for replacement and new construction sectors, respectively

Table 8J.4.3 Percent of Product Switching for Replacement and New Owner Units in Residential Sector

Consumer Option	National Standard at:*							
	90% AFUE		92% AFUE		95% AFUE		98% AFUE	
	North	*Rest of Country*	*North*	*Rest of Country*	*North*	*Rest of Country*	*North*	*Rest of Country*
Purchase NWGF at Standard Level	88.40%	79.99%	88.89%	80.02%	87.02%	75.08%	84.67%	65.35%
Switch from Non-Cond. NWGF to EF**	3.08%	5.76%	2.76%	5.68%	3.08%	5.79%	3.41%	7.20%
Switch from Non-Cond. NWGF to HP**	8.52%	14.26%	8.35%	14.30%	9.89%	19.12%	11.92%	27.44%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Switch from GSWH to ESWH	2.68%	2.56%	2.27%	2.71%	2.76%	3.04%	3.33%	3.94%

* Note: Components may not add to 100 percent due to rounding.

**Includes households that also switch from a gas water heater to an electric water

Table 8J.4.4 Percent of Product Switching for New Construction Units in Residential Sector

Consumer Option	**National Standard at:***							
	90% AFUE		**92% AFUE**		**95% AFUE**		**98% AFUE**	
	North	*Rest of Country*	*North*	*Rest of Country*	*North*	*Rest of Country*	*North*	*Rest of Country*
Purchase NWGF at Standard Level	82.91%	78.89%	83.12%	78.77%	79.06%	74.62%	73.29%	67.34%
Switch from Non-Cond. NWGF to EF**	5.13%	5.15%	4.91%	5.03%	5.56%	7.04%	7.26%	6.78%
Switch from Non-Cond. NWGF to HP**	11.97%	15.95%	11.97%	16.12%	15.38%	18.34%	19.44%	25.88%
Total	100%	100%	100.0%	100%	100.0%	100%	100.0%	100%
Switch from GSWH to ESWH	7.26%	6.28%	7.26%	6.41%	7.91%	7.66%	11.32%	7.91%

* Note: Components may not add to 100 percent due to rounding.
**Includes households that also switch from a gas water heater to an electric water heater.

Table 8J.4.5 and Table 8J.4.6 show the average marginal energy prices in 2021 for NWGFs that did not switch to other heating products and those that did in the residential sector in North and Rest of Country for both replacements and new construction. In general, households that switched had lower electricity prices and higher fuel prices. A significantly higher number of households using liquefied petroleum gas (LPG) switched to electricity due to the high price of LPG.

Table 8J.4.5 Average Marginal Energy Prices, Residential Sector, North

Product Class and Type of Switching	EL	Replacements		New Construction	
		Electricity *$/kWh*	Fuel *$/MMBtu*	Electricity *$/kWh*	Fuel *$/MMBtu*
NWGF 80%	0	$0.12	$11.42	$0.11	$13.52
NWGF 90%	1	$0.12	$11.19	$0.11	$13.18
NWGF 92%	2	$0.12	$11.21	$0.11	$13.20
NWGF 95%	3	$0.12	$11.19	$0.11	$13.12
NWGF 98%	4	$0.12	$11.19	$0.11	$13.06
80% NWGF to EF	0	NA	NA	NA	NA
80% NWGF to EF	1	$0.10	$27.46	$0.09	$23.08
80% NWGF to EF	2	$0.10	$28.50	$0.09	$22.79
80% NWGF to EF	3	$0.10	$27.02	$0.08	$22.96
80% NWGF to EF	4	$0.09	$25.08	$0.08	$22.32
80% NWGF to HP	0	NA	NA	NA	NA
80% NWGF to HP	1	$0.09	$13.61	$0.10	$17.00
80% NWGF to HP	2	$0.09	$13.54	$0.10	$16.91
80% NWGF to HP	3	$0.09	$13.39	$0.10	$16.97
80% NWGF to HP	4	$0.10	$13.30	$0.10	$16.31
GSWH to ESWH	0	NA	NA	NA	NA
GSWH to ESWH	1	$0.10	$15.95	$0.10	$17.11
GSWH to ESWH	2	$0.10	$15.99	$0.10	$16.50
GSWH to ESWH	3	$0.10	$16.29	$0.10	$16.33
GSWH to ESWH	4	$0.09	$17.56	$0.10	$15.40

Table 8J.4.6 Average Marginal Energy Prices, Residential Sector, South

Product Class	EL	Replacements		New Construction	
		Electricity *$/kWh*	Fuel *$/MMBtu*	Electricity *$/kWh*	Fuel *$/MMBtu*
NWGF 80%	0	$0.12	$11.23	$0.11	$11.41
NWGF 90%	1	$0.12	$10.71	$0.11	$11.09
NWGF 92%	2	$0.12	$10.71	$0.11	$11.08
NWGF 95%	3	$0.12	$10.70	$0.11	$10.97
NWGF 98%	4	$0.12	$10.70	$0.11	$10.87
80% NWGF to EF	0	NA	NA	NA	NA
80% NWGF to EF	1	$0.10	$20.80	$0.11	$16.67
80% NWGF to EF	2	$0.10	$20.89	$0.11	$16.77
80% NWGF to EF	3	$0.10	$20.30	$0.11	$16.73
80% NWGF to EF	4	$0.10	$18.46	$0.10	$18.14
80% NWGF to HP	0	NA	NA	NA	NA
80% NWGF to HP	1	$0.11	$11.33	$0.13	$12.21
80% NWGF to HP	2	$0.11	$11.38	$0.13	$12.22
80% NWGF to HP	3	$0.11	$11.38	$0.13	$12.22
80% NWGF to HP	4	$0.11	$11.15	$0.12	$11.94
GSWH to ESWH	0	NA	NA	NA	NA
GSWH to ESWH	1	$0.12	$17.30	$0.12	$15.22
GSWH to ESWH	2	$0.12	$17.41	$0.12	$15.11
GSWH to ESWH	3	$0.12	$17.80	$0.12	$14.22
GSWH to ESWH	4	$0.11	$18.04	$0.11	$15.44

8J.5 PRODUCT SWITCHING SENSITIVITY ANALYSIS RESULTS

8J.5.1 Introduction

Four switching scenarios were analyzed: a reference case based on the assumption of a 3.5-year payback (referred to hereafter as *Ref.*); a second scenario which presents no switching (referred to hereafter as *None*); a low product switching scenario which is based on the assumption of a 4.5-year payback (referred to hereafter as *Low*); and, a high product switching scenario based on the assumption of a 2.5-year payback (referred to hereafter as *High*). The 2.5-year payback assumption for the High switching scenario is based on the 2013 AHCS data, while the 4.5-year payback assumption for the Low switching scenario is based on using regional data for California from 2008 AHCS data.

8J.5.2 Sensitivity Results

Table 8J.5.1 presents the LCC and PBP results comparison for all the scenarios. In general, the results with higher switching have greater LCC savings, lower simple PBP, and a lower fraction of consumers that experience net cost.

Table 8J.5.1 Comparison of LCC and Payback Period Results Product Switching for Non-Weatherized Gas Furnaces

EL	Average LCC Savings *2013$*				Simple Payback Period *Years*				% of Consumers that Experience Net Cost			
	Ref.	**High**	**Low**	**None**	**Ref.**	**High**	**Low**	**None**	**Ref.**	**High**	**Low**	**None**
National												
1	$236	$185	$259	$164	10.6	10.3	10.3	12.2	22%	22%	21%	23%
2	$305	$253	$329	$238	7.7	7.6	7.6	9.0	20%	20%	19%	20%
3	$388	$320	$418	$311	8.9	8.7	8.8	9.6	24%	25%	23%	24%
4	$441	$353	$481	$332	12.0	11.9	12.1	12.9	40%	41%	39%	41%
North												
1	$208	$172	$224	$169	8.8	8.7	8.7	9.6	11%	12%	11%	12%
2	$277	$241	$295	$244	5.3	5.2	5.3	5.9	10%	10%	10%	10%
3	$374	$321	$399	$343	7.8	7.8	7.8	8.0	14%	14%	13%	14%
4	$467	$405	$504	$435	11.8	11.8	11.8	12.0	37%	38%	36%	37%
Rest of Country												
1	$267	$199	$299	$158	11.8	11.6	11.6	13.8	33%	34%	32%	35%
2	$336	$267	$366	$232	9.5	9.2	9.3	11.0	31%	32%	29%	32%
3	$404	$318	$441	$276	10.1	9.9	10.0	11.3	35%	36%	33%	36%
4	$412	$294	$455	$215	12.4	12.2	12.6	14.3	43%	44%	41%	47%

Table 8J.5.2 through Table 8J.5.5 present the switching results for each of the sensitivity scenarios.

Table 8J.5.2 Comparison of Product Switching Results for Non-Weatherized Gas Furnaces for Replacements and New Owners in the Residential Sector

	Consumer Option	National Standard at:*							
		90% AFUE		92% AFUE		95% AFUE		98% AFUE	
		North	*Rest of Country*	*North*	*Rest of Country*	*North*	*Rest of Country*	*North*	*Rest of Country*
Ref.	Purchase NWGF at Standard Level	88.40%	79.99%	88.89%	80.02%	87.02%	75.08%	84.67%	65.35%
	Switch from Non-Cond. NWGF to EF**	3.08%	5.76%	2.76%	5.68%	3.08%	5.79%	3.41%	7.20%
	Switch from Non-Cond. NWGF to HP**	8.52%	14.26%	8.35%	14.30%	9.89%	19.12%	11.92%	27.44%
	Switch from GSWH to ESWH	2.68%	2.56%	2.27%	2.71%	2.76%	3.04%	3.33%	3.94%
Low	Purchase NWGF at Standard Level	90.19%	82.29%	90.51%	82.47%	89.29%	78.35%	87.43%	69.29%
	Switch from Non-Cond. NWGF to EF**	2.43%	4.57%	2.19%	4.49%	2.35%	4.53%	2.51%	5.31%
	Switch from Non-Cond. NWGF to HP**	7.38%	13.15%	7.30%	13.03%	8.35%	17.12%	10.06%	25.40%
	Switch from GSWH to ESWH	2.11%	2.27%	1.87%	2.41%	2.11%	2.82%	2.68%	3.64%
High	Purchase NWGF at Standard Level	86.05%	76.49%	86.21%	76.38%	84.18%	69.96%	82.16%	59.04%
	Switch from Non-Cond. NWGF to EF**	3.49%	8.06%	3.49%	7.98%	4.06%	8.91%	4.38%	11.03%
	Switch from Non-Cond. NWGF to HP**	10.46%	15.45%	10.30%	15.63%	11.76%	21.13%	13.46%	29.93%
	Switch from GSWH to ESWH	3.24%	2.93%	2.92%	3.04%	3.57%	3.56%	4.06%	4.34%

* Note: Components may not add to 100 percent due to rounding.

**Includes households that also switch from a gas water heater to an electric water heater.

Table 8J.5.3 Comparison of Product Switching Results for Non-Weatherized Gas Furnaces for New Constructions in the Residential Sector

	Consumer Option	National Standard at:*							
		90% AFUE		92% AFUE		95% AFUE		98% AFUE	
		North	*Rest of Country*	*North*	*Rest of Country*	*North*	*Rest of Country*	*North*	*Rest of Country*
Ref.	Purchase NWGF at Standard Level	82.91%	78.89%	83.12%	78.77%	79.06%	74.62%	73.29%	67.34%
	Switch from Non-Cond. NWGF to EF**	5.13%	5.15%	4.91%	5.03%	5.56%	7.04%	7.26%	6.78%
	Switch from Non-Cond. NWGF to HP**	11.97%	15.95%	11.97%	16.21%	15.38%	18.34%	19.44%	25.88%
	Switch from GSWH to ESWH	7.26%	6.28%	7.26%	6.41%	7.91%	7.66%	11.32%	7.91%
Low	Purchase NWGF at Standard Level	90.60%	90.95%	90.38%	91.83%	87.61%	90.95%	84.83%	85.93%
	Switch from Non-Cond. NWGF to EF**	3.85%	0.88%	3.42%	0.88%	4.27%	1.38%	4.70%	2.39%
	Switch from Non-Cond. NWGF to HP**	5.56%	8.17%	6.20%	7.29%	8.12%	7.66%	10.47%	11.68%
	Switch from GSWH to ESWH	4.06%	2.51%	4.06%	2.64%	4.06%	3.52%	5.98%	4.52%
High	Purchase NWGF at Standard Level	79.06%	74.75%	79.70%	74.50%	72.44%	70.60%	66.45%	62.56%
	Switch from Non-Cond. NWGF to EF**	6.20%	7.91%	5.56%	8.04%	7.48%	9.42%	9.62%	8.92%
	Switch from Non-Cond. NWGF to HP**	14.74%	17.34%	14.74%	17.46%	20.09%	19.97%	23.93%	28.52%
	Switch from GSWH to ESWH	10.47%	7.79%	10.26%	7.66%	13.46%	8.92%	16.24%	9.67%

* Note: Components may not add to 100 percent due to rounding.
**Includes households that also switch from a gas water heater to an electric water heater.

Table 8J.5.4 Comparison of Product Switching Results for Non-Weatherized Gas Furnaces for Replacements and New Owners in the Residential Sector for 90% AFUE Efficiency Level

Consumer Option	90% AFUE					
	Reference Case		**Low Switching**		**High Switching**	
	North	*Rest of Country*	*North*	*Rest of Country*	*North*	*Rest of Country*
Purchase NWGF at Standard Level	88.40%	79.99%	90.19%	82.29%	86.05%	76.49%
Switch from Non-Cond. NWGF to EF**	3.08%	5.76%	2.43%	4.57%	3.49%	8.06%
Switch from Non-Cond. NWGF to HP**	8.52%	14.26%	7.38%	13.15%	10.46%	15.45%
Total	100%	100%	100%	100%	100%	100%
Switch from GSWH to ESWH	2.68%	2.56%	2.11%	2.27%	3.24%	2.93%

* Note: Components may not add to 100 percent due to rounding.
**Includes households that also switch from a gas water heater to an electric water heater.

Table 8J.5.5 Comparison of Product Switching Results for Non-Weatherized Gas Furnaces for New Constructions in the Residential Sector for 90% AFUE Efficiency Level

Consumer Option	90% AFUE					
	Reference Case		**Low Switching**		**High Switching**	
	North	*Rest of Country*	*North*	*Rest of Country*	*North*	*Rest of Country*
Purchase NWGF at Standard Level	82.91%	78.89%	90.60%	90.95%	79.06%	74.75%
Switch from Non-Cond. NWGF to EF**	5.13%	5.15%	3.85%	0.88%	6.20%	7.91%
Switch from Non-Cond. NWGF to HP**	11.97%	15.95%	5.56%	8.17%	14.74%	17.34%
Total	100%	100%	100%	100%	100%	100%
Switch from GSWH to ESWH	7.26%	6.28%	4.06%	2.51%	10.47%	7.79%

* Note: Components may not add to 100 percent due to rounding.
**Includes households that also switch from a gas water heater to an electric water heater.

8J.6 GTI 2014 PRODUCT SWITCHING SURVEY

The Gas Technology Institute (GTI) recently conducted a survey intended to determine the degree to which home builders and installation contractors would switch from installing space or water-heating products that use natural gas to products that use electricity or other fuels if NWGF AFUE standards increased.[17]

8J.6.1 Survey Representation

The results GTI provided DOE in September 2014 included responses from 206 home builders and 590 installation contractors. The survey asked in which of ten Census regions each builder or contractor operated; some respondents operated in more than one Census region. The distribution of the respondents by Census region is shown in Table 8J.6.1 (another 103 respondents were neither builders nor installers). Table 8J.6.1 also shows the distribution of NWGF installations in the RECS 2009 sample by region. The distribution of all NWGFs in the entire 2009 RECS household sample is shown for installers, while the distribution of NWGFs only in homes built between 2005 and 2009 is shown for builders to represent the new construction sample.

Table 8J.6.1 Distribution of GTI Survey Respondents and NWGF Installations in 2009 RECS by Census Region

Census Region	Survey Respondents				2009 RECS NWGF Installations	
	Number		Distribution			
	Builders	Installers	Builders	Installers	Builders	Installers
1: Pacific	12	27	6%	5%	15%	14%
2: Mountain North	0	43	0%	7%	7%	6%
3: West North Central	35	76	17%	13%	10%	11%
4: East North Central	61	54	30%	9%	9%	26%
5: Mid Atlantic	16	196	8%	33%	13%	12%
6: New England	2	20	1%	3%	2%	2%
7: South Atlantic	51	108	25%	18%	20%	11%
8: East South Central	23	7	11%	1%	8%	5%
9: West South Central	6	47	3%	8%	10%	10%
10: Mountain South	0	12	0%	2%	7%	4%
Total	206	590	100%	100%	100%	100%

Note: 2009 RECS distribution of all NWGFs shown for installers, and distribution of NWGFs in homes built between 2005 and 2009 shown for builders.

Because some survey respondents operate in multiple Census regions, DOE used the State in which each builder or installer is headquartered as reported by the survey to conduct a regional analysis (see section 8J.6.2). . Table 8J.6.2 shows the number and distribution of builders and installers headquartered in the five largest States.

Table 8J.6.2 Distribution of GTI Survey Respondents by Headquarter, 2013 Population, and RECS 2009 Furnace Installations for Five Largest States

Census Region: State	Survey respondents				2013 Population	2009 RECS NWGF Installations	
	Number		Distribution				
	Builders	Installers	Builders	Installers		Builders	Installers
1: CA	1	6	0%	1%	12%	10%	12%
9: TX	2	3	1%	1%	8%	7%	7%
7: FL	2	0	1%	0%	6%	2%	1%
5: NY	0	1	0%	0%	6%	2%	4%
4: IL	25	0	12%	0%	4%	2%	7%
Total	30	10	15%	2%	37%	23%	31%

8J.6.2 Survey Results

The GTI survey asked respondents to provide the distribution of nine combinations of space- and water-heating products currently installed in new homes or installations:

- Non-condensing (low efficiency) NWGF + GSWH;
- Condensing (high efficiency) NWGF + GSWH;
- Electric heat pump + GSWH;
- Electric furnace or baseboard + GSWH;
- Non-condensing (low efficiency) NWGF + ESWH;
- Condensing (high efficiency) NWGF + ESWH;
- Electric heat pump + ESWH;
- Electric furnace or baseboard + ESWH;
- Other combinations of space- + water-heating equipment.

The survey asked the current distribution of product combinations and what respondents expected the distribution would be after adoption of a NWGF efficiency standard that would prohibit installation of non-condensing (low efficiency) NWGFs.

Table 8J.6.3 and Table 8J.6.4 show the average distribution of products installed for the nine combinations of space- and water-heating products before (pre) and after adoption of (post) the NWGF standard for home builders and installation contractors, respectively. Four measures of the fraction of homes switching fuel from natural gas to electricity are calculated in the tables: Measure 1 is the fraction of homes that would switch from natural gas products for both space and water heating to electricity for at least one of the two end-uses; Measure 2 is the fraction of homes that would switch from gas to electricity for space heating only; and Measure 3 is the fraction of homes that would switch from gas to electricity for water heating only. The percentages of the relevant product combinations used to calculate the product switching in each measure are shown in blue in each table. For example, Table 8J.6.3 indicates that under fuel-switching Measure 1, home builders currently install gas products for both space- and water-heating in 74.7 percent of new home construction (17.2 percent non-condensing NWGFs and 57.4 percent condensing NWGFs). This percentage was expected decrease to 68.9 percent after adoption of a condensing NWGF AFUE standard, with 5.5 percent of new homes built switching from all gas space- and water-heating products to using electricity for at least one of the two end uses.

Table 8J.6.3 Percent of U.S. Home Builder Respondents Who Would Switch from Gas to Electric Fuel for Installed Space- or Water-Heating Products

Space Heating	Water Heating	1. From all gas to not all gas		2. From gas to electric space heating		3. From gas to electric water heating	
		Pre	Post	Pre	Post	Pre	Post
Low-eff NWGF	GSWH	17.2%	0.0%	17.2%	0.0%	17.2%	0.0%
Hi-eff NWGF	GSWH	57.4%	68.9%	57.5%	68.9%	57.5%	68.9%
HP	GSWH	3.2%	7.0%	3.2%	7.0%	3.2%	7.0%
EF	GSWH	0.6%	0.3%	0.6%	0.3%	0.6%	0.3%
Low-eff NWGF	ESWH	3.9%	0.0%	3.9%	0.0%	3.9%	0.0%
Hi-eff NWGF	ESWH	8.5%	13.7%	8.5%	13.7%	8.5%	13.7%
HP	ESWH	5.5%	6.7%	5.5%	6.7%	5.5%	6.7%
EF	ESWH	2.0%	1.6%	2.0%	1.6%	2.0%	1.6%
Other		1.7%	1.9%	1.7%	1.9%	1.7%	1.9%
Total		100%	100%	100%	100%	100%	100%
Total in Measure		74.7%	68.9%	87.1%	82.5%	78.4%	76.1%
Percent fuel switching			5.8%		4.6%		2.3%

Note: The relevant percentages used to calculate each measure are shown in blue.

Table 8J.6.4 Percent of U.S. Installation Contractor Respondents Who Would Switch from Gas to Electric Fuel for Installed Space- or Water-Heating Products

Space Heating	Water Heating	1. From all gas to not all gas		2. From gas to electric space heating		3. From gas to electric water heating	
		Pre	Post	Pre	Post	Pre	Post
Low-eff NWGF	GSWH	30.4%	0.0%	30.4%	0.0%	30.4%	0.0%
Hi-eff NWGF	GSWH	48.1%	71.8%	48.1%	71.8%	48.1%	71.8%
HP	GSWH	3.4%	8.1%	3.4%	8.1%	3.4%	8.1%
EF	GSWH	1.2%	1.8%	1.2%	1.8%	1.2%	1.8%
Low-eff NWGF	ESWH	2.4%	0.0%	2.4%	0.0%	2.4%	0.0%
Hi-eff NWGF	ESWH	3.2%	5.1%	3.2%	5.1%	3.2%	5.1%
HP	ESWH	5.5%	6.8%	5.5%	6.8%	5.5%	6.8%
EF	ESWH	1.3%	1.5%	1.3%	1.5%	1.3%	1.5%
Other		4.6%	5.0%	4.6%	5.0%	4.6%	5.0%
Total		100.0%	100.0%	100%	100%	100%	100%
Total in Measure		78.5%	71.8%	84.0%	76.9%	83.1%	81.6%
Percent fuel switching			6.8%		7.2%		1.5%

Note: The relevant percentages used to calculate each measure are shown in blue.

Figure 8J.6.1 and Figure 8J.6.2 show the GTI estimates for builders and installers, respectively, for the Nation and by Census region.

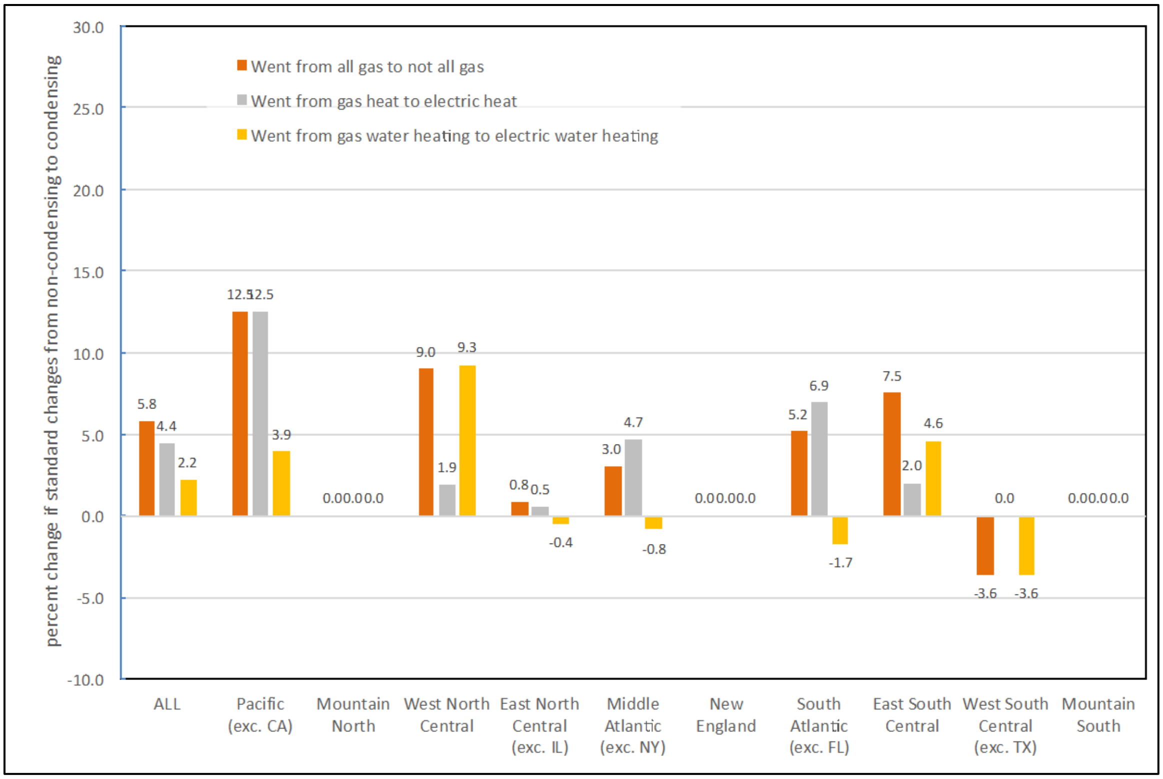


Figure 8J.6.1 Percent Fuel Switching for Home Builders by Census Region

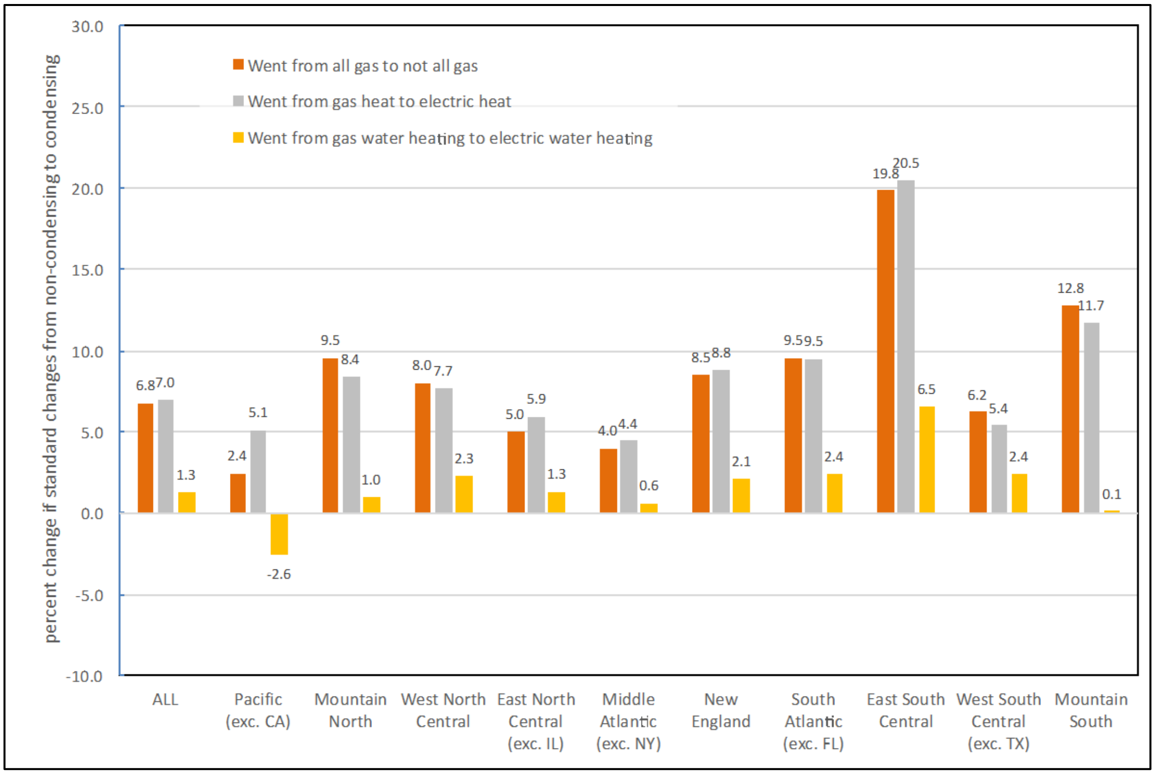


Figure 8J.6.2 **Percent Fuel Switching for Installation Contractors by Census Region**

Table 8J.6.5 displays the switching results for all measures described in Table 8J.6.3 and Table 8J.6.4 for builders and installation contractors in the North and Rest of Country regions. DOE determined the region (North or Rest of Country) by the State in which the builder or contractor is headquartered, rather than the Census region(s) of operation, to determine the distribution of unique respondents (see section 8J.6.1).

Table 8J.6.5 Percent of Households that Would Switch from Gas to Electric Fuel for Installed Space-Heating Products under All Measures, by Headquarter Region

Space Heating	Water Heating	Builders				Installation Contractors			
		North		South		North		South	
		Pre	Post	Pre	Post	Pre	Post	Pre	Post
Low-eff NWGF	GSWH	17.4%	0.0%	16.9%	0.0%	24.0%	0.0%	43.0%	0.0%
Hi-eff NWGF	GSWH	64.9%	77.0%	45.6%	56.3%	60.0%	78.2%	25.3%	58.7%
HP	GSWH	2.1%	4.2%	4.9%	11.3%	2.8%	6.4%	4.4%	11.3%
EF	GSWH	0.1%	0.1%	1.4%	0.6%	0.9%	1.7%	1.7%	1.8%
Low-eff NWGF	ESWH	1.7%	0.0%	7.4%	0.0%	2.2%	0.0%	2.6%	0.0%
Hi-eff NWGF	ESWH	8.4%	11.2%	8.8%	17.4%	3.0%	4.7%	3.5%	5.9%
HP	ESWH	1.9%	4.4%	11.2%	10.2%	3.0%	4.0%	10.2%	12.2%
EF	ESWH	1.8%	1.1%	2.3%	2.4%	0.9%	1.4%	2.0%	1.7%
Other		1.7%	1.9%	1.7%	1.9%	3.2%	3.5%	7.3%	8.5%
Total		100%	100%	100%	100%	100%	100%	100%	100%
Measure 1	Total	82.3%	77.0%	62.5%	56.3%	83.9%	78.2%	68.4%	58.7%
	Switch		-5.3%		-6.2%		-5.7%		-9.7%
Measure 2	Total	92.4%	88.3%	78.6%	73.7%	89.1%	82.9%	74.4%	64.6%
	Switch		-4.2%		-4.9%		-6.2%		-9.9%
Measure 3	Total	84.5%	81.3%	68.8%	68.2%	87.6%	86.4%	74.5%	71.8%
	Switch		-3.2%		-0.6%		-1.2%		-2.7%

Table 8J.6.6 estimates the change in space heating installations by home builders and installation contractors before and after adoption of a condensing NWGF AFUE standard, regardless of the fuel used for water heating. The change in the distribution of space heating technologies is calculated based on the fraction of NWGF installations prior to adoption of the standards. For builders, NWGF installations will decrease 5.2 percent, with a 5.7-percent increase in electric heat pump installations, a 0.8-percent decrease in electric furnace installations, and a 0.3-percent increase in other space-heating installations. For contractors, NWGF installations will decrease 8.7 percent, with a 7.1-percent increase in electric heat pump, a 1.0-percent increase in electric furnace, and a 0.7-percent increase in other space-heating installations.

Table 8J.6.6 Percent of Households that Would Switch from Gas to Electric Fuel for Installed Space-Heating Products

Space Heating Product	Measure 2. From gas to electric space heating					
	Builders			*Installation Contractors*		
	Pre	*Post*	*Switch*	*Pre*	*Post*	*Switch*
NWGF	87.1%	82.5%	-5.2%	84.1%	76.7%	-8.7%
HP	8.7%	13.7%	5.7%	8.9%	14.8%	7.1%
EF	2.6%	1.9%	-0.8%	2.5%	3.3%	1.0%
Other	1.7%	1.9%	0.3%	4.6%	5.2%	0.7%
Total	100%	100%	0.0%	100%	100%	0.0%

Figure 8J.6.3 shows the percentage increase in the fraction of homes with electric heat pumps installed, by home builders and installation contractors, with the population distribution of the ten Census regions superimposed. The survey results suggest that a condensing NWGF AFUE standard is expected to increase national heat pump installations by 5.0 percent for builders and 6.0 percent for installers nationwide, with large increases in the Pacific region, excluding California, (14-percent increase for builders) and the East South Central region (20-percent increase for installers).

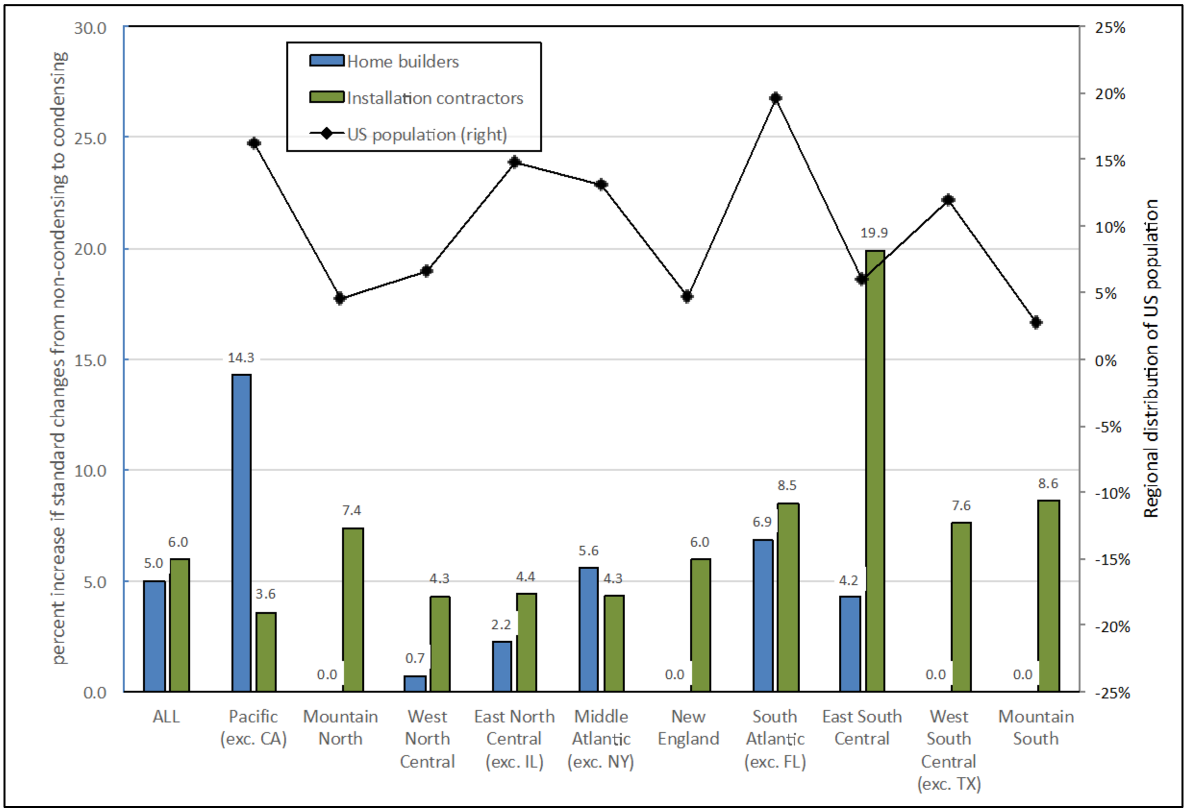


Figure 8J.6.3 Percent Increase in the Fraction of Homes with Electric Heat Pumps

Figure 8J.6.4 shows the fraction of current NWGF installations performed by builders and installers that are condensing NWGFs, by Census region. Home builders install condensing NWGFs at a higher rate than installation contractors, both overall (76 percent vs. 61 percent) and by region. The fraction of condensing NWGFs installed by home builders is lowest in the South Atlantic and West South Central regions (71 and 70 percent, respectively), while the fraction installed by contractors is lowest in the Mountain South (26 percent), West South Central (44 percent), South Atlantic (44 percent), and East South Central (43 percent) regions.

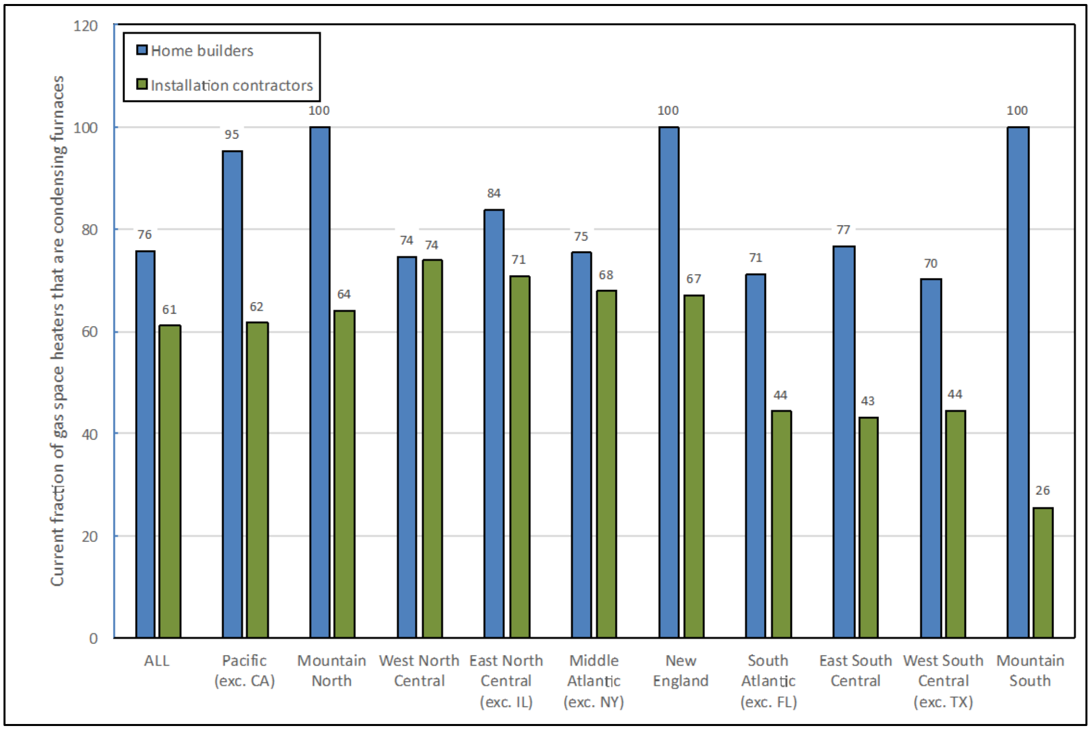


Figure 8J.6.4 **Fraction of Condensing NWGFs Installed by Builders and Installers**

Table 8J.6.7 compares the national amount of fuel switching from the GTI survey, before and after weighting the degree of switching in each Census region by the fraction of NWGFs installed in each region from RECS 2009. The distribution of all NWGFs in RECS 2009 was used to weight fuel switching for installers, while the distribution of NWGFs only in homes built between 2005 and 2009 was used to weight fuel switching for builders. Weighting by NWGFs installations in RECS 2009 reduces the national average fuel switching for both builders but has little effect on the national averages for installers.

Table 8J.6.7 **National Average Fuel Switching Percentage, before and after Weighting by Region Population**

Product Switching Scenario	U.S. average (%)		U.S. average, weighted by 2009 RECS NWGFs (%)	
	Builders	***Installers***	***Builders***	***Installers***
All gas to not all gas	5.8	6.8	4.5	6.8
NWGF to electric space	4.6	7.2	4.4	7.3
GSWH to ESWH	2.3	1.5	1.0	1.2
Increase in HP regardless of water heating fuel	5.0	6.0	4.9	6.1
Current percent of NWGFs that are non-condensing	75.8	61.0	81.3	60.3

Note: 2009 RECS distribution of all NWGFs used for installers, and distribution of NWGFs in homes built between 2005 and 2009 used for builders.

8J.6.3 Results Comparison

Table 8J.6.8 through Table 8J.6.10 present the comparison of fuel switching results from GTI's survey and DOE's analysis by region (National, North, and Rest of Country) and market (replacement and new construction).

Table 8J.6.8 Comparison of GTI and DOE National Fuel Switching

Heating Product Type	GTI Survey		DOE	
	Pre	Post	Pre	Post
Replacement				
NWGF (non-condensing)	38.1%	-	54%	-
NWGF (condensing)	61.9%	89.4%	46%	90.6%
Heat Pump	-	7.6%	-	6.8%
Electric Furnace	-	1.6%	-	2.7%
Other	-	1.3%	-	0.0%
New Construction				
NWGF (non-condensing)	21.2%	-	51%	-
NWGF (condensing)	78.8%	94.9%	49%	90.0%
Heat Pump	-	6.4%	-	7.4%
Electric Furnace	-	-1.5%	-	2.6%
Other	-	0.1%	-	0.0%

Table 8J.6.9 Comparison of GTI and DOE North Fuel Switching

Heating Product Type	GTI Survey		DOE	
	Pre	Post	Pre	Post
Replacement				
NWGF (non-condensing)	28.0%	-	37.6%	-
NWGF (condensing)	72.0%	91.9%	62.4%	95.0%
Heat Pump	-	4.9%	-	3.8%
Electric Furnace	-	2.4%	-	1.2%
Other	-	0.9%	-	0.0%
New Construction				
NWGF (non-condensing)	17.9%	-	36.8%	-
NWGF (condensing)	82.1%	91.0%	63.2%	92.9%
Heat Pump	-	10.8%	-	5.4%
Electric Furnace	-	-2.0%	-	1.8%
Other	-	0.2%	-	0.0%

Table 8J.6.10 Comparison of GTI and DOE Rest of Country Fuel Switching

Heating Product Type	GTI Survey		DOE	
	Pre	Post	Pre	Post
Replacement				
NWGF (non-condensing)	61.9%	-	75.4%	-
NWGF (condensing)	38.1%	83.9%	24.6%	85.0%
Heat Pump	-	14.0%	-	10.5%
Electric Furnace	-	-0.1%	-	4.5%
Other	-	2.2%	-	0.0%
New Construction				
NWGF (non-condensing)	27.7%	-	68.5%	-
NWGF (condensing)	72.3%	102.6%	31.5%	86.5%
Heat Pump	-	-2.3%	-	9.8%
Electric Furnace	-	-0.5%	-	3.7%
Other	-	0.1%	-	0.0%

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APPENDIX 8K. LIFE-CYCLE COST ANALYSIS USING ALTERNATIVE ECONOMIC GROWTH SCENARIOS FOR RESIDENTIAL FURNACES

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APPENDIX 8K. LIFE-CYCLE COST ANALYSIS USING ALTERNATIVE ECONOMIC GROWTH SCENARIOS FOR RESIDENTIAL FURNACES

8K.1 INTRODUCTION

This appendix presents life-cycle cost (LCC) results using energy price projections from alternative economic growth scenarios. The scenarios are based on the High Economic Growth case and the Low Economic Growth case from Energy Information Administration (EIA)'s *Annual Energy Outlook 2014* (*AEO 2014*).[1]

This appendix describes the High and Low Economic Growth scenarios in further detail. See appendix 8A for details about how to generate LCC results for High Economic Growth and Low Economic Growth scenarios using the LCC spreadsheet.

8K.2 DESCRIPTION OF HIGH AND LOW ECONOMIC SCENARIOS

To generate LCC results reported in chapter 8, DOE uses the Reference case energy price projections from *AEO 2014*. The reference case is a business-as-usual estimate, given known market, demographic, and technological trends. For *AEO 2014*, 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 *AEO 2014* uses High and Low Economic Growth scenarios to project the possible impacts of alternative economic growth assumptions on energy markets. The High Economic Growth scenario incorporates population, labor force and productivity growth rates that are higher than the Reference scenario, while these values are lower for the Low Economic Growth scenario. Economic output as measured by real GDP increases by 2.4 percent per year from 2012 through 2040, in the Reference case, 1.9 percent per year in the Low Economic Growth case, and 2.8 percent per year in the High Economic Growth case.[2]

In general, energy prices are higher in the High Economic Growth scenario and lower in the Low Economic Growth scenario than they are in the Reference Case. The energy price forecasts affect the operating cost savings at different efficiency levels. Figure 8K.2.1 through Figure 8K.2.3 show the national residential energy price trends for the Reference, High Economic Growth, and Low Economic Growth scenarios. Because *AEO 2014* projections end in 2040, DOE used the growth rate between 2030 and 2040 to estimate energy prices after 2040 in the high and low scenarios, which are represented with a dashed line in the charts.

Because *AEO 2014* provides the price trends by census division, each sampled household is matched to the appropriate census division price trend. See appendix 8E for details about how energy price trends by census division are applied in the LCC analysis.

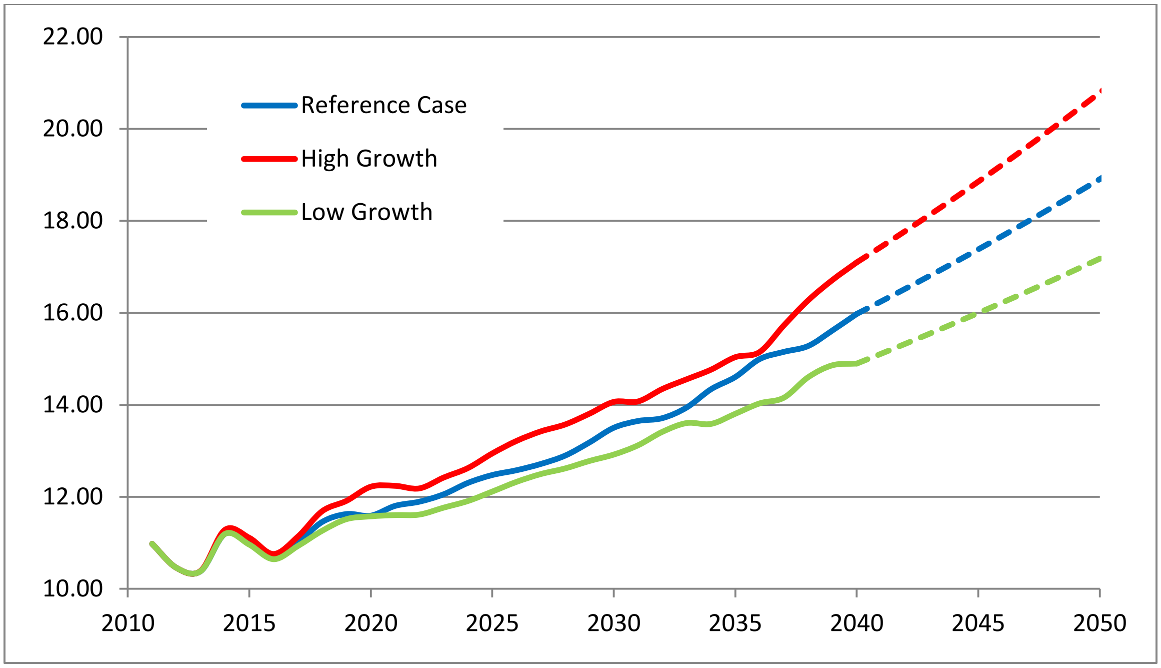

Figure 8K.2.1 **Electricity Price Forecasts for Reference Case and High and Low Economic Growth Scenarios (National)**

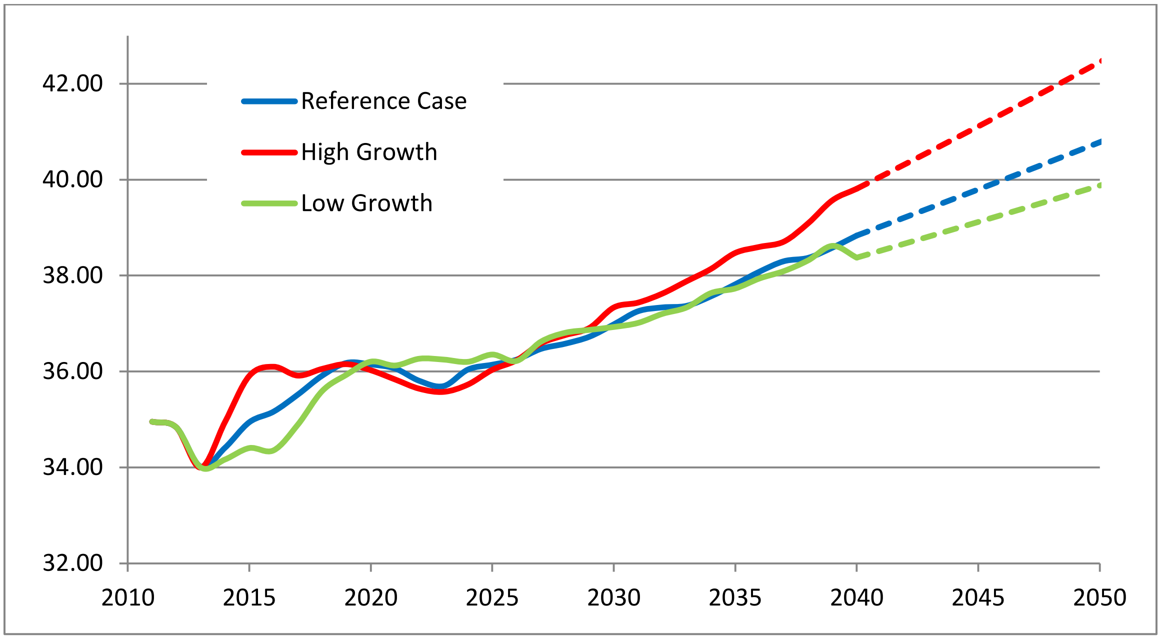

Figure 8K.2.2 **Natural Gas Price Forecasts for Reference Case and High and Low Economic Growth Scenarios (National)**

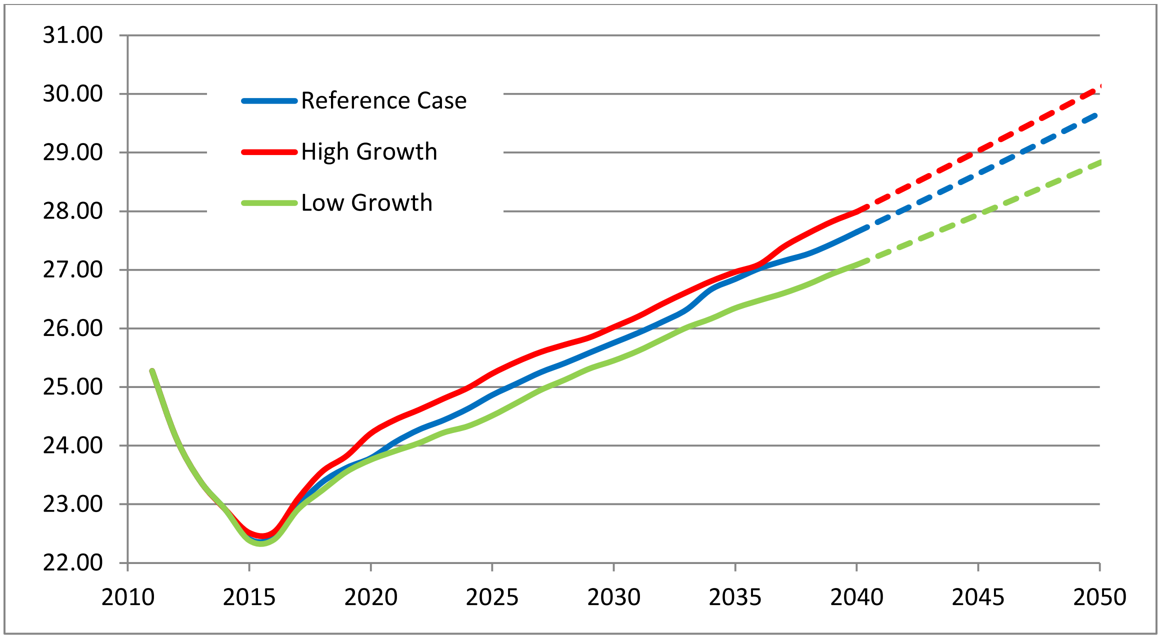

Figure 8K.2.3 LPG Price Forecasts for Reference Case and High and Low Economic Growth Scenarios (National)

8K.3 RESULTS

8K.3.1 AFUE Standards Results

Table 8K.3.1 through Table 8K.3.4 summarize the LCC and PBP results for the High-Economic Growth scenario by efficiency level (EL) for NWGFs and MHGFs AFUE standards. Table 8K.3.5 through Table 8K.3.8 summarize the LCC and PBP results for the Low Economic Growth scenario by EL for NWGFs and MHGFs AFUE standards. Table 8K.3.9 compares average LCC savings and simple payback for these scenarios to the Reference case for AFUE standards.

Table 8K.3.1 Average LCC and PBP Results by Efficiency Level for Non-Weatherized Gas Furnaces AFUE Standards − High Economic Growth Scenario

Efficiency Level	AFUE	Average Costs *2013$*				Simple Payback *years*
		Installed Cost	First Year's Operating Cost	Lifetime Operating Cost	LCC	
National						
0	80%	$2,218	$657	$10,655	$12,874	--
1	90%	$2,652	$602	$9,688	$12,340	7.8
2	92%	$2,667	$591	$9,522	$12,189	6.8
3	95%	$2,785	$577	$9,268	$12,053	7.1
4	98%	$2,944	$565	$9,045	$11,989	7.9
North						
0	80%	$2,410	$823	$13,330	$15,740	--
1	90%	$2,985	$751	$12,123	$15,108	8.0
2	92%	$3,000	$738	$11,911	$14,911	7.0
3	95%	$3,132	$719	$11,599	$14,731	7.0
4	98%	$3,309	$703	$11,318	$14,627	7.5
Rest of Country						
0	80%	$2,003	$470	$7,640	$9,642	--
1	90%	$2,277	$433	$6,943	$9,220	7.4
2	92%	$2,292	$426	$6,828	$9,120	6.6
3	95%	$2,394	$416	$6,640	$9,034	7.3
4	98%	$2,533	$410	$6,483	$9,016	8.9

Note: The results for each TSL are calculated assuming that all consumers use products with that efficiency level. The PBP is measured relative to the baseline product.

Table 8K.3.2 LCC Savings Relative to the Base Case Efficiency Distribution for Non-Weatherized Gas Furnaces AFUE Standards − High Economic Growth Scenario

Efficiency Level	AFUE	Life-Cycle Cost Savings	
		% of Consumers that Experience Net Cost	**Average Savings*** *2013$*
National			
0	80%	0%	--
1	90%	21%	$262
2	92%	19%	$335
3	95%	23%	$427
4	98%	38%	$490
North			
0	80%	0%	--
1	90%	11%	$227
2	92%	10%	$299
3	95%	13%	$401
4	98%	35%	$503
Rest of Country			
0	80%	0%	--
1	90%	32%	$301
2	92%	29%	$375
3	95%	33%	$456
4	98%	40%	$474

* The calculation includes buildings with zero LCC savings (no impact).

Table 8K.3.3 Average LCC and PBP Results by Efficiency Level for Mobile Home Gas Furnaces AFUE Standards − High Economic Growth Scenario

Efficiency Level	AFUE	Average Costs *2013$* Installed Cost	 First Year's Operating Cost	 Lifetime Operating Cost	 LCC	Simple Payback *years*
National						
0	80%	$1,551	$710	$11,116	$12,667	--
1	92%	$1,721	$632	$9,897	$11,618	2.2
2	95%	$1,864	$615	$9,638	$11,502	3.3
3	97%	$1,979	$608	$9,513	$11,492	4.2
North						
0	80%	$1,590	$840	$13,073	$14,662	--
1	92%	$1,760	$747	$11,631	$13,390	1.8
2	95%	$1,902	$727	$11,312	$13,214	2.8
3	97%	$2,017	$717	$11,155	$13,172	3.5
Rest of Country						
0	80%	$1,489	$501	$7,968	$9,458	--
1	92%	$1,658	$447	$7,108	$8,766	3.1
2	95%	$1,802	$436	$6,944	$8,746	4.8
3	97%	$1,918	$432	$6,871	$8,789	6.2

Note: The results for each TSL are calculated assuming that all consumers use products with that efficiency level. The PBP is measured relative to the baseline product.

Table 8K.3.4 LCC Savings Relative to the Base Case Efficiency Distribution for Mobile Home Gas Furnaces AFUE Standards − High Economic Growth Scenario

Efficiency Level	AFUE	Life-Cycle Cost Savings	
		% of Consumers that Experience Net Cost	Average Savings* *2013$*
National			
0	80%	0%	--
1	92%	7%	$711
2	95%	13%	$802
3	97%	24%	$812
North			
0	80%	0%	--
1	92%	4%	$789
2	95%	8%	$925
3	97%	21%	$967
Rest of Country			
0	80%	0%	--
1	92%	12%	$586
2	95%	21%	$604
3	97%	29%	$561

* The calculation includes buildings with zero LCC savings (no impact).

Table 8K.3.5 Average LCC and PBP Results by Efficiency Level for Non-Weatherized Gas Furnaces AFUE Standards − Low Economic Growth Scenario

Efficiency Level	AFUE	Average Costs *2013$*				Simple Payback *years*
		Installed Cost	First Year's Operating Cost	Lifetime Operating Cost	LCC	
National						
0	80%	$2,218	$633	$10,011	$12,229	--
1	90%	$2,654	$582	$9,132	$11,786	8.4
2	92%	$2,669	$572	$8,978	$11,647	7.3
3	95%	$2,789	$558	$8,742	$11,531	7.6
4	98%	$2,948	$547	$8,542	$11,491	8.5
North						
0	80%	$2,410	$796	$12,560	$14,970	--
1	90%	$2,985	$727	$11,443	$14,428	8.4
2	92%	$3,001	$714	$11,241	$14,242	7.3
3	95%	$3,134	$696	$10,948	$14,082	7.3
4	98%	$3,310	$681	$10,692	$14,002	7.8
Rest of Country						
0	80%	$2,003	$451	$7,138	$9,140	--
1	90%	$2,281	$418	$6,527	$8,808	8.5
2	92%	$2,295	$411	$6,427	$8,722	7.5
3	95%	$2,401	$402	$6,255	$8,656	8.2
4	98%	$2,540	$397	$6,119	$8,660	10.0

Note: The results for each TSL are calculated assuming that all consumers use products with that efficiency level. The PBP is measured relative to the baseline product.

Table 8K.3.6 LCC Savings Relative to the Base Case Efficiency Distribution for Non-Weatherized Gas Furnaces AFUE Standards − Low Economic Growth Scenario

Efficiency Level	AFUE	Life-Cycle Cost Savings	
		% of Consumers that Experience Net Cost	Average Savings* *2013$*
National			
0	80%	0%	--
1	90%	22%	$203
2	92%	20%	$269
3	95%	25%	$345
4	98%	42%	$385
North			
0	80%	0%	--
1	90%	12%	$185
2	92%	10%	$255
3	95%	15%	$343
4	98%	39%	$422
Rest of Country			
0	80%	0%	--
1	90%	35%	$224
2	92%	32%	$285
3	95%	37%	$348
4	98%	45%	$344

* The calculation includes buildings with zero LCC savings (no impact).

Table 8K.3.7 Average LCC and PBP Results by Efficiency Level for Mobile Home Gas Furnaces AFUE Standards − Low Economic Growth Scenario

Efficiency Level	AFUE	Average Costs *2013$*				Simple Payback *years*
		Installed Cost	First Year's Operating Cost	Lifetime Operating Cost	LCC	
National						
0	80%	$1,551	$693	$10,659	$12,211	--
1	92%	$1,721	$617	$9,494	$11,214	2.2
2	95%	$1,864	$601	$9,245	$11,109	3.4
3	97%	$1,979	$593	$9,127	$11,106	4.3
North						
0	80%	$1,590	$823	$12,579	$14,168	--
1	92%	$1,760	$732	$11,195	$12,954	1.9
2	95%	$1,902	$712	$10,888	$12,790	2.8
3	97%	$2,017	$702	$10,738	$12,755	3.5
Rest of Country						
0	80%	$1,489	$484	$7,571	$9,060	--
1	92%	$1,658	$432	$6,757	$8,415	3.2
2	95%	$1,802	$422	$6,602	$8,404	5.0
3	97%	$1,918	$417	$6,534	$8,452	6.5

Note: The results for each TSL are calculated assuming that all consumers use products with that efficiency level. The PBP is measured relative to the baseline product.

Table 8K.3.8 LCC Savings Relative to the Base Case Efficiency Distribution for Mobile Home Gas Furnaces AFUE Standards − Low Economic Growth Scenario

Efficiency Level	AFUE	Life-Cycle Cost Savings	
		% of Consumers that Experience Net Cost	Average Savings* *2013$*
National			
0	80%	0%	--
1	92%	8%	$672
2	95%	14%	$754
3	97%	26%	$757
North			
0	80%	0%	--
1	92%	4%	$751
2	95%	8%	$878
3	97%	23%	$913
Rest of Country			
0	80%	0%	--
1	92%	14%	$545
2	95%	23%	$555
3	97%	31%	$507

* The calculation includes buildings with zero LCC savings (no impact).

Table 8K.3.9 Comparison of Average LCC Savings and Simple Payback Period Results for NWGFs and MHGFs AFUE Standards − Reference Case and High and Low Economic Growth Scenarios

Product Class	EL	Average LCC Savings *2013$*			Simple Payback Period *Years*		
		High Growth	**Low Growth**	**Reference Case**	**High Growth**	**Low Growth**	**Reference Case**
National							
Non-Weatherized Gas Furnace	1	$262	$203	$236	7.8	8.5	8.2
	2	$335	$269	$305	6.8	7.5	7.2
	3	$427	$345	$388	7.1	8.2	7.4
	4	$490	$385	$441	7.9	10.0	8.3
Mobile Home Gas Furnace	1	$711	$672	$691	2.2	2.2	2.2
	2	$802	$754	$778	3.3	3.4	3.3
	3	$812	$757	$784	4.2	4.3	4.2
North							
Non-Weatherized Gas Furnace	1	$227	$185	$208	8.0	8.4	8.3
	2	$299	$255	$277	7.0	7.3	7.2
	3	$401	$343	$374	7.0	7.3	7.2
	4	$503	$422	$467	7.5	7.8	7.7
Mobile Home Gas Furnace	1	$789	$751	$770	1.8	1.9	1.8
	2	$925	$878	$902	2.8	2.8	2.8
	3	$967	$913	$941	3.5	3.5	3.5
Rest of Country							
Non-Weatherized Gas Furnace	1	$301	$224	$267	7.4	8.4	8.1
	2	$375	$285	$336	6.6	7.3	7.1
	3	$456	$348	$404	7.3	7.6	7.9
	4	$474	$344	$412	8.9	8.5	9.6
Mobile Home Gas Furnace	1	$586	$545	$565	3.1	3.2	3.2
	2	$604	$555	$579	4.8	5.0	5.0
	3	$561	$507	$533	6.2	6.5	6.4

8K.3.2 Standby Mode and Off Mode Standards Results

Table 8K.3.10 through Table 8K.3.13 summarize the LCC and PBP results for the High-Economic Growth scenario by efficiency level (EL) for NWGFs and MHGFs standby and off mode standards. Table 8K.3.14 through Table 8K.3.17 summarize the LCC and PBP results for the Low Economic Growth scenario by EL for NWGFs and MHGFs standby and off mode standards. Table 8K.3.18 compares average LCC savings and simple payback for these scenarios to the Reference case standby and off mode standards.

Table 8K.3.10 Average LCC and PBP Results by Efficiency Level for Non-Weatherized Gas Furnaces Standby Mode and Off Mode Standards − High Economic Growth Scenario

Efficiency Level	Average Costs *2013$*				Simple Payback *years*
	Installed Cost	First Year's Operating Cost	Lifetime Operating Cost	LCC	
0	$0	$11	$161	$161	--
1	$2	$9	$139	$141	1.3
2	$17	$9	$134	$152	9.7
3	$18	$8	$124	$142	7.5

Note: The results for each TSL are calculated assuming that all consumers use products with that efficiency level. The PBP is measured relative to the baseline product.

Table 8K.3.11 LCC Savings Relative to the Base Case Efficiency Distribution for Non-Weatherized Gas Furnaces Standby Mode and Off Mode Standards − High Economic Growth Scenario

Efficiency Level	Life-Cycle Cost Savings	
	% of Consumers that Experience Net Cost	Average Savings* *2013$*
0	0%	--
1	2%	$12
2	15%	$6
3	9%	$13

* The calculation includes buildings with zero LCC savings (no impact).

Table 8K.3.12 Average LCC and PBP Results by Efficiency Level for Mobile Home Gas Furnaces Standby Mode and Off Mode Standards − High Economic Growth Scenario

Efficiency Level	Average Costs *2013$*				Simple Payback *years*
	Installed Cost	First Year's Operating Cost	Lifetime Operating Cost	LCC	
0	$0	$10	$156	$156	--
1	$2	$9	$135	$137	1.2
2	$16	$9	$131	$146	9.2
3	$17	$8	$121	$138	7.1

Note: The results for each TSL are calculated assuming that all consumers use products with that efficiency level. The PBP is measured relative to the baseline product.

Table 8K.3.13 LCC Savings Relative to the Base Case Efficiency Distribution for Mobile Home Gas Furnaces Standby Mode and Off Mode Standards − High Economic Growth Scenario

Efficiency Level	Life-Cycle Cost Savings	
	% of Consumers that Experience Net Cost	Average Savings* *2013$*
0	0%	--
1	0%	$1
2	1%	$0
3	1%	$1

* The calculation includes buildings with zero LCC savings (no impact).

Table 8K.3.14 Average LCC and PBP Results by Efficiency Level for Non-Weatherized Gas Furnaces Standby Mode and Off Mode Standards − Low Economic Growth Scenario

Efficiency Level	Average Costs *2013$*				Simple Payback *years*
	Installed Cost	First Year's Operating Cost	Lifetime Operating Cost	LCC	
0	$0	$11	$159	$159	--
1	$2	$9	$137	$139	1.3
2	$17	$9	$132	$149	9.7
3	$18	$8	$122	$141	7.5

Note: The results for each TSL are calculated assuming that all consumers use products with that efficiency level. The PBP is measured relative to the baseline product.

Table 8K.3.15 LCC Savings Relative to the Base Case Efficiency Distribution for Non-Weatherized Gas Furnaces Standby Mode and Off Mode Standards − Low Economic Growth Scenario

Efficiency Level	Life-Cycle Cost Savings	
	% of Consumers that Experience Net Cost	Average Savings* *2013$*
0	0%	--
1	2%	$12
2	15%	$6
3	9%	$13

* The calculation includes buildings with zero LCC savings (no impact).

Table 8K.3.16 Average LCC and PBP Results by Efficiency Level for Mobile Home Gas Furnaces for Standby Mode and Off Mode Standards − Low Economic Growth Scenario

Efficiency Level	Average Costs *2013$*				Simple Payback *years*
	Installed Cost	First Year's Operating Cost	Lifetime Operating Cost	LCC	
0	$0	$10	$154	$154	--
1	$2	$9	$133	$135	1.2
2	$16	$9	$129	$145	9.2
3	$17	$8	$119	$136	7.1

Note: The results for each TSL are calculated assuming that all consumers use products with that efficiency level. The PBP is measured relative to the baseline product.

Table 8K.3.17 LCC Savings Relative to the Base Case Efficiency Distribution for Mobile Home Gas Furnaces for Standby Mode and Off Mode Standards − Low Economic Growth Scenario

Efficiency Level	Life-Cycle Cost Savings	
	% of Consumers that Experience Net Cost	Average Savings* *2013$*
0	0%	--
1	0%	$1
2	1%	$0
3	1%	$1

* The calculation includes buildings with zero LCC savings (no impact).

Table 8K.3.18 Comparison of Average LCC Savings and Simple Payback Period Results for NWGFs and MHGFs Standby and Off Mode − Reference Case and High and Low Economic Growth Scenarios

Product Class	EL	Average LCC Savings *2013$*			Simple Payback Period *Years*		
		High Growth	Low Growth	Reference Case	High Growth	Low Growth	Reference Case
Non-Weatherized Gas Furnace	1	$12	$12	$12	1.3	1.3	1.3
	2	$6	$6	$6	9.7	9.7	9.7
	3	$13	$13	$13	7.5	7.5	7.5
Mobile Home Gas Furnace	1	$1	$1	$1	1.2	1.2	1.2
	2	$0	$0	$0	9.2	9.2	9.2
	3	$1	$1	$1	7.1	7.1	7.1

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APPENDIX 8L. INSTALLATION SCENARIO CONSIDERING USE OF ALTERNATIVE VENTING TECHNOLOGY

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APPENDIX 8L. INSTALLATION SCENARIO CONSIDERING USE OF ALTERNATIVE VENTING TECHNOLOGY

8L.1 INTRODUCTION

This appendix describes DOE's analysis of the potential impacts on consumers of non-weatherized gas furnaces (NWGFs) of the use of a new venting technology developed by M&G DuraVent. The DuraVent product is a patent-pending vent retrofit system that can vent a condensing residential furnace and atmospheric combustion water heater through the same vent. The DuraVent system enables reuse of the existing metal vent or masonry chimney and is comprised of a new vent cap and appropriate liner(s). The proposed design is discussed in detail in a report published by Oak Ridge National Laboratory (ORNL).[1, 2]

The venting technology that DOE applied in the main analysis may require resizing of venting to accommodate an orphaned water heater, installing separate polyvinyl chloride (PVC) horizontal venting for the condensing furnace, and, in some cases, may require structural modifications. The DuraVent product has the potential to utilize the existing vent or chimney and thereby reduce the complexity and cost of installing a condensing furnace for some consumers.

8L.2 DESCRIPTION OF DURAVENT VENTING TECHNOLOGY

Traditionally, replacing a non-condensing NWGF with a condensing NWGF involved high installation costs, in large part due to having to install a new PVC venting system for the condensing furnace and modify the existing venting system to accommodate the orphaned water heater. The DuraVent product allows a condensing furnace and water heater to be vented concentrically through the existing vent or chimney, eliminating the need to create new penetrations in the walls or ceiling as well as avoiding separate PVC horizontal venting for the condensing furnace. The flue streams from the condensing furnace and the water heater remain separate and exhaust individually to the outside.

Figure 8L.2.1 shows the DuraVent product installed in an existing Type B double-wall metal vent. The existing vent cap is replaced with a new one that supports a flexible stainless steel liner inserted in the existing metal vent to serve as the flue for the new condensing furnace. The annular space between the liner and the original Type B vent serves as the flue for the water heater.

Figure 8L.2.2 shows the DuraVent product installed in an existing masonry chimney. The existing vent cap is replaced with a new one that supports an outer flexible aluminum liner and an inner flexible stainless steel liner. The stainless steel liner serves as the flue for the new condensing furnace. The annular space between the two liners serves as the flue for the water heater.

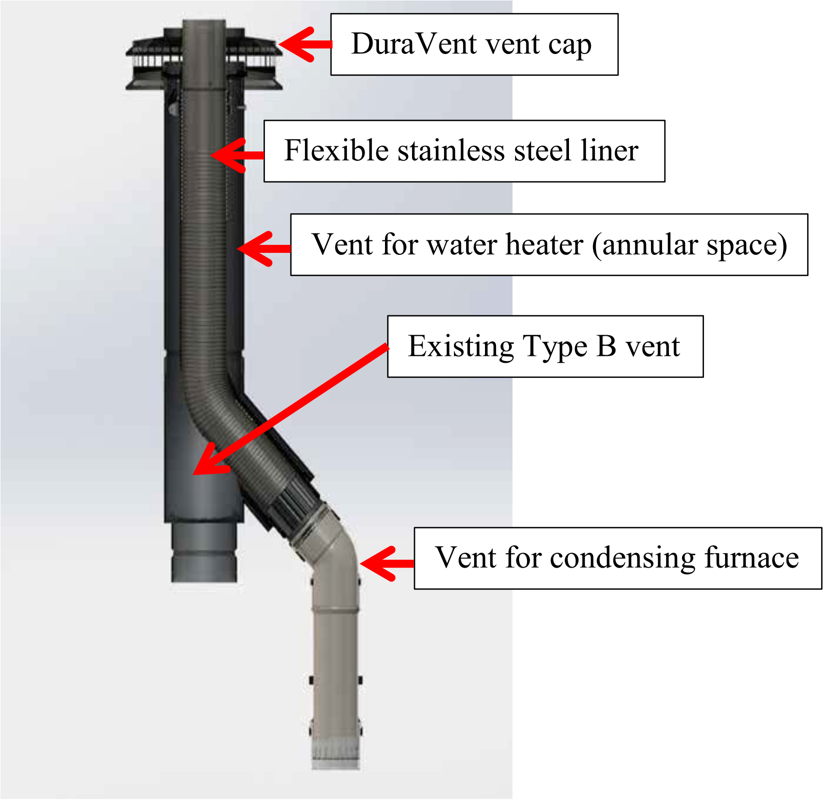

Figure 8L.2.1 Common Venting of a Condensing Furnace and an Atmospheric Combustion Water Heater in a Type B Double-Wall Metal Vent using DuraVent Retrofit[1, 2]

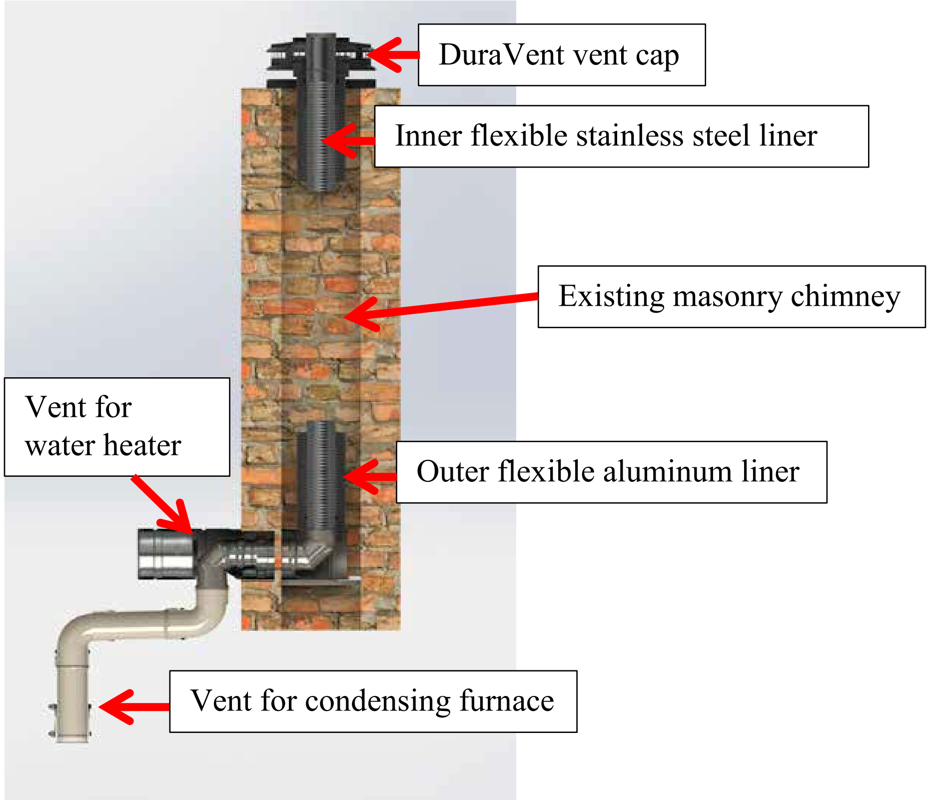

Figure 8L.2.2 Common Venting of a Condensing Furnace and an Atmospheric Combustion Water Heater in a Masonry Chimney using DuraVent Retrofit[1, 2]

8L.3 ANALYSIS METHOD

The analysis focused on households in replacement situations with pre-existing common venting of a non-condensing NWGF and water heater, which account for approximately 7 percent of all NWGF installations. Appendix 8D describes how these households were identified. In appendix 8D, the situations for which the DuraVent technology is applicable are labeled as installation Cases C and D. These cases require vent resizing, chimney relining, or a new water heater vent connector to accommodate the orphaned water heater. Case C represents 6.3 percent of the installations, while Case D represents 0.4 percent. Many of these households are in the North, where common venting is much more prevalent than in the Rest of Country. These two cases can also be identified in Figure 8L.4.1 and Figure 8L.4.2.

For households with common venting, DOE applied costs for the DuraVent technology based on communication with the authors of the ORNL report.[3] Table 8L.3.1 presents a summary of the DuraVent installation costs. The relevant costs from Table 8L.3.1 were applied to each specific situation, depending on whether the house has a masonry chimney or a Type B metal vent.

Table 8L.3.1 ORNL Installation Costs for DuraVent Installation Scenario

Component	Chimney	Type B with 2" PVC	Type B with 3" PVC
Flexible Liner ($/foot)	16.56*	9.90	10.88
All Other Components ($)	440.27	142.61	158.17
Labor Hours (hr)	10.30	6.50	6.50

* This cost includes $10.88 for 3" FasNSeal Flex and $5.68 for 3" Aluminum Flex

Table 8L.3.2 shows the average venting installation cost based on existing venting technologies (Reference Case) compared to the DuraVent technology. The average savings from the DuraVent technology is $453. The actual range of installation cost varies depending on the venting type (masonry chimney or a Type B metal vent) and PVC venting diameter (which mostly depends on the input capacity of the furnace as explained in appendix 8D).

DOE determined that the DuraVent design would be less expensive than the existing venting technologies for 85 percent of households with pre-existing common venting of a non-condensing NWGF and water heater. The DuraVent design is especially beneficial for a small subset of households that includes high cost row houses and condos (0.4 percent of all installations).[a] The DuraVent design is also beneficial for households where separate venting of the condensing furnace requires significant cost (due to vent length or whether house modifications are needed) and/or in some cases when the common masonry chimney or a Type B metal vent is very long (such as in houses with two or more stories).

Table 8L.3.2 Average Venting Installation Costs for Households where DuraVent Technology is Applicable (Installation Cases C and D)

Installation Type	2013$			
	Reference Case	DuraVent Scenario	Difference	Fraction Benefiting
Replacement of Common Vent (+Need to Resize Orphaned Water)*	$1,206	$753	-$453	85%

* These cases require orphaned water heater vent resizing, chimney relining, or new water heater vent connector.

8L.4 RESULTS

DOE used the LCC spreadsheet developed for the rulemaking analysis to analyze the impacts on consumers of applying the DuraVent technology. The analysis accounts for cases where the household is projected to switch to an electric heating product (electric furnace, heat pump) instead of installing a condensing furnace. For approximately 6 percent of the households in replacement situations with common venting, switching is preferable to applying the DuraVent technology, according to the switching criteria applied in the analysis (see appendix 8J and Figure 8L.4.2).

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[a] As explained in appendix 8D, high cost row houses and condos are cases which have a common vent and the house structure shares one or more walls with another house. For a fraction of these households the installation requires significant installation cost due to potential house modifications and very long vents.

Table 8L.4.1 compares average LCC savings and simple payback between the reference case (the default installation costs used in the analysis) and the DuraVent scenario. The results are presented for the entire household sample, the target household sample, and the high-cost row house/condo sample. The entire household sample includes all households used in the analysis, with the DuraVent technology applied to a fraction of the replacement households. The target household sample refers to all households in replacement situations with pre-existing common venting of a non-condensing NWGF and water heater (installation cases C and D), which represents 7 percent of all installations. The high-cost row house/condo sample refers to very high cost households that are a subset of the target household sample, which represents 0.4 percent of all installations.

The difference in LCC and PBP results between the reference case and the DuraVent scenario is largest for the row house/condo sample, and next largest for the target household sample. For the target household sample, the average LCC savings go from negative to positive at most of the considered efficiency levels, and the PBP declines substantially. The percent of consumers that experience net cost declines modestly in the DuraVent scenario for all three samples.

For the entire household sample, the average LCC savings are $27-$32 higher in the DuraVent scenario than in the reference case, and the PBP is 1.0 to 1.5 years lower. The percent of consumers that experience net cost is only slightly lower (one percent or less) in the DuraVent scenario.

For the target household sample, the average LCC savings are approximately $164-$176 higher in the DuraVent scenario than in the reference case, and the PBP is 6 to 8 years lower. The percent of consumers that experience net cost is 5 to 6 percent lower in the DuraVent scenario.

Table 8L.4.1 Comparison of LCC and Payback Period Results for Reference Case and DuraVent Installation Cost Scenarios for Non-Weatherized Gas Furnaces

EL (AFUE)	Average LCC Savings *2013$*		Simple Payback Period *Years*		% of Consumers that Experience Net Cost	
	DuraVent Scenario	Reference Case	DuraVent Scenario	Reference Case	DuraVent Scenario	Reference Case
Entire Household Sample						
1 (90%)	$264	$236	6.7	8.2	21%	22%
2 (92%)	$332	$305	5.9	7.2	19%	20%
3 (95%)	$419	$388	6.3	7.4	23%	24%
4 (98%)	$473	$441	7.3	8.3	39%	40%
Target Household Sample						
1 (90%)	-$35	-$199	17	25	33%	38%
2 (92%)	$32	-$141	14	22	30%	36%
3 (95%)	$102	-$74	13	19	32%	38%
4 (98%)	$160	-$16	13	19	51%	56%
High Cost Row House/Condos Sample						
1 (90%)	-$51	-$297	18	32	38%	42%
2 (92%)	$84	-$243	15	27	38%	40%
3 (95%)	$178	-$205	14	25	38%	42%
4 (98%)	$204	-$180	14	25	57%	60%

Figure 8L.4.1 and Figure 8L.4.2 show the total installed cost differential, the shipments fractions and the product switching results for the reference case and the DuraVent scenario, respectively. The results are shown separately for households where resizing of the vent system has a high cost (Case C) and for households where resizing could be accomplished at low cost (Case D). For both Cases C and D, the total installed cost differential between installing a condensing furnace and a base-case furnace, along with the shipments fraction, is shown for several household types (All types = all household or building types; Type A = Single Family Detached; Type B = Single Family Attached; Type C = Multi-Family; and Type D = Commercial Buildings).

Figure 8L.4.1 and Figure 8L.4.2 also show the fraction of the considered installations that would or would not switch to other product types (*i.e.*, heat pump (HP), electric furnace (EF), or electric storage water heater (ESWH)). For the fraction of households that switch space and/or water heating products, Figure 8L.4.1 and Figure 8L.4.2 show the switching fractions to different electric product types (HP, HP + ESWH, EF, EF + ESWH, or ESWH only) for the reference case installation costs and the DuraVent technology installation costs, respectively. In addition, for the high-cost row house/condo subset (a subset of case C), Figure 8L.4.1 and Figure 8L.4.2 separately show the total installed cost differential, the shipments fractions and the product switching results. See appendix 8J for more details on the product switching methodology.

Case C households see a decrease from $1,446 total installed cost in the reference case compared to $1,228 total installed cost in the DuraVent scenario, which results in a decrease in product switching from 21.7 percent to 17.9 percent. Case D households see a decrease in total installed cost from $651 in the reference case to $615 in the DuraVent scenario, which results in a small decrease in product switching. High-cost row house/condo households see a decrease in total installed cost from $1,965 in the reference case to $1,178 in the DuraVent scenario, which results in a decrease in product switching from 37.5 percent to 5.0 percent.

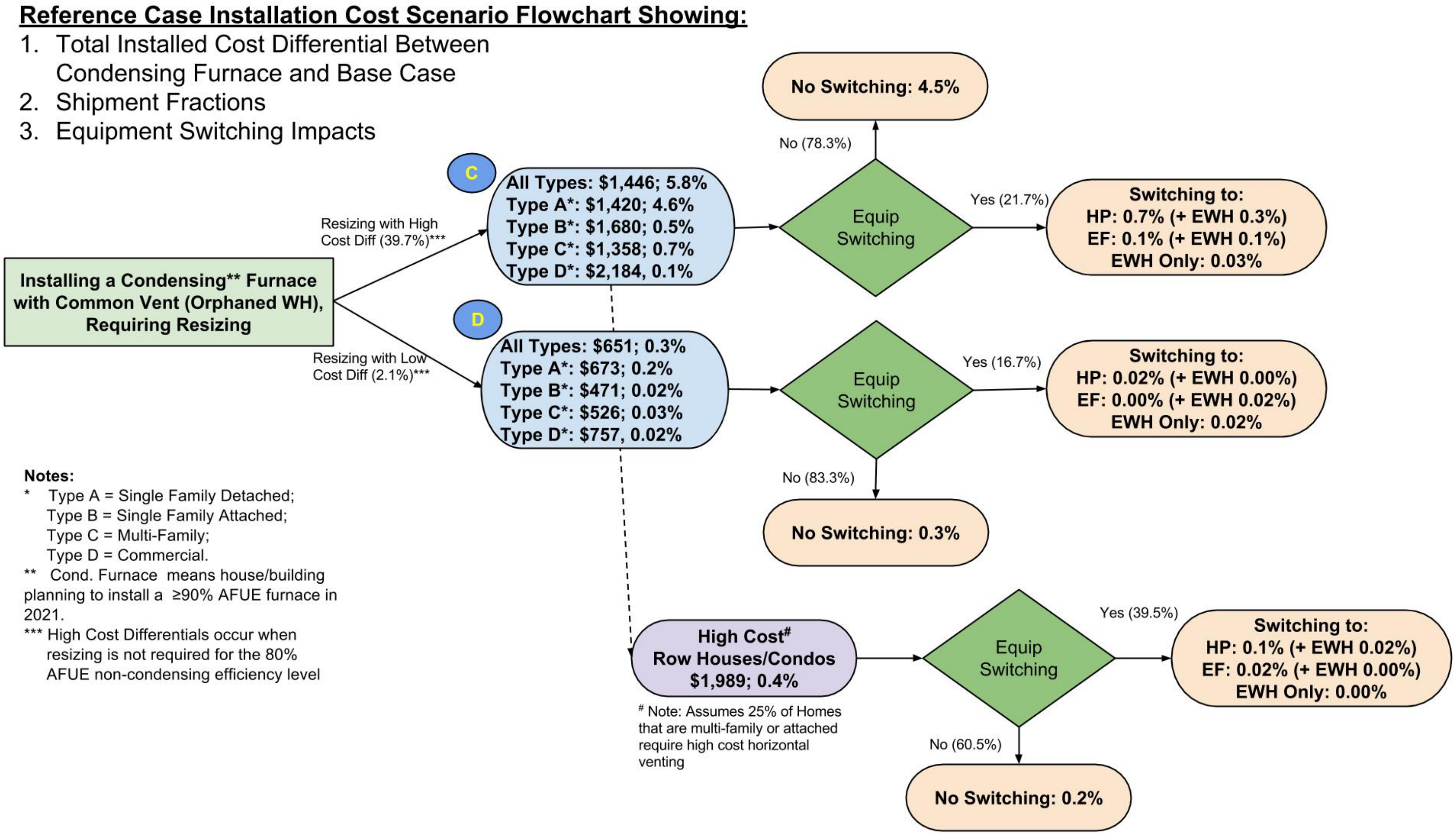
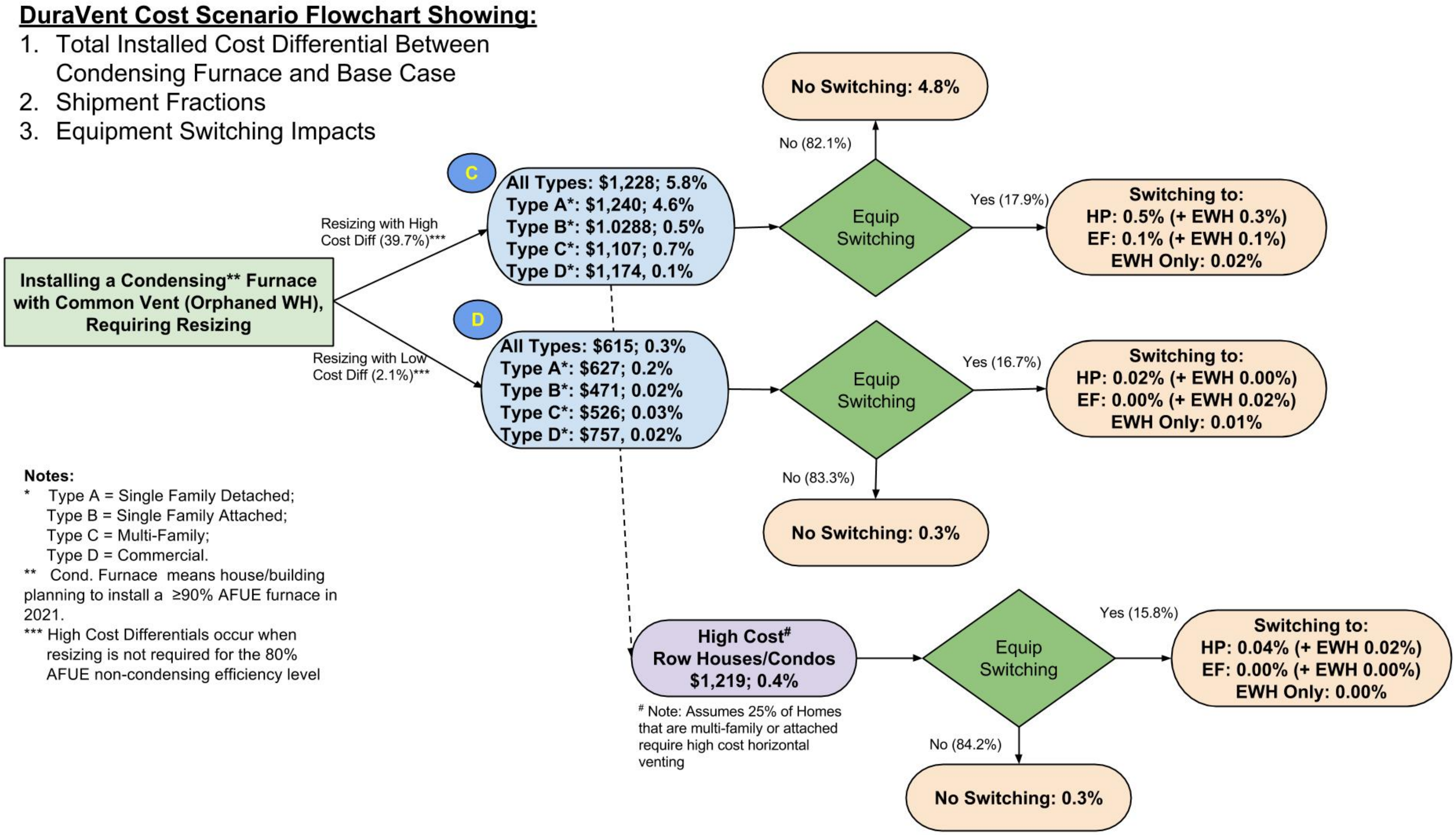


Figure 8L.4.1 **Total Installed Cost, Shipment Fractions, and Switching Impacts for Installation Cases C and D Using Reference Case Installation Costs**


DuraVent Cost Scenario Flowchart Showing:

1. Total Installed Cost Differential Between Condensing Furnace and Base Case
2. Shipment Fractions
3. Equipment Switching Impacts

Note: Assumes 25% of Homes that are multi-family or attached require high cost horizontal venting

Notes:

* Type A = Single Family Detached;
Type B = Single Family Attached;
Type C = Multi-Family;
Type D = Commercial.

** Cond. Furnace means house/building planning to install a ≥90% AFUE furnace in 2021.

*** High Cost Differentials occur when resizing is not required for the 80% AFUE non-condensing efficiency level

Figure 8L.4.2 Total Installed Cost, Shipment Fractions, and Switching Impacts for Installation Cases C and D Using DuraVent Scenario

REFERENCES

1. Momen, A. M., J. Munk, K. Biswas, and P. Hughes, *Condensing Furnace Venting Part 1: The Issue, Prospective Solutions, and Facility for Experimental Evaluation*, October 2014. Oak Ridge National Laboratory. Oak Ridge, Tennessee. <http://web.ornl.gov/sci/buildings/docs/Condensing-Furnace-Venting-Part1-Report.pdf >

2. Momen, A. M., J. Munk, K. Biswas, and P. Hughes, *Condensing Furnace Venting Part 2: Evaluation of Same-Chimney Vent Systems for Condensing Furnaces and Natural Draft Water Heaters*, February 2015. Oak Ridge National Laboratory. Oak Ridge, Tennessee. <http://web.ornl.gov/sci/buildings/docs/Condensing-Furnace-Venting-Part2-Report.pdf>

3. Hughes, P., *Personal communication. E-mail to LBNL,* August 2014, 2014. Oak Ridge National Laboratory. Oak Ridge, TN.

CHAPTER 9. SHIPMENTS ANALYSIS

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CHAPTER 9. SHIPMENTS ANALYSIS

9.1 INTRODUCTION

Estimates of future product shipments are a necessary input to calculations of the national energy savings (NES) and net present value (NPV), as well as to the manufacturer impact analysis (MIA). This chapter describes the data and methods the U.S. Department of Energy (DOE) used to project annual product shipments and presents results for residential furnace product classes considered in this analysis, specifically, non-weatherized gas furnaces (NWGFs) and mobile home gas furnaces (MHGFs).

The shipments model divides the shipments of NWGFs and MHGFs into specific market segments. The model starts from a historical base year and calculates retirements and shipments by market segment for each year of the analysis period. This approach produces an estimate of the total product stock, broken down by age or vintage, in each year of the analysis period. In addition, the product stock efficiency distribution is calculated for the base case and for each standards case for each product class. The stock distribution is used in the national impact analysis (NIA) to estimate the total costs and benefits associated with each efficiency level.

The shipments model was developed as a Microsoft Excel spreadsheet that is accessible on DOE's Appliance and Commercial Equipment Standards website (www1.eere.energy.gov/buildings/appliance_standards/product.aspx/productid/72). Appendix 10A discusses how to access and utilize the shipments model spreadsheet, which is integrated into the spreadsheet for the NIA. This chapter explains how the shipments model is constructed and provides some summary output.

The analysis incorporates a large number of components or market segments, describing different product classes, market sectors and geographic regions. For simplicity, the methodology is explained for a single product class for consumers for the country as a whole. Section 9.2 defines the different market segments considered in the analysis. Section 9.3.1 defines the input data, pre-processing and calibration steps that are used in the model. Section 9.4 defines the decision models used to differentiate between the base case and efficiency levels. Section 9.3 presents the modifications to the input data that were used to develop shipments models specific to the North and Rest of Country regions used in the analysis. Section 9.5 presents summary output from the shipments model for the base cases.

9.2 SHIPMENTS MODEL METHODOLOGY

The shipments model disaggregates the total stock according to the following characteristics:

1. Product class: Two residential furnace product classes were considered in this analysis: NWGFs and MHGFs.

2. Application market sector: For NWGFs, residential and commercial building sectors; approximately 97 percent of shipments are to the residential sector, with the remaining 3 percent going to the commercial sector.[1] This ratio is held constant over the analysis period. For MHGFs, 100 percent of shipments are to the residential sector.

3. Region: For NWGFs and MHGFs, residential and commercial building sectors were divided into North and Rest of Country regions based on the same regions analyzed in the June 2011 direct final rule (see Table 9.2.1). The allocation of individual States to the regions was largely based on whether a State's annual heating degree day (HDD)[a] average is above or below 5,000, which offers a threshold point at which space heating demand is significant enough to require longer operation of heating systems, thereby providing a basis for utilization of higher-efficiency systems.

Table 9.2.1 Rest of Country and North Regions for Analysis of Furnace AFUE Standards

Rest of Country	Northern Region Standard	
Alabama	Alaska	Pennsylvania
Arizona	Colorado	Rhode Island
Arkansas	Connecticut	South Dakota
California	Idaho	Utah
Delaware	Illinois	Vermont
District of Columbia	Indiana	Washington
Florida	Iowa	West Virginia
Georgia	Kansas	Wisconsin
Hawaii	Maine	Wyoming
Kentucky	Massachusetts	
Louisiana	Michigan	
Maryland	Minnesota	
Mississippi	Missouri	
Nevada	Montana	
New Mexico	Nebraska	
North Carolina	New Hampshire	
Oklahoma	New Jersey	
South Carolina	New York	
Tennessee	North Dakota	
Texas	Ohio	
Virginia	Oregon	

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[a] DOE used the population weighted state HDD as determined by the National Oceanic and Atmospheric Administration (NOAA) in its 1971-2000 United States Climate Normals report, available at http://hurricane.ncdc.noaa.gov/climatenormals/hcs/HCS_51.pdf (last accessed July 28, 2014).

The residential furnace shipments model considers three product market segments (hereafter referred to as "market segments") as follows:

1. New housing: a certain fraction of new buildings acquire furnaces in each future year. This fraction is defined as the new construction saturation, which varies by year, and by product class.
2. Existing owners (replacements): these are defined as existing buildings with furnaces installed. This category receives new shipments when existing products are replaced.
3. New owners: these are defined as existing buildings that acquire furnaces for the first time during the analysis period. The new owners primarily consist of households that during a major remodel add or switch to NWGFs. DOE estimated that there were no new owners of MHGFs.

In addition, DOE took into account product switching of owners of NWGFs which may choose to replace an existing NWGF with another type of space heating product (such as an electric furnace or a heat pump) if the NWGF efficiency standard is amended. The fraction of product switching decreases over the analysis period.

9.2.2 Fundamental Shipment Model

The fundamental dependent variable in the shipments model is the product stock, which is represented as a function of the analysis year (indexed by *j),* and product vintage or age (the product age is noted as *a,* and is equal to the analysis year minus the vintage). The stock function is adjusted in each year of the analysis period by new shipments coming in and broken or demolished product 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 product class p and age a in analysis year j,
$Rem_p(j, a)$ = number of units of product class p and age a removed in analysis year j, and
$Ship_p(j)$ = number of units of product class p shipped in year j.

Removals due to product 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 base case are then:

$$Rem_p(j,a) = [1 - f_p(a)] \times Stock_p(j,a)\,.$$

Eq. 9.3

The total number of shipments for each product class is the sum of the shipments to each of the three market segments:

$$Ship_p(j) = Rpl_p(j) + NC_p(j) + NO_p(j)$$

Eq. 9.4

Where:

$Rpl_p(j)$ = number of units of product p replaced in year j, which depends on removed units and units in demolished buildings,
$NC_p(j)$ = number of units installed in new construction of product p in year j, and
$NO_p(j)$ = number of units shipped to "new owners" of product p in year j (NWGFs only).

9.2.3 Replacement Shipments

The shipments model assumes that units that are taken from demolished buildings, $Dem(j)$, are included in the mix of broken units $Rem_p(j)$. As the demolished units do not need to be replaced, they are deducted from $Rem_p(j)$ when calculating the required replacements, as represented by the following expression:

$$Rpl_p(j) = Rem_p(j) - Dem(j)$$

Eq. 9.5

When a furnace fails, it is removed from the stock or is repaired for extended use. The following retirement function $r_p(a)$ is used to represent the probability that a unit will fail at age a.

$$Rem_p(j) = \sum_a r_p(a) \times Stock_p(j,a)$$

Eq. 9.6

Retirement functions and product lifetimes are discussed in more detail in chapter 8.

In each year, products are removed from demolished buildings. As represented by the following expression, the shipments model assumes that the saturation of the product in the demolished buildings is the same as that of the overall building population.

$$Dem(j) = D(j) \times sat(p, j-1)$$

Eq. 9.7

The number of demolished buildings is calculated by:

$$D(j) = H\_Stock(j-1) + H\_Starts(j) - H\_Stock(j)$$

Eq. 9.8

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 products demolished in analysis year *j*, and
sat(*p*,*j*) = saturation of products of product class p for all buildings in year j.

9.2.4 Shipments to New Construction

DOE multiplied new construction market saturations by projections of new housing units to estimate shipments to the new construction segment. On a product class basis, the determination of shipments to new construction is represented by the following expression:

$$NC_p(j) = NC\_Starts\_res(j) \times NC\_Sat\_res_p(j) + NC\_Starts\_com(j) \times NC\_Sat\_com_p(j)$$

Eq. 9.9

Where:

$NC\_Starts\_res(j)$ = number of new residential housing starts in year *j*,
$NC\_Sat\_res_p(j)$ = new residential housing saturation for product class *p* and year *j*,
$NC\_Starts\_com(j)$ = number of new commercial building starts in year *j* (NWGFs only), and
$NC\_Sat\_com_p(j)$ = new commercial building saturation for product class *p* and year *j* (NWGFs only).

9.2.5 Shipments to New Owners

The third market segment consists of new owners of NWGFs, and also includes an adjustment for switching to a different product type. Because there are no data on the extent of these phenomena, DOE estimated historical shipments to this market segment as a residual, using the following equation:

$$NO(j) = Shipment(j) - (RU(j) + NU(j))$$

Eq. 9.10

Where:

j = year where historical shipment data is available,

NO(*j*) = new owners (if positive) or adjustment for switching (if negative) for year *j*,
Shipment(*j*) = historical shipment in year *j*,
RU(*j*) = estimated replacement units in year *j*, and
NU(*j*) = new units for new homes in year *j*.

The shipments model begins with an estimate of the building stock and product stock in the base year, and adds shipments and removes retirements each year. In principle, only building and market saturation data are needed to allow the shipments model to estimate shipments to new construction and replacements. The third product segment, new owners, is more difficult to describe based on existing data. For NWGFs, DOE used data from Decision Analysts' *American Home Comfort Survey* to estimate that 9 percent of total shipments are to new owners.[2] For MGHFs, DOE assumed that there were no new owner shipments.

9.3 DATA INPUTS AND SUPPORTING CALCULATIONS

9.3.1 Historical Shipments

DOE used historical shipments data (*i.e.*, domestic shipments and imports) to populate its shipments model for NWGFs and MHGFs. As part of its data submittal to DOE's 2011 furnace standards rulemaking, the Air-Conditioning, Heating, and Refrigeration Institute (AHRI) provided combined NWGF and MHGF historical shipments data from 2005-2009.[2] Historical shipments for 1972-2005 were also provided by AHRI[b] from previous data submittals to DOE.[3, 4] In addition, DOE obtained national shipments of gas furnaces[c] from 2010-2013 from AHRI's website.[d] *Appliance Magazine* (*AM*) has published shipments data of gas furnaces from 1961 to 2012.[5]

DOE disaggregated MHGF shipments from the gas furnace total by using a combination of data from the U.S. Census[6] and American Housing Survey (AHS).[7] Disaggregated condensing and non-condensing gas furnace shipments by region were available from 1992 to 2009, and these data were used to estimate shipments by region before 1992.

A fraction of NWGFs are shipped to commercial buildings; therefore, DOE considered the future shipments of NWGFs to commercial buildings in this analysis. DOE used the Residential Energy Consumption Survey (RECS) 2009[8] and Commercial Building Energy Consumption Survey (CBECS) 2003[9] to determine the number of NWGFs in residential and commercial applications. DOE estimated that NWGFs shipped to commercial buildings accounted for 3 percent of the total historical shipments of NWGFs, while all MHGFs were

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[b] Previously known as Gas Appliance Manufacturers Association (GAMA).
[c] Combined NWGF and MHGF shipments.
[d] Both annual and monthly shipments are available from www.ahrinet.org/site/497/Resources/Statistics/Historical-Data/Furnaces-Historical-Data.

shipped to residential buildings. Details of the methodology to determine the fraction of NWGFs shipped to commercial buildings are described in appendix 9B.

The historical shipments from 1960 to 2013 of NWGFs and MHGFs are shown in Figure 9.3.1.

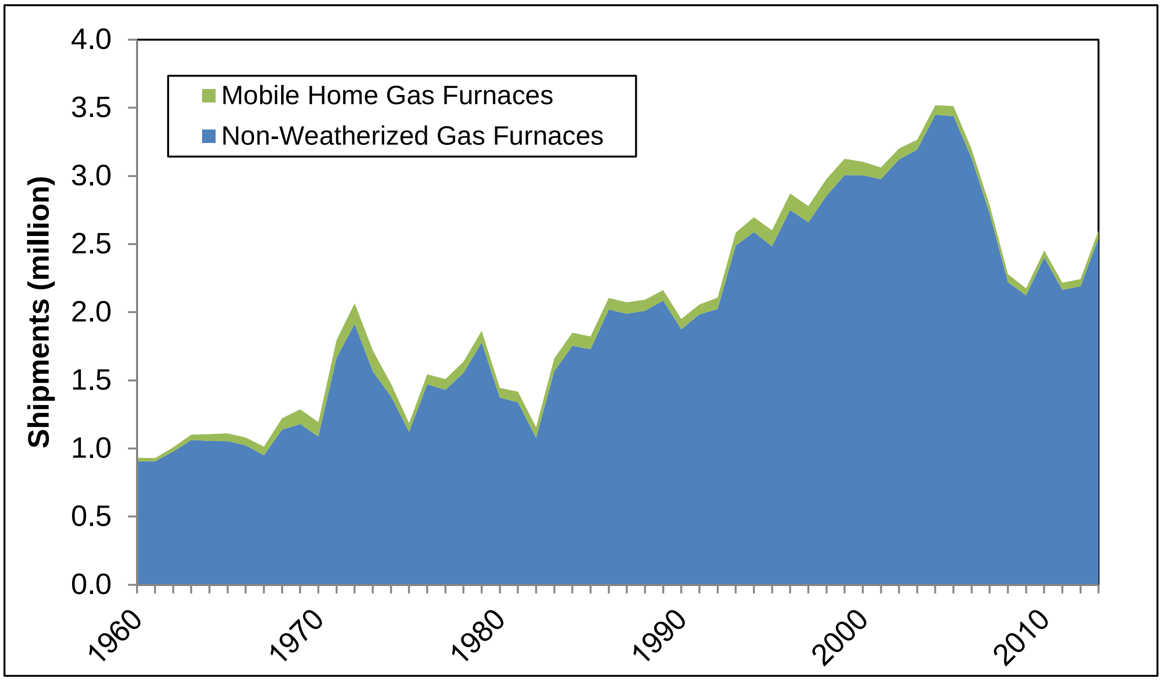

Figure 9.3.1 **Historical Shipments of Non-Weatherized Gas Furnaces and Mobile Home Gas Furnaces, 1960-2013**

9.3.2 Allocation of Historical Shipments to Regions

As described in section 9.2, shipments are divided into North and Rest of Country regions for NWGFs and MHGFs. DOE developed regional allocation factors to divide historical shipments of NWGFs and MHGFs into North and Rest of Country regions. The regional allocation factors from NWGFs and MHGFs were based on regional shipments data submitted by AHRI for the years 1992 through 2009. Table 9.3.1 provides the regional shipment market share data for the two regions. For each product class, the market share values total to 100 percent.

Table 9.3.1 Furnace Regional Shipment Market Shares (%)*

Year	Non-Weatherized Gas Furnace		Mobile Home Gas Furnace	
	North	Rest of Country	North	Rest of Country
1992	54.6	45.4	59.3	40.7
1993	51.4	48.6	59.3	40.7
1994	53.9	46.1	59.3	40.7
1995	54.2	45.8	57.5	42.5
1996	53.1	46.9	54.8	45.2
1997	52.6	47.4	54.4	45.6
1998	51.3	48.7	53.2	46.8
1999	51.8	48.2	55.1	44.9
2000	51.8	48.2	58.7	41.3
2001	48.8	51.2	59.9	40.1
2002	49.2	50.8	61.1	38.9
2003	49.8	50.2	61.6	38.4
2004	48.1	51.9	57.4	42.6
2005	48.7	51.3	50.9	49.1
2006	48.2	51.8	51.7	48.3
2007	49.9	50.1	52.1	47.9
2008	54.8	45.2	49.2	50.8
2009	54.9	45.1	49.7	50.3

Source: AHRI Shipments Data disaggregated into NWGF and MHGF using methodology described in appendix 9B.
* Market shares for each product class add up to 100%.

9.3.3 New Construction and New Construction Saturations

DOE determined historical new residential housing starts up to 2012 by using U.S. Census data[10, 11] and determined historical commercial floor space up to 2012 from the NEMS data published in EIA's *Annual Energy Outlook 2014* (*AEO 2014*).[12] From 2013 to 2040 (the last year in *AEO 2014*), DOE used projections from *AEO 2014* projections. After 2040, DOE extrapolated housing starts and commercial floor space from the trend in *AEO 2014* projected data from 2030-2040.

DOE developed residential regional new construction saturations from *Characteristics of New Housing* data from the U.S. Census Bureau.[10] The data disaggregates furnace saturations for single-family and multi-family households into the four Census Regions (*i.e.*, Northeast, Midwest, Rest of Country, and West). DOE used regional allocation factors (as discussed in section 9.3.2) to properly allocate saturations into North and Rest of Country regions. Figure 9.3.2 and Figure 9.3.3 depict the historical and projected regional new construction saturations for NWGFs and MHGFs, respectively. The regional saturations depicted in Figure 9.3.2 and Figure 9.3.3 were determined using the entire U.S. housing stock. In other words, the sum of the regional saturations equals the national saturation.

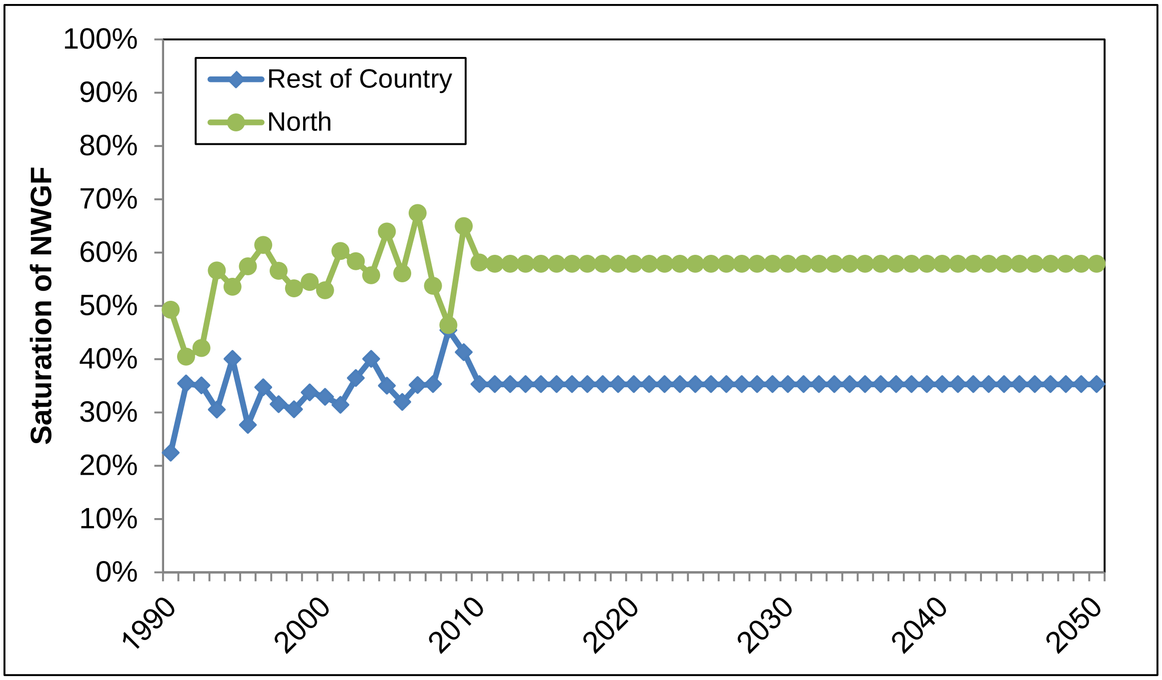

Figure 9.3.2 Non-Weatherized Gas Furnace Regional Saturations in Residential New Construction

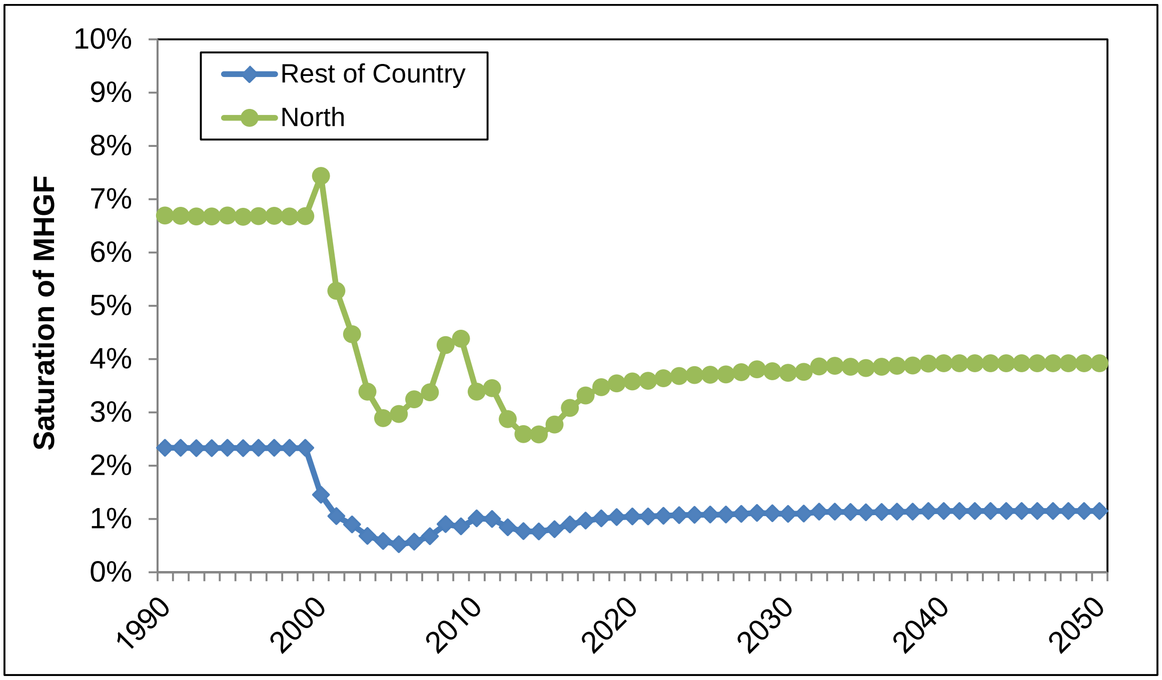

Figure 9.3.3 Mobile Home Gas Furnace National and Regional Saturations in Residential New Construction

9.3.4 Shipments to New Owners

The new owners primarily consist of households that during a major remodel add or switch to NWGFs. DOE assumed that there were no new owners of MHGFs. For NWGFs, DOE assumed that new owners correspond, on average, to 10 percent of the replacement market segment from 2021 to 2050, which is equal to half of the new owners observed in the shipments model from 2009-2013.

9.4 DECISION MODEL FOR PRODUCT SWITCHING

As described in chapter 8, DOE developed a consumer choice model to estimate the response of builders and home owners to potential amended NWGF standards. The model considers the options available to each sample household, which are to purchase and install: (1) a furnace that meets a particular efficiency level, (2) a heat pump (HP), or (3) an electric furnace (EF). In addition, DOE considered the possibility that households for which installation of a condensing furnace would leave an “orphaned” gas storage water heater (GSWH) that would require expensive re-sizing of the vent system might choose instead to purchase an electric storage water heater (ESWH) when they choose any of the above three options. To calculate the households that switched products and to calculate the impact on the energy use for the households that switched, DOE calculated the energy use for the alternative space heating and water heating options. For the heat pump option, DOE also accounted for the cooling energy use of each relevant household that might switch from gas furnace and central air conditioner (CAC) to a heat pump.

The shipments model accounts for projected switching by reducing the base case shipments of NWGFs and adding shipments of the electric heating options. The retirement function for these products uses lifetime distributions with a mean of 21.5 years for electric furnaces, 19.0 years for heat pumps, and 12.3 years for electric storage water heaters.

Table 9.4.1 shows the fraction of shipments in 2021 by product type in different regions and in replacement and new construction applications relative to base-case shipments of 80-percent AFUE NWGFs. The difference in the fraction of shipments between the baseline (efficiency level (EL) 0) and each proposed NWGF EL within each switching scenario represents the fraction of consumers switching from a non-condensing (80-percent AFUE) NWGF to an alternative space heating option due to a NWGF standard at the respective EL, including a more-efficient NWGF. No product switching was considered for commercial applications. Table 9.4.2 shows the fraction of shipments that switched from GSWHs to ESWHs under standards cases at each EL.

Table 9.4.1 Fraction of Total Shipments by Product Type in 2021 (Residential Applications)

Space Heating Option	NWGF AFUE	Fraction of Shipments (%)			
		North		*Rest of Country*	
		Replacement	*New Const.*	*Replacement*	*New Const.*
NWGF 80%	80%	100.0	100.0	100.0	100.0
NWGF 90%	90%	88.4	82.9	80.0	78.9
NWGF 92%	92%	88.9	83.1	80.0	78.8
NWGF 95%	95%	87.0	79.1	75.1	74.6
NWGF 98%	98%	84.7	73.3	65.4	67.3
80% NWGF to EF	80%	0.0	0.0	0.0	0.0
	90%	3.1	5.1	5.8	5.2
	92%	2.8	4.9	5.7	5.0
	95%	3.1	5.6	5.8	7.0
	98%	3.4	7.3	7.2	6.8
80% NWGF to HP	80%	0.0	0.0	0.0	0.0
	90%	8.5	12.0	14.3	16.0
	92%	8.4	12.0	14.3	16.2
	95%	9.9	15.4	19.1	18.3
	98%	11.9	19.4	27.4	25.9

EF = electric furnace; HP = heat pump.

Table 9.4.2 Fraction of Total Shipments Switching from GSWH to ESWH in 2021 (Residential Applications)

Water Heating Option	NWGF AFUE	Fraction of Shipments (%)			
		North		*Rest of Country*	
		Replacement	*New Const.*	*Replacement*	*New Const.*
GSWH to ESWH	80%	0.0	0.0	0.0	0.0
	90%	2.7	7.3	2.6	6.3
	92%	2.3	7.3	2.7	6.4
	95%	2.8	7.9	3.0	7.7
	98%	3.3	11.3%	3.9	7.9

GSWH = gas storage water heater; ESWH = gas storage water heater.

The fraction of switching is assumed to decrease steadily after 2021 for several reasons. First, the estimated trend in product prices is such that the cost difference between higher-efficiency NWGFs and the electric heating options will decline. Second, the number of high-cost NWGF installations is expected to decrease because the stock of homes that would need modifications will gradually decline as new furnaces and water heaters are installed. DOE assumed that the rate of switching would decline linearly until there is no switching in 2050.

See appendix 8J for further details on the product switching model.

9.5 RESULTS

As detailed in chapter 10, DOE created TSLs that combine specific efficiency levels (ELs) across product classes. Table 9.5.1 and Table 9.5.2 show the TSLs and associated ELs for AFUE standards and standby and off mode standards, respectively.

Table 9.5.1 Trial Standard Levels for AFUE Standards

Product Class	**TSL 1***	**TSL 2***	**TSL 3**	**TSL 4**	**TSL 5**
			Efficiency Level		
Non-Weatherized Gas Furnaces	1/0	3/0	2	3	4
Mobile Home Gas Furnace	1/0	2/0	1	2	3
			AFUE (%)		
Non-Weatherized Gas Furnaces	90/80	95/80	92	95	98
Mobile Home Gas Furnace	92/80	95/80	92	95	97

*Regional TSL (North/Rest of Country)

Table 9.5.2 Trial Standard Levels for Standby and Off Mode Standards

Product Class	**TSL 1**	**TSL 2**	**TSL 3**
		Efficiency Level	
Non-Weatherized Gas Furnaces	1	2	3
Mobile Home Gas Furnace	1	2	3
		Power (*watt*)	
Non-Weatherized Gas Furnaces	9.5	9.2	8.5
Mobile Home Gas Furnace	9.5	9.2	8.5

This section presents the shipments forecasts for the base case for NWGFs and MHGFs. Figures are presented showing base case shipments by product class, market segment (new construction, replacements, and new owners), and region (North and Rest of Country).

9.5.1 Base Case Shipments

Figure 9.5.1 shows the projected base case shipments by furnace product class, Figure 9.5.2 shows the projected base case shipments by market segment, and Figure 9.5.3 shows the projected base case shipments by region for NWGFs and MHGFs. The base case shipments for AFUE and standby and off mode standards are identical.

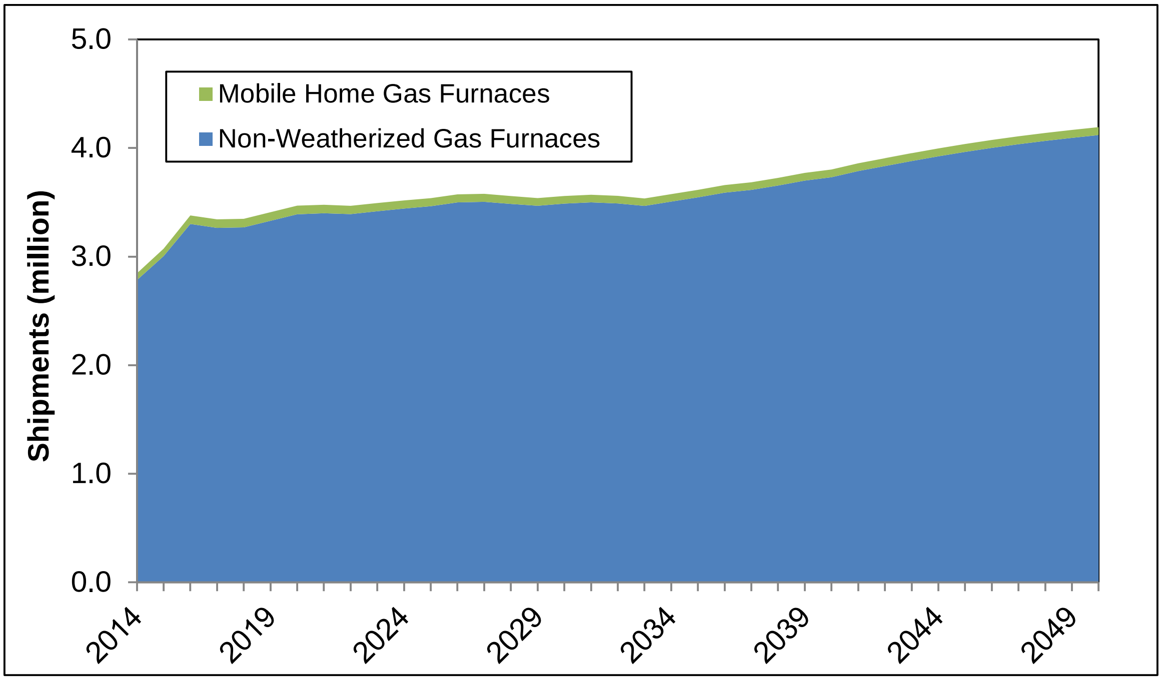

Figure 9.5.1 Base Case Shipments by Product Class

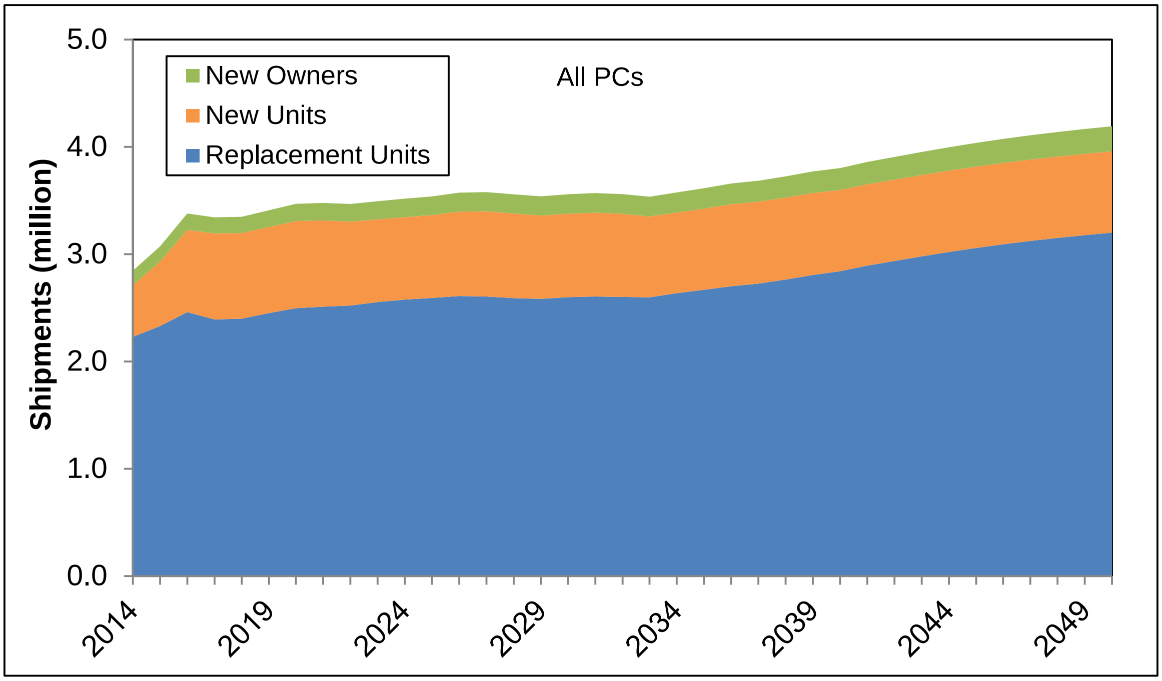

Figure 9.5.2 Base Case Shipments by Market Segment

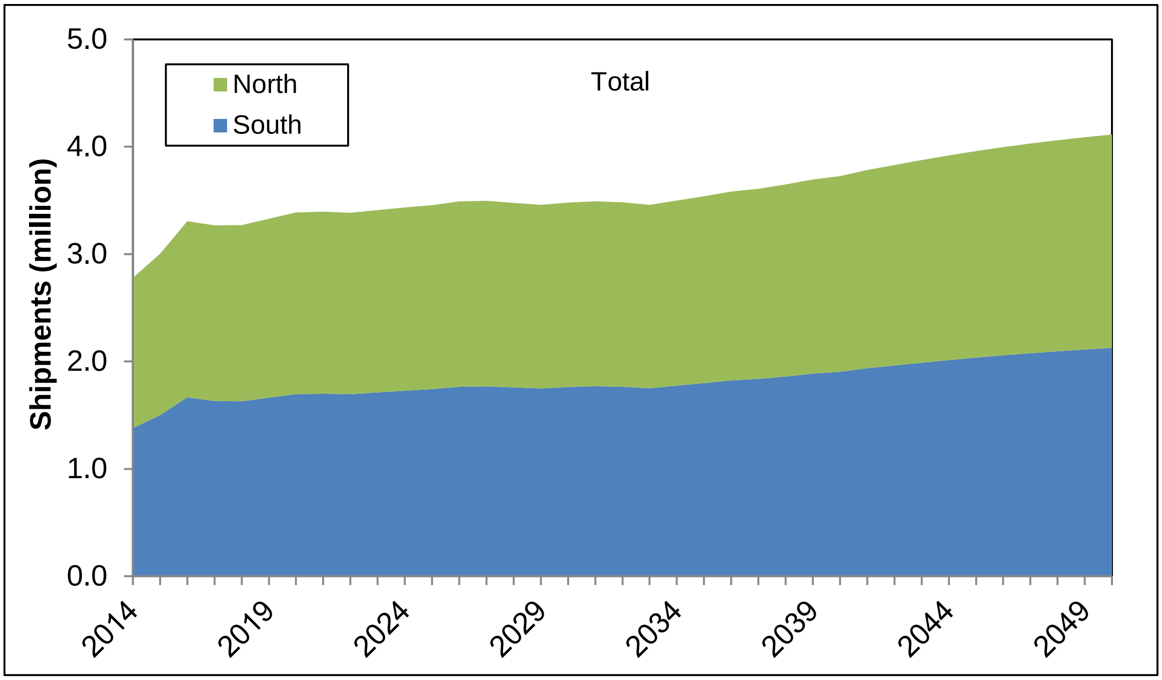

Figure 9.5.3 Base Case Shipments by Region

9.5.2 Shipments Impacts Due to Standards

Figure 9.5.4 shows total projected shipments of NWGFs in the AFUE base case and under each AFUE standards case. Because a fraction of NWGFs switch to electric furnaces or heat pumps based on consumers' decisions, the projection for the ELs shows a decline from the standard compliance year (2021). The decline becomes smaller in later years because the number of consumers that use less-efficient non-condensing NWGFs decreases. Figure 9.5.5 shows total projected shipments of MHGFs. The total shipment projections for mobile home gas furnaces are identical in AFUE base case and standards cases because DOE estimated that no MHGFs will be switched to other products.

DOE also created trial standard levels (TSLs) for specific efficiency levels that limit standby mode and off mode power consumption across product classes. Although the TSLs for standby mode and off mode power consumption did increase product cost, DOE estimated the cost increase was so small as to not impact product shipments. Therefore, the total shipment projections for NWGFs and MHGFs are identical in standby and off mode base case and standards cases.

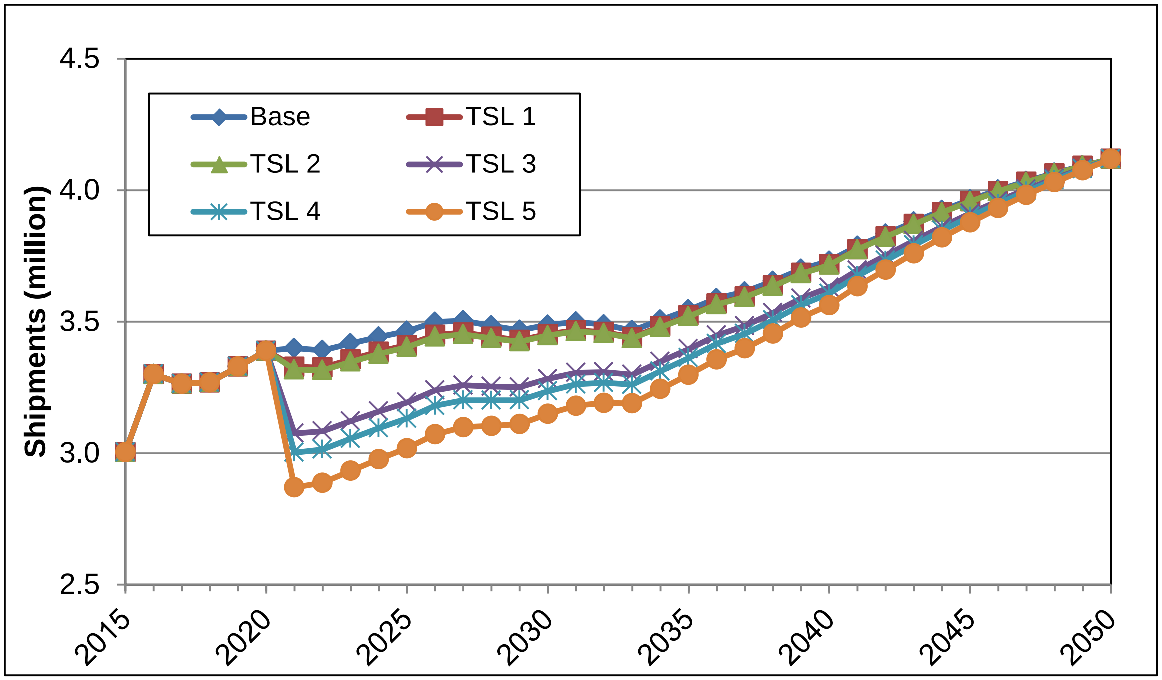

Figure 9.5.4 **Total Projected Shipments of Non-Weatherized Gas Furnaces in the Base Case and Each Standards Case**

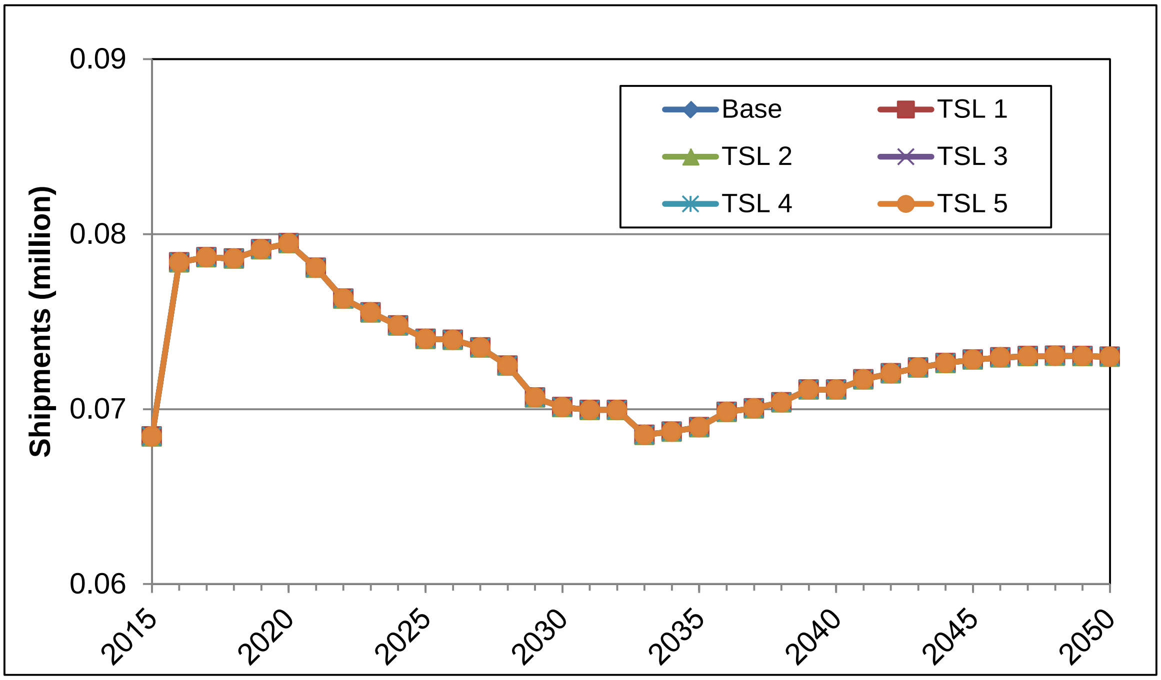

Figure 9.5.5 **Total Projected Shipments of Mobile Home Gas Furnaces in the Base Case and Each Standards Case**

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APPENDIX 9A. ADDITIONAL RESIDENTIAL FURNACE SHIPMENTS DATA

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APPENDIX 9A. ADDITIONAL RESIDENTIAL FURNACE SHIPMENTS DATA

9A.1 INTRODUCTION

DOE used historical shipments data for domestic shipments and imports to populate its shipments model for non-weatherized gas furnaces (NWGFs) and mobile home gas furnaces (MHGFs). The historical shipments data for all gas furnaces were collected from *Appliance Magazine* (AM) and the Air-Conditioning, Heating & Refrigeration Institute (AHRI).[1, 2]

9A.2 HISTORICAL SHIPMENTS DATA

9A.2.1 Appliance Magazine Shipment Data

DOE collected historical shipment data of gas furnaces[a] from Appliance Magazine as annual values for each year for the period 1961-2012,[1] as shown in Table 9A.2.1.

Table 9A.2.1 Historical Shipments of Gas Furnaces (in millions) from 1961 to 2012

Year	Shipment (million)	Year	Shipment (million)	Year	Shipment (million)	Year	Shipment (million)
1961	0.929	**1974**	1.476	**1987**	2.073	**2000**	3.104
1962	1.009	**1975**	1.186	**1988**	2.092	**2001**	3.063
1963	1.102	**1976**	1.544	**1989**	2.162	**2002**	3.202
1964	1.105	**1977**	1.509	**1990**	1.950	**2003**	3.266
1965	1.111	**1978**	1.638	**1991**	2.057	**2004**	3.519
1966	1.080	**1979**	1.863	**1992**	2.107	**2005**	3.512
1967	1.014	**1980**	1.445	**1993**	2.585	**2006**	3.197
1968	1.222	**1981**	1.417	**1994**	2.697	**2007**	2.782
1969	1.287	**1982**	1.156	**1995**	2.601	**2008**	2.280
1970	1.194	**1983**	1.662	**1996**	2.871	**2009**	2.175
1971	1.795	**1984**	1.849	**1997**	2.779	**2010**	2.453
1972	2.066	**1985**	1.822	**1998**	2.977	**2011**	2.216
1973	1.720	**1986**	2.105	**1999**	3.126	**2012**	2.243

9A.2.2 Summary of Historical Data by Product Class

DOE used the historical shipment data of gas furnaces from *Appliance Magazine*, shown in Table 9A.2.1, as the annual shipment data for the period from 1960-2013. DOE disaggregated MHGF shipments from the gas furnace total by using a combination of data from the U.S. Census[3] and American Housing Survey (AHS).[4] The shipments of residential NWGFs and MHGFs are summarized in Table 9A.2.2.

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[a] Includes both NWGFs (residential and commercial) and MHGFs.

Table 9A.2.2 Historical Shipments of Residential Furnaces by Product Class

Year	NWGF	MHGF	Year	NWGF	MHGF	Year	NWGF	MHGF
1960	0.905	0.027	**1978**	1.555	0.083	**1996**	2.750	0.121
1961	0.906	0.024	**1979**	1.778	0.085	**1997**	2.660	0.119
1962	0.978	0.031	**1980**	1.373	0.072	**1998**	2.854	0.124
1963	1.062	0.040	**1981**	1.339	0.078	**1999**	3.006	0.120
1964	1.055	0.050	**1982**	1.077	0.079	**2000**	3.005	0.099
1965	1.054	0.057	**1983**	1.567	0.095	**2001**	2.977	0.086
1966	1.023	0.057	**1984**	1.753	0.096	**2002**	3.121	0.081
1967	0.950	0.064	**1985**	1.728	0.094	**2003**	3.194	0.072
1968	1.138	0.084	**1986**	2.019	0.086	**2004**	3.448	0.071
1969	1.179	0.108	**1987**	1.989	0.084	**2005**	3.439	0.073
1970	1.088	0.106	**1988**	2.011	0.081	**2006**	3.130	0.067
1971	1.665	0.130	**1989**	2.085	0.077	**2007**	2.720	0.062
1972	1.914	0.152	**1990**	1.874	0.076	**2008**	2.221	0.059
1973	1.566	0.154	**1991**	1.984	0.073	**2009**	2.123	0.052
1974	1.383	0.094	**1992**	2.023	0.084	**2010**	2.401	0.052
1975	1.123	0.063	**1993**	2.489	0.096	**2011**	2.164	0.053
1976	1.472	0.073	**1994**	2.588	0.109	**2012**	2.190	0.053
1977	1.430	0.079	**1995**	2.484	0.117	**2013**	2.544	0.058

9A.2.3 Disaggregation of Shipment by Region

DOE estimated that the 48.9 percent of the overall NWGF were shipped to Rest of Country and 40.7 percent of the overall MHGF were shipped to Rest of Country based on shipments data by State and by region from the Air-Conditioning, Heating, and Refrigeration Institute (AHRI).[5, 6, 7] DOE used the historical shipments, census data and the fractions shipped to Rest of Country to derive the shipments by region in Table 9A.2.3.

Table 9A.2.3 Historical Shipments of Furnaces from 1960 to 2013

Year	**NWGF**		**MHGF**		**Year**	**NWGF**		**MHGF**	
	North	***Rest of Country***	***North***	***Rest of Country***		***North***	***Rest of Country***	***North***	***Rest of Country***
1960	0.440	0.465	0.011	0.016	**1987**	0.968	1.021	0.034	0.050
1961	0.440	0.466	0.010	0.014	**1988**	0.979	1.032	0.033	0.048
1962	0.475	0.502	0.013	0.018	**1989**	1.014	1.071	0.032	0.046
1963	0.517	0.546	0.016	0.023	**1990**	0.912	0.962	0.031	0.045
1964	0.514	0.541	0.020	0.030	**1991**	0.965	1.019	0.030	0.043
1965	0.514	0.540	0.023	0.034	**1992**	0.918	1.105	0.034	0.050
1966	0.499	0.524	0.023	0.034	**1993**	1.211	1.278	0.039	0.057
1967	0.464	0.486	0.026	0.038	**1994**	1.192	1.396	0.044	0.065
1968	0.557	0.581	0.034	0.050	**1995**	1.137	1.347	0.050	0.067
1969	0.578	0.601	0.044	0.064	**1996**	1.289	1.461	0.055	0.067
1970	0.534	0.554	0.043	0.063	**1997**	1.260	1.399	0.054	0.065
1971	0.815	0.850	0.053	0.077	**1998**	1.390	1.464	0.058	0.066
1972	0.937	0.977	0.062	0.090	**1999**	1.448	1.558	0.054	0.066
1973	0.769	0.797	0.063	0.091	**2000**	1.448	1.557	0.041	0.058
1974	0.676	0.707	0.038	0.056	**2001**	1.524	1.452	0.035	0.052
1975	0.548	0.575	0.026	0.037	**2002**	1.585	1.536	0.031	0.049
1976	0.717	0.754	0.030	0.043	**2003**	1.604	1.589	0.028	0.044
1977	0.697	0.732	0.032	0.047	**2004**	1.789	1.659	0.030	0.041
1978	0.758	0.797	0.034	0.049	**2005**	1.766	1.673	0.036	0.037
1979	0.866	0.912	0.035	0.050	**2006**	1.621	1.509	0.032	0.035
1980	0.670	0.704	0.029	0.043	**2007**	1.362	1.358	0.030	0.032
1981	0.653	0.685	0.032	0.046	**2008**	1.004	1.217	0.030	0.029
1982	0.527	0.550	0.032	0.047	**2009**	0.957	1.166	0.026	0.026
1983	0.765	0.802	0.039	0.056	**2010**	1.161	1.240	0.025	0.027
1984	0.855	0.898	0.039	0.057	**2011**	1.047	1.117	0.025	0.028
1985	0.843	0.885	0.038	0.056	**2012**	1.060	1.130	0.025	0.028
1986	0.983	1.036	0.035	0.051	**2013**	1.218	1.325	0.040	0.018

9A.3 FRACTION OF RESIDENTIAL FURNACES SHIPPED TO COMMERCIAL BUILDINGS

DOE derived NWGF and MHGF shipments by building types from the Energy Information Administration’s (EIA) Residential Energy Consumption Survey (RECS) 2009[8] and Commercial Building Energy Consumption Survey (CBECS) 2003[9] data. DOE assumed that gas-fired central warm air furnaces in residential and commercial buildings that are smaller than 10,000 sq. ft. are NWGFs and one to three NWGFs are used per commercial building, depending on the size of the building.[b] The number of NWGFs and MHGFs derived from RECS 2009 and

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[b] DOE assumed that there is one NWGF per 4,000 square feet.

CBECS 2003 indicates that 3 percent of NWGFs were shipped to the commercial sector, and all MHGFs were shipped to the residential sector.

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CHAPTER 10. NATIONAL IMPACT ANALYSES

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CHAPTER 10. NATIONAL IMPACT ANALYSES

10.1 INTRODUCTION

This chapter examines selected national impacts attributable to each trial standard level (TSL) considered for non-weatherized gas furnaces (NWGFs) and mobile home gas furnaces (MHGFs). 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 Microsoft Excel spreadsheet model, which is accessible on the Internet (www1.eere.energy.gov/buildings/appliance_standards/product.aspx/productid/72). The spreadsheet model, termed the National Impact Analysis (NIA) model, calculates energy savings and NPV for the nation. Details regarding and instructions for using the NIA model are provided in appendix 10A. The NIA model incorporates the shipments model that DOE used to project future purchases of NWGFs and MHGFs.

10.2 TRIAL STANDARD LEVELS

DOE developed TSLs that combine efficiency levels for each product class of NWGFs and MHGFs. Table 10.2.1 presents the efficiency levels (EL) and Annual Fuel Utilization Efficiency (AFUE) for each product class in each TSL. TSL 5 consists of the max-tech efficiency levels. TSL 4 consists of those efficiency levels that provide the maximum NES with NPV greater than zero using a 7-percent discount rate (see section 10.7.2 for NPV results). TSL 3 consists of the efficiency levels that represent 92-percent AFUE for each product class. TSL 2 represents 95-percent efficiency level for the North and baseline non-condensing efficiency level for the Rest of Country. TSL 1 consists of the baseline condensing efficiency level for the North and baseline non-condensing efficiency level for the Rest of Country.

Table 10.2.1 Trial Standard Levels for AFUE Standards

Product Class	TSL 1*	TSL 2*	TSL 3	TSL 4	TSL 5
			Efficiency Level		
Non-Weatherized Gas Furnaces	1/0	3/0	2	3	4
Mobile Home Gas Furnace	1/0	2/0	1	2	3
			AFUE (%)		
Non-Weatherized Gas Furnaces	90/80	95/80	92	95	98
Mobile Home Gas Furnace	92/80	95/80	92	95	97

*Regional TSL (North/Rest of Country)

Table 10.2.2 presents the TSLs and the corresponding product class efficiency levels (by efficiency level and power) that DOE considered for NWGF and MHGF standby mode and off mode power consumption.

Table 10.2.2 Trial Standard Levels for Standby and Off Mode Standards

Product Class	TSL 1	TSL 2	TSL 3
		Efficiency Level	
Non-Weatherized Gas Furnaces	1	2	3
Mobile Home Gas Furnace	1	2	3
		Power (*watt*)	
Non-Weatherized Gas Furnaces	9.5	9.2	8.5
Mobile Home Gas Furnace	9.5	9.2	8.5

10.3 OVERVIEW OF THE NATIONAL IMPACTS ANALYSIS

10.3.1 National Energy Savings

DOE calculates annual national energy savings (NES) as the difference between two projections: the base case (without new standards) and a standards case (with new standards). The calculation of annual national energy savings (NES_y) are represented by the following expression:

$$NES_y = AEC_{natl-base} - AEC_{natl-std}$$

Eq. 10.1

Cumulative energy savings are the sum of each annual *NES* over the lifetime of products shipped in the period that extends from a standard's assumed compliance date for 30 years. This calculation is represented by the following equation:

$$NES_{cum} = \sum NES_y$$

Eq. 10.2

DOE calculated *AEC* by multiplying the number or stock of a given product (by vintage) by its unit energy consumption (also by vintage). The calculation of the national and each regional *AEC* is represented by the following equation:

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

Eq. 10.3

Where:

AEC = annual energy consumption each year for the Nation in quadrillion British thermal units (Btus), or quads, summed over vintages of the product stock, $STOCK_V$,

NES_{cum} = national cumulative energy savings (quads),
NES_y = national annual energy savings (quads),
$STOCK_V$ = stock of product (millions of units) of vintage V that survive in the year for which DOE calculated annual energy consumption,
UEC_V = annual energy consumption per product in kilowatt-hours (kWh); electricity consumption is converted from site energy to power plant energy (quads) by applying an annual conversion factor (see section 10.5.5),
natl = designates the quantity corresponding to the Nation,
base = designates the quantity corresponding to the 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 product was purchased as a new unit.

The stock of product depends on annual shipments and the lifetime of the given product. As described in chapter 9, DOE projected shipments for the base case and each standards case. Based on the sample of furnace users in the LCC and PBP analysis, DOE estimated that a fraction of NWGFs (3 percent) is shipped to commercial buildings, while all MHGFs are shipped to residential buildings. The national energy saving from NWGFs in the standard cases includes the saving from both residential and commercial furnace users.

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 NPV is described by the equation:

$$NPV = PVS - PVC$$

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 the product and installation).

DOE determined the *PVS* and *PVC* according to the following expressions:

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

Eq. 10.5

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

Eq. 10.6

DOE calculated the total annual savings in operating cost by multiplying the number or stock of a given product (by vintage) by its per-unit operating cost savings (also by vintage). DOE calculated the total annual increase in installed cost by multiplying the number or stock of a given product (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 product stock, $STOCK_V$,
TIC = total annual increase in installed cost each year summed over vintages of the product stock, $STOCK_V$,
DF =discount factor in each year,
$STOCK_V$ = stock of product (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 product was purchased as a new unit, and
y = year in the projection.

As mentioned in section 10.3.1, DOE estimated that 3 percent of NWGFs are shipped to commercial buildings. The net present value of consumer benefits in the standard cases for NWGFs includes the benefits from both residential and commercial furnace users.

DOE determined the *PVC* for each year from the compliance date of the standard through 2050. DOE determined the *PVS* for each year from the compliance date of the standard until the year when units purchased in 2021-2050 retire. DOE calculated costs and savings as the difference between each standards case and the base case.

DOE calculated a discount factor from the discount rate and the number of years between the "present" (2014, 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 NWGFs and MHGFs projected over time for the base case (without new standards) and for each of the standards cases (with potential new standards). The NWGFs AFUE standards cases include the impacts of product switching.

10.4.1 Base and Standards Case Efficiencies in 2021

For each residential furnace product class, DOE developed a distribution of efficiencies in the base cases for 2021 (the assumed compliance date for new standards), as described in chapter 8. In each standards case, DOE assumed a "roll-up" scenario to establish the efficiency distribution for 2021.[a] Product efficiencies in the base case that did not meet the standard under consideration would "roll up" to meet the new standard level. All efficiency shares in the base case that were above the standard under consideration would not be affected.

Table 10.4.1 presents the efficiency distributions in 2021 for the base case and for each TSL for NWGFs and MHGFs used in residential applications. The results are presented for the national level TSLs when those are applicable; otherwise, the results are disaggregated between the North and Rest of Country regions. For the base case efficiency distributions disaggregated by region, see appendix 8I.

Table 10.4.1 Non-Weatherized Gas Furnaces and Mobile Home Gas Furnaces: Efficiency Distributions (National) in 2021 for AFUE Standards

		Market Share (percent)					
			Trial Standard Level (TSL)				
	Efficiency Level	**Base Case**	**1***	**2***	**3**	**4**	**5**
Non-Weatherized Gas Furnaces							
0	80% AFUE - Baseline	54.5	NA / 75.8	NA / 75.8			
1	90% AFUE - Cond. Baseline	5.1	24.7 / 4.0	NA / 4.0			
2	92% AFUE - Incr. HX Area	17.4	34.1 / 15.4	NA / 15.4	75.9		
3	95% AFUE - Incr. HX Area	22.6	40.4 / 4.7	99.2 / 4.7	23.7	99.5	
4	98% AFUE - Max Tech	0.4	0.8 / 0.1	0.8 / 0.1	0.5	0.5	100.0
Mobile Home Gas Furnaces							
0	80% AFUE - Baseline	77.1	NA / 87.8	NA / 87.8			
1	92% AFUE - Cond. Baseline	12.2	80.1 / 9.6	NA / 9.6	89.3		
2	95% AFUE - Incr. HX Area	10.6	19.7 / 2.6	99.7 / 2.6	10.6	99.9	
3	97% AFUE - Max Tech	0.1	0.3 / NA	0.3 / NA	0.1	0.1	100.0

*Regional TSL (North/Rest of Country)

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[a] The 90-percent AFUE standard case assumes that some of the market rolls up to 92-percent AFUE instead of 90-percent AFUE because the extra installed cost is minimal.

Table 10.4.2 Non-Weatherized Gas Furnaces and Mobile Home Gas Furnaces: Efficiency Distributions (National) in 2021 for Standby and Off-Mode Standards

Efficiency Level		Market Share (percent)			
			Trial Standard Level (TSL)		
		Base Case	1	2	3
Non-Weatherized Gas Furnaces					
0	Baseline	60.8			
1	Linear PS, Toroidal Xfmr	0.0	60.8		
2	Switch Mode PS	17.3	17.3	78.0	
3	SMPS, Toroidal Xfmr	22.0	22.0	22.0	100.0
Mobile Home Gas Furnaces					
0	80% AFUE - Baseline	3.4			
1	92% AFUE - Cond. Baseline	0.0	3.4		
2	95% AFUE - Incr. HX Area	0.8	0.8	4.3	
3	97% AFUE - Max Tech	95.7	95.7	95.7	100.0

10.4.2 Projected Efficiency Trends After 2021

Base Case

In the absence of amended standards, the implementation of ENERGY STAR®'s new performance criteria would gradually increase the market shares of condensing NWGFs and MHGFs. To project base-case efficiency over the 30-year shipments period, DOE extrapolated the historical trends in efficiency that were described in chapter 8. DOE estimated that the national market share of condensing products would grow from 45 percent in 2021 to 61 percent by 2050 for NWGFs, and from 23 percent to 29 percent for MHGFs. The market shares of the different condensing efficiency levels (i.e., 90-, 92-, 95-, and 98-percent AFUE for NWGF and 92-, 95-, and 97-percent AFUE for MHGF) are maintained in the same proportional relationship as in 2021. Figure 10.4.1 and Figure 10.4.2 shows the assumed base case market shares of NWGFs and MHGFs at each EL throughout the analysis period (2021-2050).

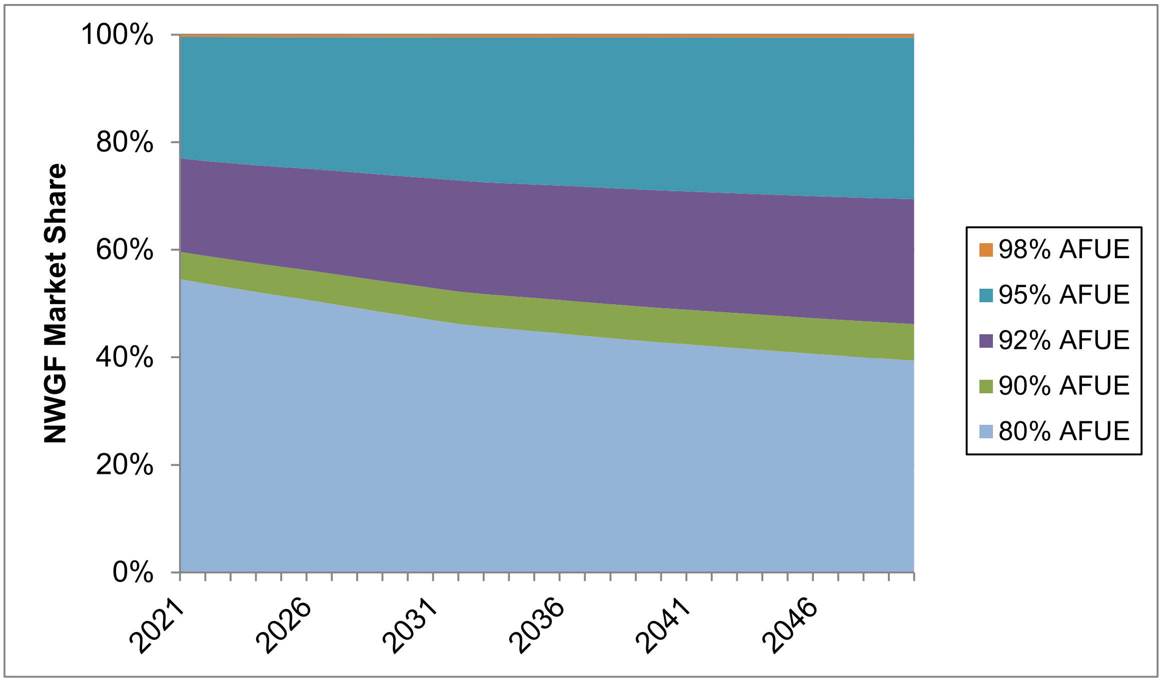

Figure 10.4.1 **Projection of Base Case Efficiency Distribution for Non-Weatherized Gas Furnaces, 2021-2050**

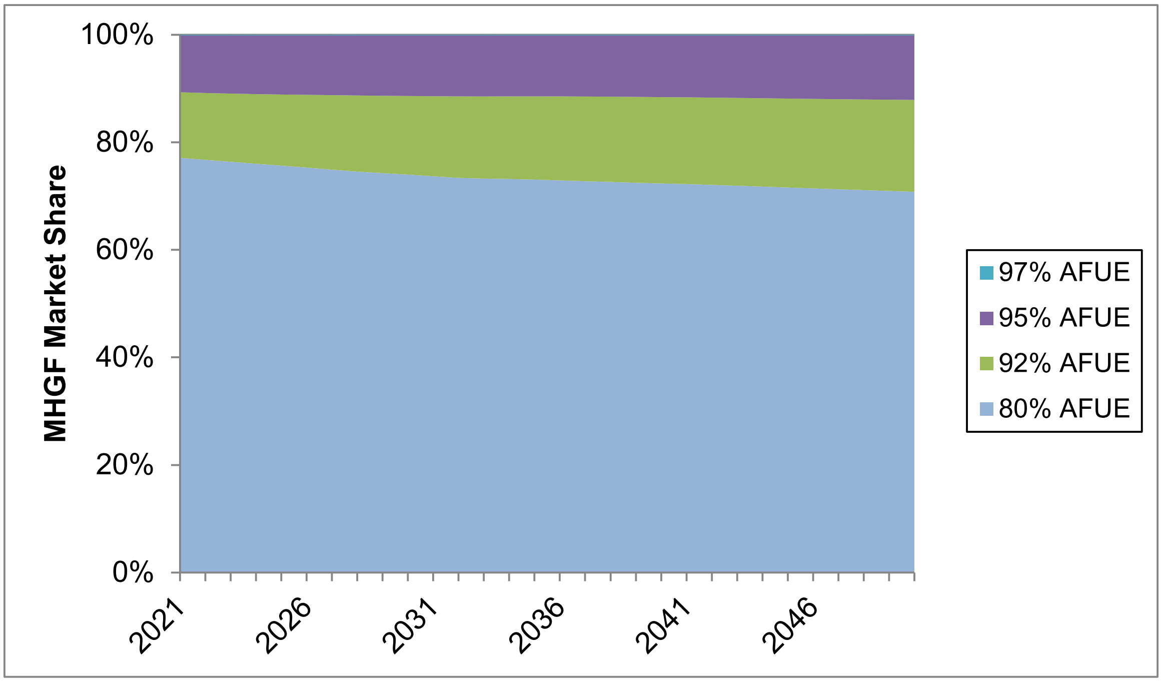

Figure 10.4.2 **Projection of Base Case Efficiency Distribution for Mobile Home Gas Furnaces, 2021-2050**

The condensing market shares throughout the analysis period in replacement installations for the nation and both analysis regions are presented in Figure 10.4.3 for NWGFs and in Figure

10.4.4 for MHGFs. In the case of replacement units, DOE estimated that there would be growth in the overall market share of condensing NWGFs from 48.5 percent in 2021 to 63.7 percent in 2050. Similarly, DOE estimated that there would be growth in the overall market share of condensing MHGFs from 24.4 percent in 2021 to 30.9 percent in 2050. More details are available in appendix 8I.

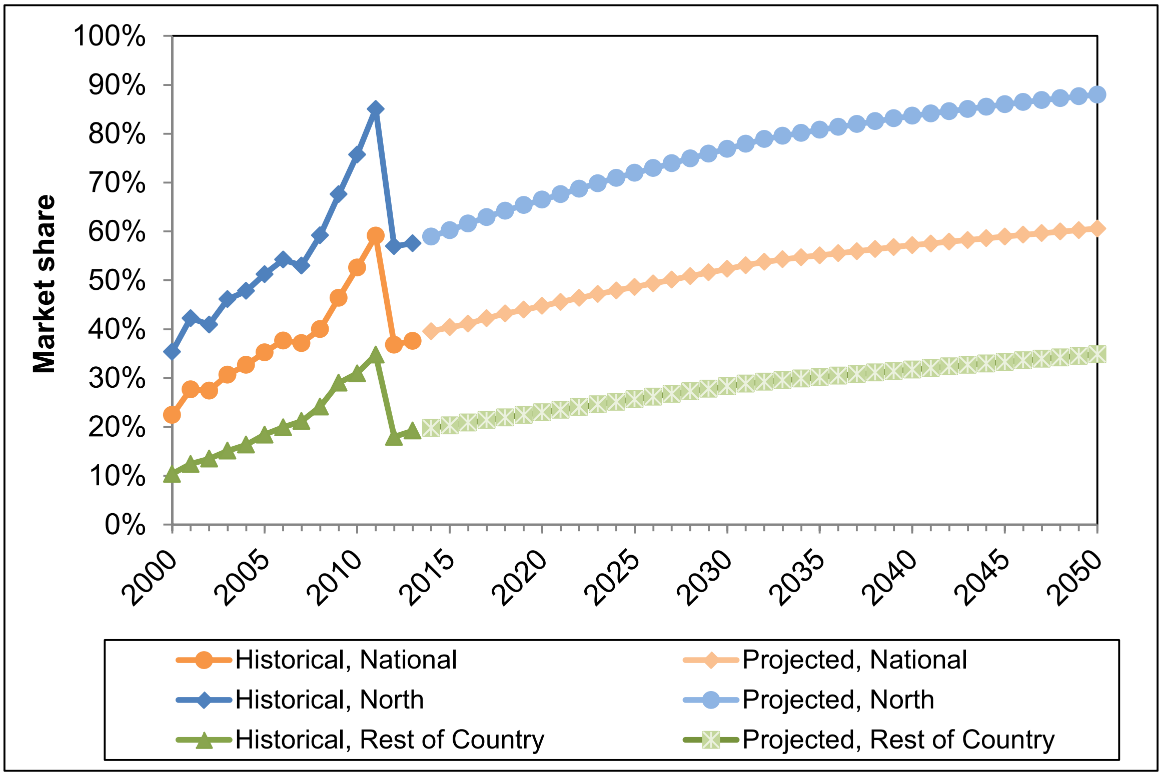

Figure 10.4.3 **Base Case Market Share of Condensing Non-Weatherized Gas Furnaces by Region, 2000-2050**

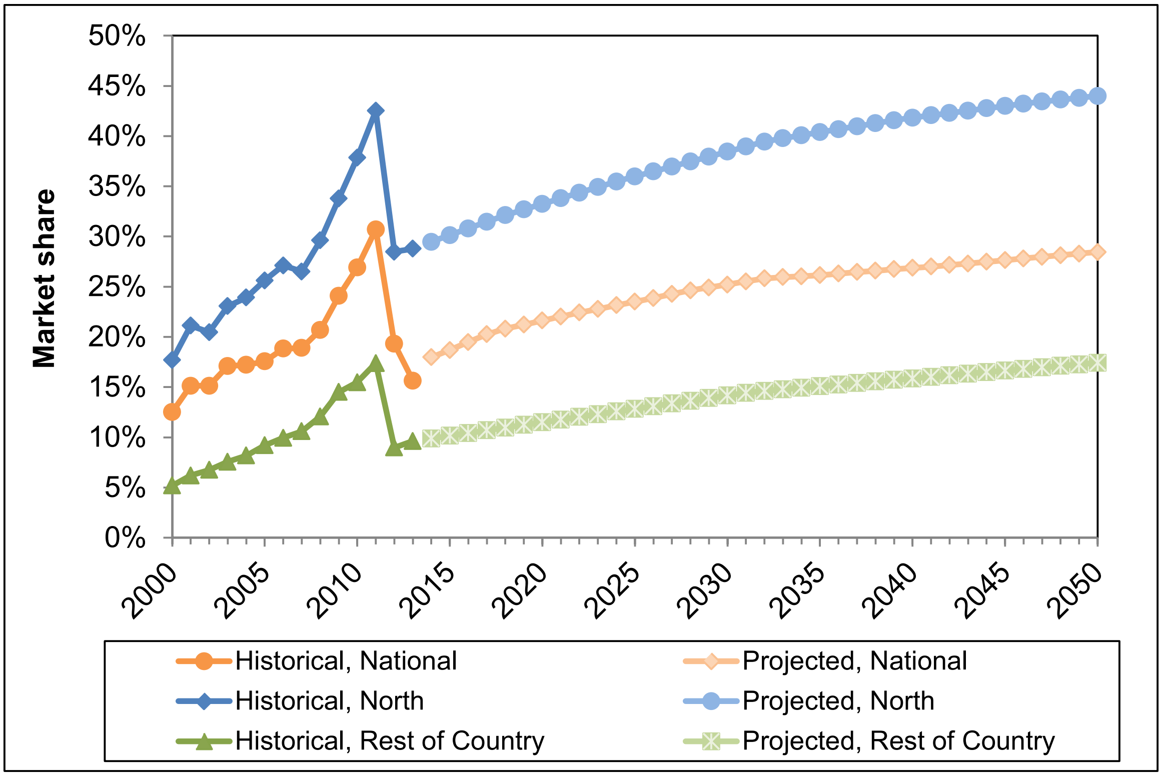

Figure 10.4.4 Base Case Market Share of Condensing Mobile Home Gas Furnaces, 2000-2050

Standards Cases

After the year of compliance, DOE estimated growth in efficiency in the standards cases, except in the max-tech standards case (98-percent AFUE). The estimated growth accounts for potential changes in ENERGY STAR criteria after amended standards are implemented and the response of manufacturers to minimum standards in the condensing range. In the 90-percent AFUE, 92-percent AFUE and 95-percent AFUE standards cases, the growth in the market share of furnaces above the standard level is set to match the similar rate in the base case, which is 0.5 percent per year.

Figure 10.4.5 through Figure 10.4.8 show the national market shares of each efficiency level in the four standards cases below max-tech for NWGFs. For the proposed NWGF AFUE standards (TSL 3, requiring 92-percent AFUE), the share of 95-percent AFUE furnaces increases from 24 to 48 percent from 2021 to 2050, and the share of 98-percent AFUE furnaces increases from 0.5 to 8 percent. The growth in these shares reflects the likelihood that furnace manufacturers will promote premium products above the minimum standard, and that ENERGY STAR will target the products with highest efficiency.

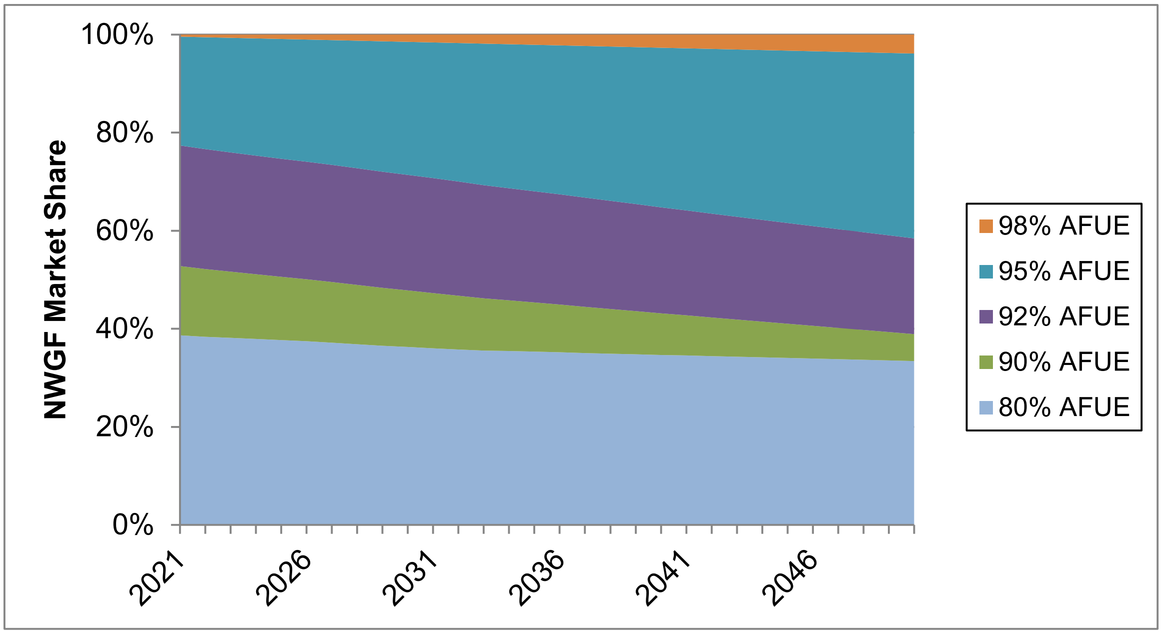

Figure 10.4.5 **Projection of Standards Case Efficiency (TSL 1) Distribution for Non-Weatherized Gas Furnaces AFUE Standards, 2021-2050**

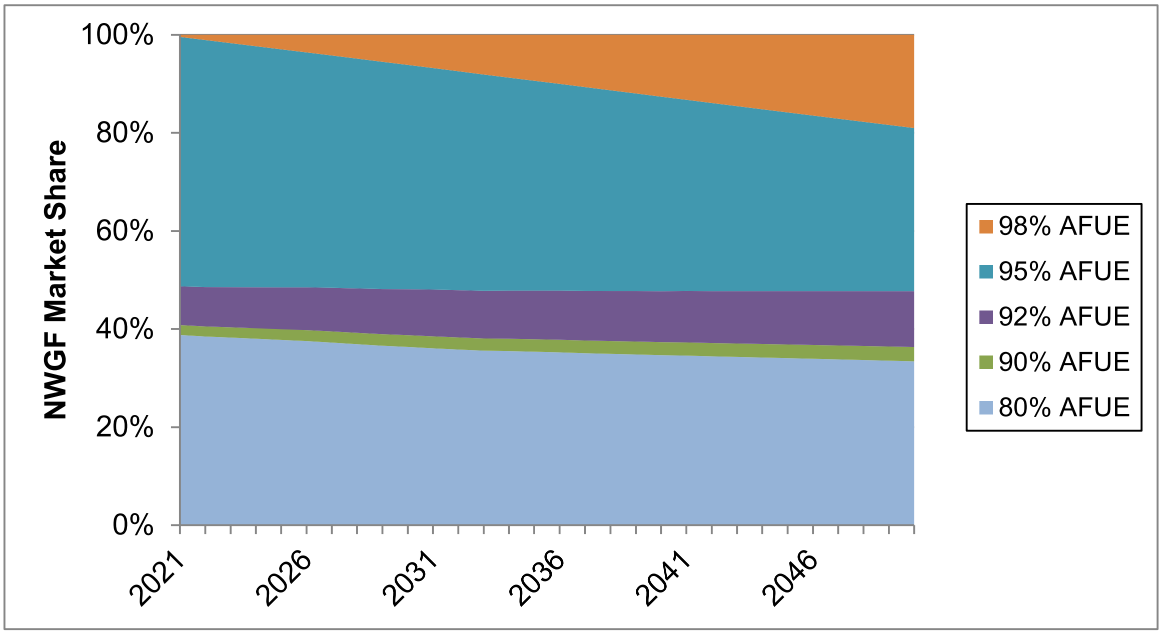

Figure 10.4.6 **Projection of Standards Case Efficiency (TSL 2) Distribution for Non-Weatherized Gas Furnaces AFUE Standards, 2021-2050**

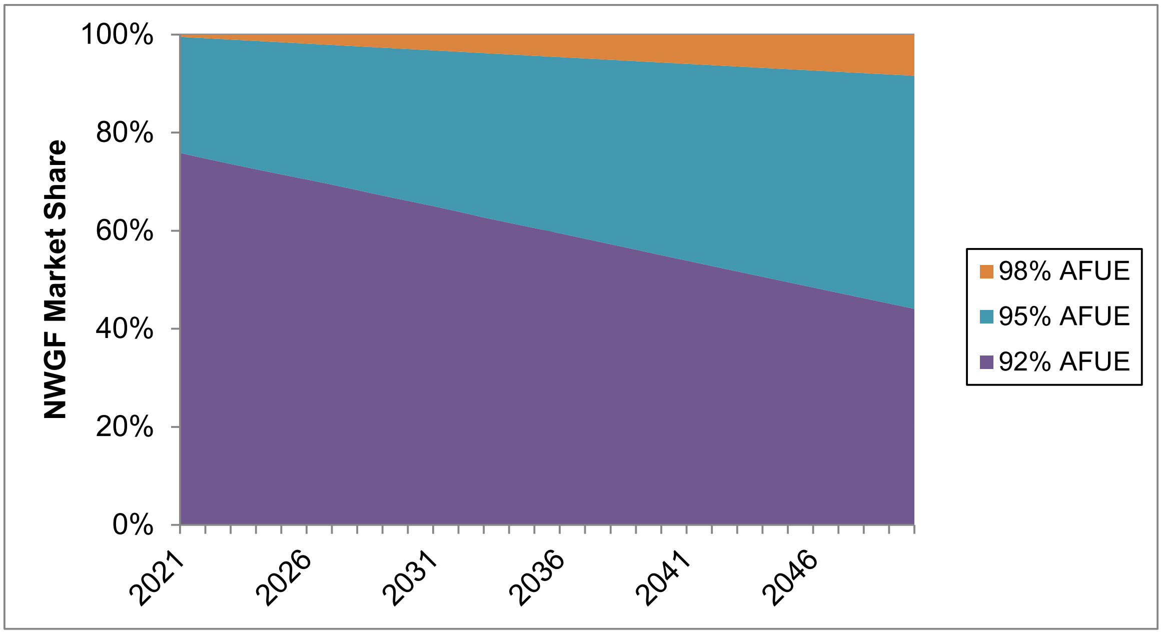

Figure 10.4.7 **Projection of Standards Case Efficiency (TSL 3) Distribution for Non-Weatherized Gas Furnaces AFUE Standards, 2021-2050**

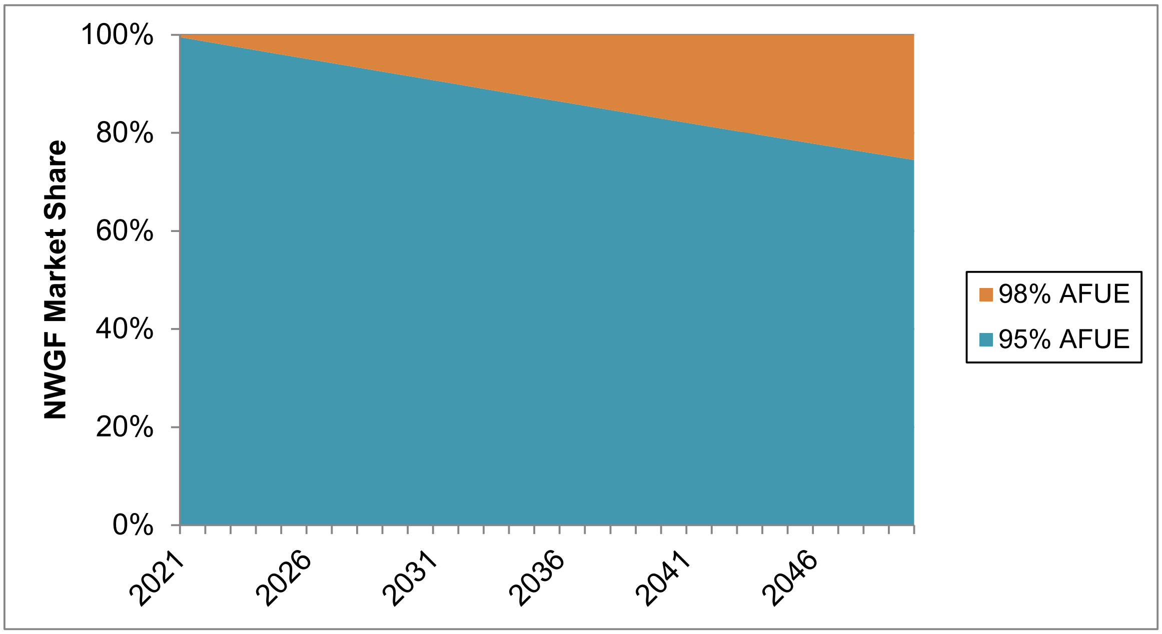

Figure 10.4.8 **Projection of Standards Case Efficiency (TSL 4) Distribution for Non-Weatherized Gas Furnaces AFUE Standards, 2021-2050**

Figure 10.4.10 through Figure 10.4.12 show the market shares of each efficiency level in the two standards cases below max-tech for MHGFs. For the proposed MHGF AFUE standards (TSL 3, requiring 92-percent AFUE), the share of 95-percent MHGFs increases from 11 percent to 32 percent, and the share of 97-percent AFUE MHGFs increases from 0.1 percent to 2.6 percent.

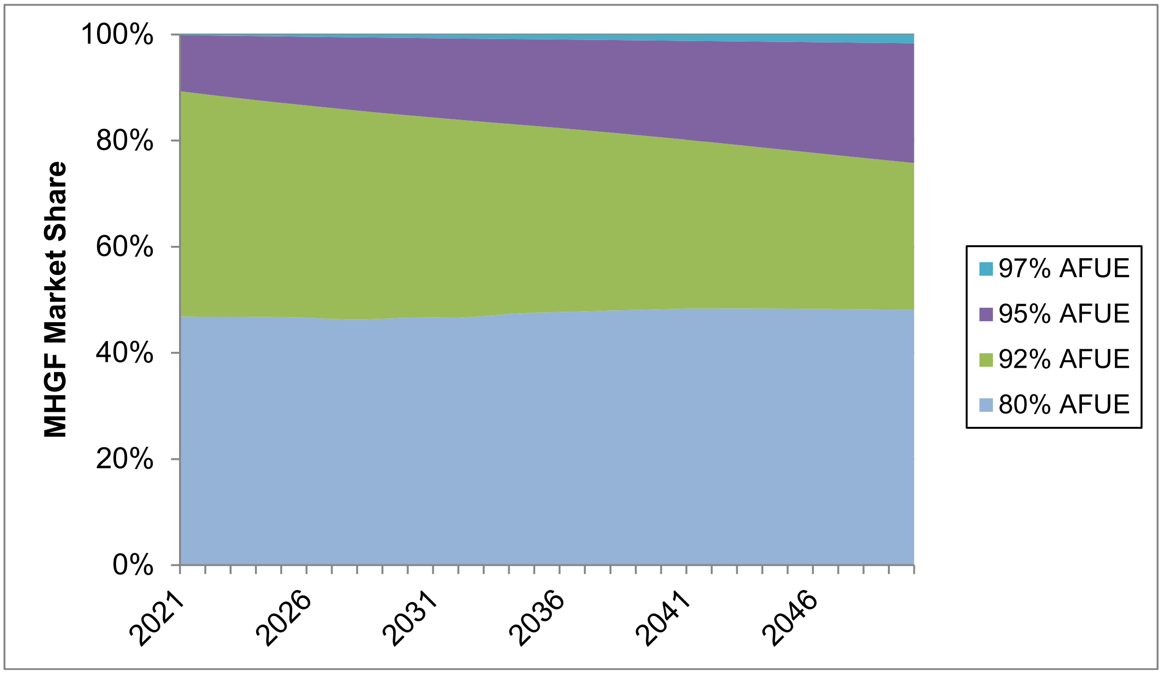

Figure 10.4.9 **Projection of Standards Case Efficiency (TSL 1) Distribution for Mobile Home Gas Furnaces AFUE Standards, 2021-2050**

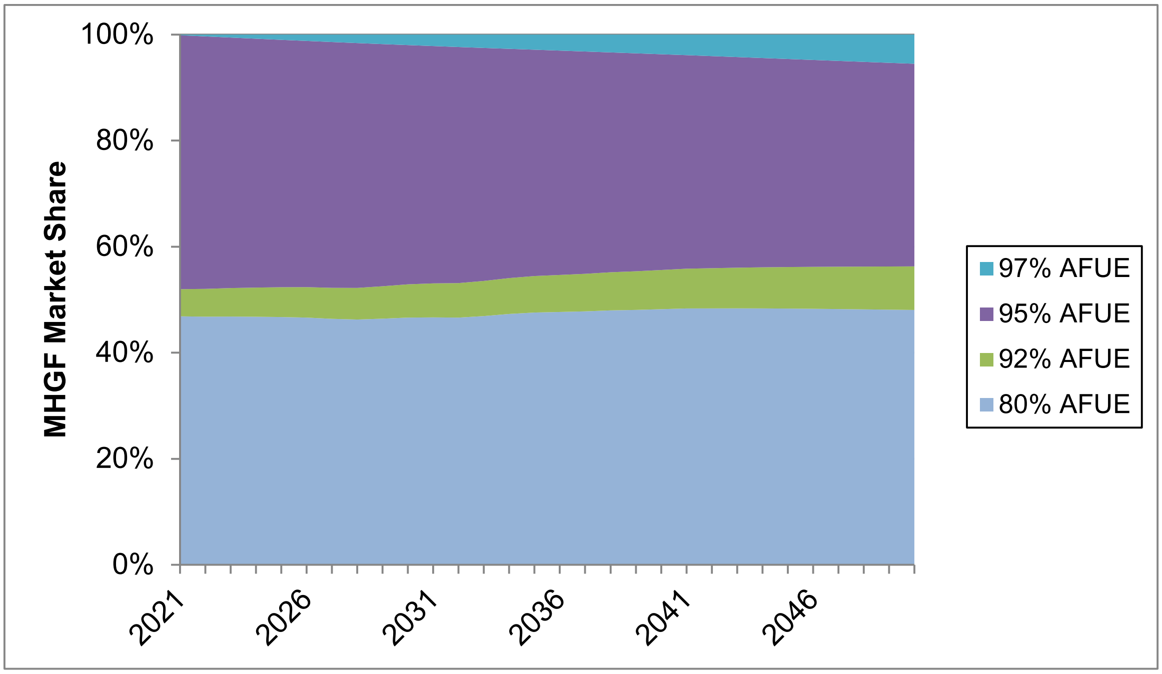

Figure 10.4.10 **Projection of Standards Case Efficiency (TSL 2) Distribution for Mobile Home Gas Furnaces AFUE Standards, 2021-2050**

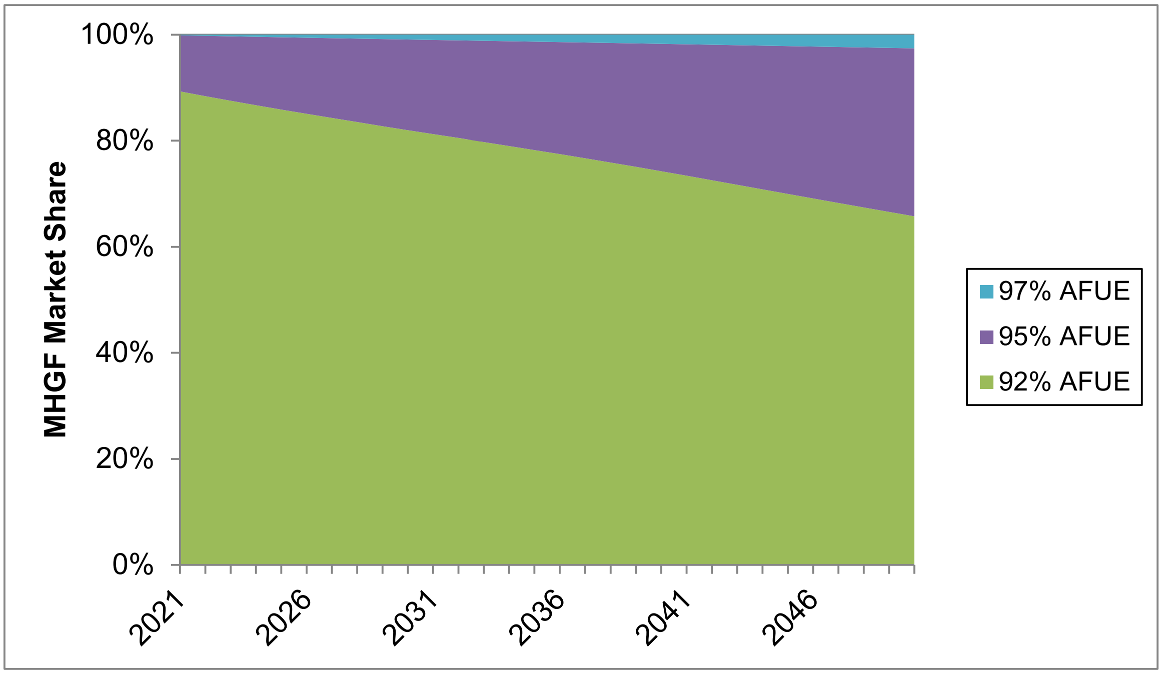

Figure 10.4.11 **Projection of Standards Case Efficiency (TSL 3) Distribution for Mobile Home Gas Furnaces AFUE Standards, 2021-2050**

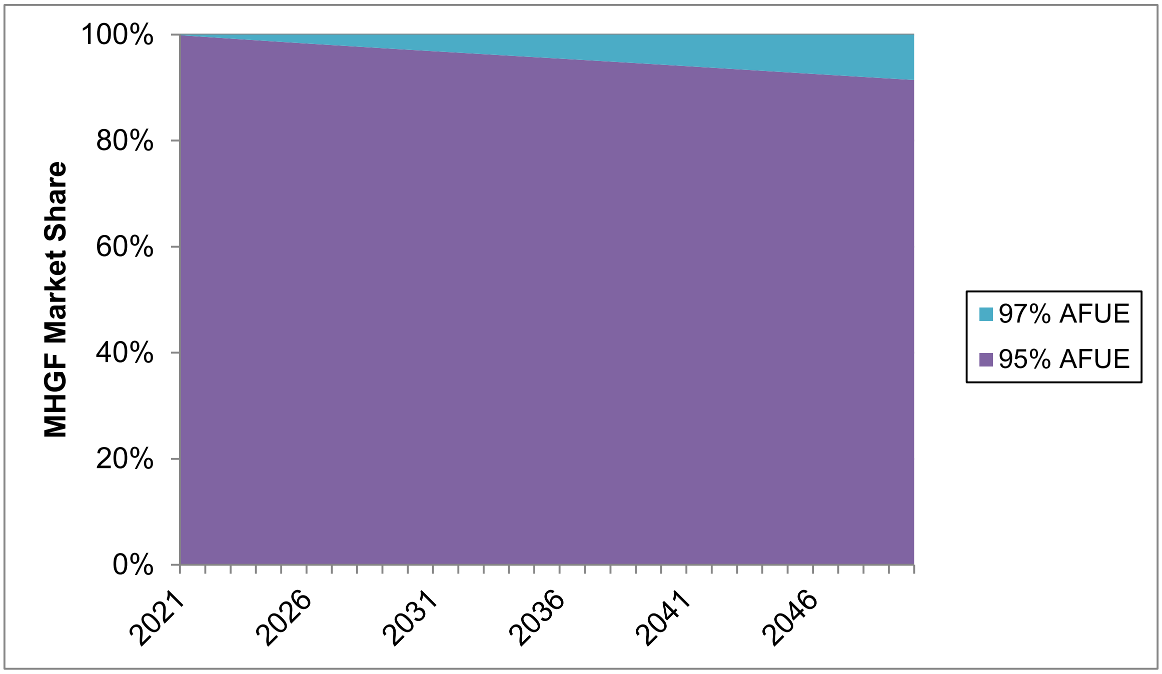

Figure 10.4.12 Projection of Standards Case Efficiency (TSL 4) Distribution for Mobile Home Gas Furnaces AFUE Standards, 2021-2050

10.5 NATIONAL ENERGY SAVINGS

The inputs for calculating national energy savings are:

- average annual energy consumption per unit (*UEC*),
- shipments,
- product stock ($STOCK_V$),
- annual energy consumption for the Nation (*AEC*), and
- power plant primary energy use factor (*src_conv*).

The accounting of national energy savings includes the energy use of the electric heating systems that some consumers switch to under those TSLs that would require a condensing furnace.

10.5.1 Annual Energy Consumption per Unit

For each product class, DOE presented the per-unit annual energy consumption as a function of product efficiency in chapter 7, Energy Use Analysis. Because the per-unit annual energy consumption is directly dependent on efficiency, DOE used the shipments-weighted energy efficiency of the base 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 base and standards cases.

Table 10.5.1 presents the base case and standards case shipment-weighted annual UECs for NWGFs and MHGFs in 2021. For NWGFs, the values are a weighted average of residential and commercial furnace users. The table shows the energy use of NWGFs and MHGFs associated with higher efficiencies. The values after 2021 change according to the projected efficiency trends in each case.

Table 10.5.1 Average Annual Furnace Energy Use for the Base and Standards Cases in 2021 for AFUE Standard

Product Class	Base Case	TSLs				
		1	2	3	4	5
Non-Weatherized Gas Furnaces						
Average Annual Fuel Use (MMBtu/yr)	38.8	37.6	37.0	36.9	36.3	35.3
Average Annual Elec Use (kWh/yr)	319.8	317.3	311.7	317.0	306.4	335.3
Mobile Home Gas Furnace						
Average Annual Fuel Use (MMBtu/yr)	29.4	27.9	27.5	26.5	25.9	25.4
Average Annual Elec Use (kWh/yr)	233.6	233.9	227.3	229.5	223.9	245.5

Table 10.5.2 Average Annual Electricity Use for the Base and Standards Cases in 2021 for Standby and Off-Mode Standard

Product Class	Base Case	Trial Standard Levels		
		1	2	3
	kWh/year			
Non-Weatherized Gas Furnaces	75.0	68.3	66.9	62.9
Mobile Home Gas Furnaces	67.1	66.7	66.6	66.4

The results in Table 10.5.1 are not adjusted for the impact of the rebound effect discussed in chapter 8. For the NIA, DOE applied a rebound effect parameter that reduces the estimated national energy savings.

In previous rulemakings, DOE used a 20-percent rebound effect based on estimates for residential space heating in a 2009 study by Sorrell and Sommerville that examined empirical estimates of the rebound effect for various energy-using products.[1] For this NOPR, DOE examined two publications that argue that the estimates given by Sorrell and Sommerville, as well as similar estimates by Greening et al.,[2] are too high. Nadel[3] examined the underlying studies and concluded that a more likely range is 1 to 12 percent, with effects sometimes higher than this range for low-income households who could not afford to adequately heat their homes prior to weatherization. Thomas and Azevedo[4] also reviewed the methodology of the studies considered by previous researchers. They point out that some of the studies cited by previous researchers measure energy price elasticities as proxy for the direct rebound effect, and contend that energy price elasticities are an overestimate of the direct rebound effect because of the correlation between rising energy prices and investments in energy efficiency. Their preferred measures of the direct rebound effect include efficiency elasticities, energy service price elasticities, and energy price elasticities in studies that control for self-selection of efficient appliance purchase. These approaches all require data and variation in appliance energy efficiency rather than merely variation in prices to identify the rebound effect. For space heating, the studies that they select estimated a direct rebound effect ranging from 1−3 percent to 10−15 percent (from Table 1 in Thomas and Azevedo).

DOE believes that the recent re-examinations of the literature are relevant to the rebound effect for NWGFs and MHGFs. For the NOPR, DOE applied a rebound effect of 15 percent. Although a lower value might be warranted, DOE prefers to be conservative and not risk understating the rebound effect. A rebound effect of 15 percent means that 15 percent of the estimated energy savings do not materialize because of increased use of the product.

DOE also considered the effects of changes in climate and building shell efficiency on NWGF and MHGF energy use. The climate adjustment factor, which is based on the forecast of heating degree days (HDD) by region from *Annual Energy Outlook 2014* (*AEO 2014*),[5] shows a declining trend due to warmer weather. Residential regional building shell efficiency factors are also from *AEO 2014*, while commercial regional building shell efficiency factors are from *AEO 2013.* For both factors, DOE applied regional weights to make the factors specific to residential users of NWGFs and MHGFs and commercial users of NWGFs. Due to these adjustment factors, the energy-use-weighted energy use decreases by 16 percent from 2021 to 2050.

DOE also accounted for the energy use of the heat pumps, electric furnaces, and electric water heaters that some consumers switch to in the standards cases. For heat pumps, DOE used the efficiency of models that meet the energy conservation standards due to take effect on January 1, 2015, and for water heaters, it used efficiency and consumer prices for models that meet the standards due to take effect on April 16, 2015. For electric furnaces, DOE used an efficiency of 98 percent. The UECs were calculated for the specific RECS households that are projected to switch, as described in appendix 8J.

For households that switch, the annual gas use decreases relative to the base case with a gas furnace, and the annual electricity use increases. Table 10.5.3 shows the fraction of total shipments impacted by product switching and the differential in average annual fuel and electricity use compared to the base case.

Table 10.5.3 Fraction of Total Shipments Impacted by Product Switching and Differential in Average Annual Fuel and Electricity Use for NWGFs

Switching Option	TSLs				
	1	2	3	4	5
Fraction of Total Shipments Impacted					
NWGF (non-cond, not switching)	97.9%	97.6%	90.3%	88.1%	84.1%
80% NWGF to EF	0.6%	0.6%	2.6%	2.9%	3.4%
80% NWGF to HP	1.5%	1.8%	7.1%	9.0%	12.5%
GSWH to ESWH	0.6%	0.6%	1.9%	2.2%	2.7%
Average Annual Fuel Use Differential (MMBtu/yr)					
NWGF (non-cond, not switching)	0.2	0.2	1.1	1.3	1.6
80% NWGF to EF	-32.7	-30.7	-17.5	-18.0	-17.2
80% NWGF to HP	-30.8	-30.0	-21.5	-21.4	-21.0
GSWH to ESWH	-17.4	-19.2	-13.8	-14.9	-17.1
Average Annual Electricity Use Differential (kWh/yr)					
NWGF (non-cond, not switching)	8934	8861	4867	5171	5097
80% NWGF to EF	4846	4937	3035	3063	2988
80% NWGF to HP	2837	3074	2404	2590	2971
GSWH to ESWH	8934	8861	4867	5171	5097

10.5.2 Shipments

DOE projected shipments for each product class under the base case and all standards cases (see chapter 9). Several factors impact projected shipments, including total installed costs, operating cost, household income, and product lifetime. As noted earlier, the increased total installed cost of more efficient products causes some customers to forego product purchases. Consequently, shipments projected under the standards cases are lower than under the base case. DOE believes it would be inappropriate to count energy savings that result from reduced shipments due to standards. Therefore, DOE did not calculate annual energy consumption for the base case using the base case shipments projection. Instead, for each comparison of a standards case with the base case, DOE used shipments associated with that particular standards case. As a result, all of the calculated energy savings are due to higher energy efficiency in the standards case.

10.5.3 Product Stock

The stock of product in any given year depends on annual shipments and the lifetime of a given product 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 products 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 appendix 8G for further details on the survival functions that DOE used in its analysis.

10.5.4 Annual Energy Consumption

For each product class, DOE calculated the total national site (*i.e.*, the energy consumed at the household or establishment) annual energy consumption (AEC). Annual energy consumption is the product of the AEC per unit (also termed the unit energy consumption (UEC)) and the number of units of each vintage. This method accounts for differences in UEC from year to year.

10.5.5 Site-to-Power Plant Energy Use Factor

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 derived annual average site-to-power plant factors based on the version of the National Energy Modeling System (NEMS) that corresponds to *AEO 2014*. 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 2021 to 2040. For years after 2040 (the last year in the AEO), DOE maintained the 2040 value.

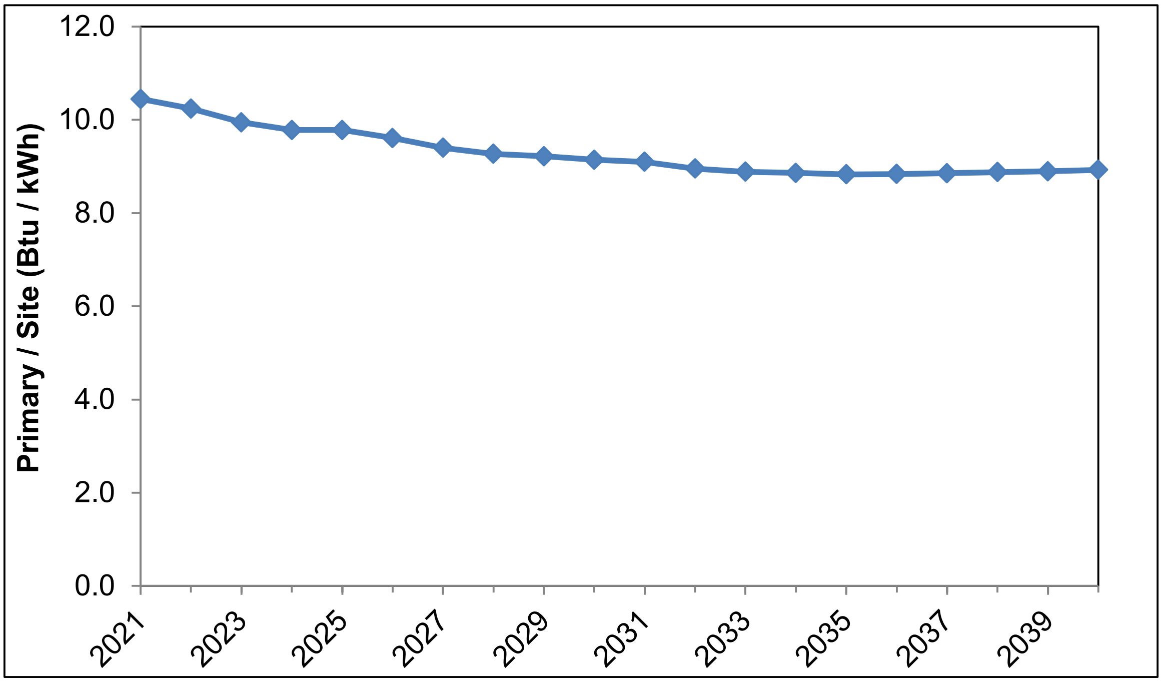

Figure 10.5.1 Primary to Site Energy Use Factor for Non-Weatherized Gas Furnace and Mobile Home Gas Furnace Electricity Use, 2021-2040

10.5.6 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 we refer to as "upstream" activities, DOE developed multipliers using the data and projections generated by the National Energy Modeling System (NEMS) used for *AEO 2014*. 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 10.5.4 shows the upstream energy multipliers used for NWGFs and MHGFs for selected years. The multipliers are applied to site energy. For years after 2040 (the last year in the AEO), DOE maintained the 2040 value.

Table 10.5.4 Full Fuel Cycle Energy Multipliers (Based on AEO 2014)

	2021	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Electricity	1.044	1.045	1.046	1.047	1.047	1.047	1.047
Natural Gas	1.110	1.111	1.113	1.114	1.114	1.114	1.114

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,
- product 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 base case and standards case) multiplied by the shipments projected for each TSL. As with calculating energy savings, DOE did not use base-case shipments to calculate total annual installed costs for all of the product classes. DOE used 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 base case and standards case) per unit multiplied by the shipments projected for each candidate standard level. As with calculating total annual installed costs, DOE used standards-case shipments to calculate savings in operating cost.

The accounting of NPV includes the installed cost and the operating cost savings of the electric heating systems that some consumers switch to under those TSLs that would require a condensing furnace.

10.6.1 Total Installed Cost per Unit

DOE described the total per-unit installed cost for each product class as a function of product efficiency in chapter 8, Life-Cycle Cost and Payback Period Analysis. Because the total per-unit annual installed cost depends directly on efficiency, DOE used the shipments-weighted efficiencies for the base 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 base and standards cases. Table 10.6.1 shows the average installed cost of NWGFs and MHGFs in 2021 for the base and standards cases.

For the LCC and PBP analysis, DOE developed a default price trend with learning rate of 20 percent to project future product prices of NWGFs and MHGFs in 2021, meaning that the price is expected to drop 20 percent with each doubling of cumulative furnace shipments. This learning rate was also used as the default value to project prices through 2050 for the NIA. To investigate the impact of different product price projections on the consumer net present value (NPV) for different efficiency levels, DOE also considered two alternative price trends. Details on how these alternative price trends were developed are in appendix 10C, which also presents the results of the sensitivity analysis.

Table 10.6.1 Average Total Installed Cost of Non-Weatherized Gas Furnaces and Mobile Home Gas Furnaces in 2021 for the Base and Standards Cases for AFUE Standard

Product Class	Base Case	Trial Standard Levels				
		1	2	3	4	5
	2013$					
Non-Weatherized Gas Furnaces	2,454	2,551	2,592	2,730	2,837	3,040
Mobile Home Gas Furnaces	1,582	1,622	1,675	1,739	1,868	1,983

Table 10.6.2 Average Total Installed Cost of Non-Weatherized Gas Furnaces and Mobile Home Gas Furnaces in 2021 for the Base and Standards Cases for Standby and Off-Mode Standard

Product Class	Base Case	Trial Standard Levels		
		1	2	3
	2013$			
Non-Weatherized Gas Furnaces	7.0	8.1	17.3	18.3
Mobile Home Gas Furnaces	16.4	16.4	16.9	17.0

DOE also accounted for the installed cost of the heat pumps, electric furnaces, and electric water heaters that some consumers switch to in the standards cases. For heat pumps, DOE used consumer prices for models that meet the energy conservation standards due to take effect on January 1, 2015, and for water heaters, it used consumer prices for models that meet the standards due to take effect on April 16, 2015. For electric furnaces, DOE used an efficiency of 98 percent and a consumer price based on RS Means.[b] For situations where a household with a gas furnace might switch to electric space heating, DOE used the installed cost of the electric heating options, including a separate circuit up to 100 amps that would need to be installed to power the electric resistance heater within an electric furnace or heat pump, as well as a cost for upgrading the electrical service panel for a fraction of households. For all installations, DOE used regional labor rates from RS Means.[c]

Table 10.6.3 shows the differential in total installed cost compared to the base case. For the fraction of total shipments impacted by product switching, see Table 10.5.3.

Table 10.6.3 Differential in Total Installed Cost for NWGFs Due to Product Switching

Switching Option	TSLs				
	1	2	3	4	5
	2013$				
NWGF (non-cond, not switching)	-2.0	-1.8	-25.2	-25.6	-23.7
80% NWGF to EF	-384	-518	-446	-563	-718
80% NWGF to HP	-637	-702	-472	-505	-572
GSWH to ESWH	328	371	106	134	174

As it did for furnaces, DOE estimated a price trend for the electric heating and water heating equipment. See chapter 8 for discussion.

10.6.2 Annual Operating Cost per Unit

The per-unit annual operating cost includes costs for energy, repair, and maintenance. DOE determined the per-unit annual savings in energy costs by multiplying the per-unit annual savings in energy consumption developed for both product classes by the appropriate energy price. For NWGFs, DOE considered operating costs separately for residential and commercial users.

Estimates of the per-unit annual energy consumption for the base case and each standards case were presented in section 10.5.1. DOE projected the per-unit annual energy consumption for the base case for all product classes by applying a growth trend in efficiency.

Energy prices and trends in energy prices are described in chapter 8. DOE projected energy prices based on annual changes in average residential and commercial energy prices in EIA's *AEO 2014* reference case scenario.

DOE described the total per-unit repair and maintenance costs for each product class as a function of product efficiency in chapter 8. Because the per-unit repair and maintenance costs

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[b] RS Means Company Inc., RS Means Facilities Maintenance & Repair Cost Data (2013).

[c] RS Means Company Inc., RS Means Residential Cost Data. Kingston, MA (2013).

depend directly on efficiency, DOE used the efficiencies for the base 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 base and standards cases.

Table 10.6.4 shows the average operating cost of NWGFs and MHGFs in 2021 for the base and standards cases. The operating costs change over time, depending on change in annual energy use and energy prices as well as repair and maintenance costs.

Table 10.6.4 Average Annual Operating Cost of Non-Weatherized Gas Furnaces and Mobile Home Gas Furnaces in 2021 for the Base and Standards Cases for AFUE Standard

Product Class	Base Case	Trial Standard Levels				
		1	2	3	4	5
	2013$					
Non-Weatherized Gas Furnaces	550	529	522	525	517	510
Mobile Home Gas Furnaces	348	337	333	321	314	312

Table 10.6.5 Average Annual Operating Cost of Non-Weatherized Gas Furnaces and Mobile Home Gas Furnaces in 2021 for the Base and Standards Cases for Standby and Off-Mode Standard

Product Class	Base Case	Trial Standard Levels		
		1	2	3
	2013$			
Non-Weatherized Gas Furnaces	8.67	7.89	7.73	7.27
Mobile Home Gas Furnaces	7.75	7.71	7.70	7.67

DOE also accounted for the annual operating cost of the heat pumps, electric furnaces, and electric water heaters that some consumers switch to in the standards cases. This cost was calculated using the UECs discussed in section 10.4 and the appropriate energy prices.

Table 10.6.6 shows the differential in operating cost compared to the base case. For the fraction of total shipments impacted by product switching, see Table 10.5.3.

Table 10.6.6 Differential in Operating Cost for NWGFs Due to Product Switching

Switching Option	TSLs				
	1	2	3	4	5
	2013$				
NWGF (non-cond, not switching)	0.6	0.6	13.4	14.8	18.7
80% NWGF to EF	-12.7	26.7	128.8	147.0	183.5
80% NWGF to HP	24.2	47.0	76.8	80.6	80.0
GSWH to ESWH	-8.9	-12.5	43.6	45.3	28.9

10.6.3 Product Stock

The stock of product in any given year depends on annual shipments and the lifetime of a given product 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 products 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 the specific section for each product class in appendix 8G for further details on the survival functions that DOE used in its analysis.

10.6.4 Increases in Total Annual Installed Cost

The increase in total annual installed cost for a product 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 candidate standards level 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 discussed, DOE applied a rebound effect to adjust its estimates of energy savings. The take-back in energy consumption associated with the rebound effect provides consumers with increased value (*e.g.*, enhanced comfort associated with use of constant circulation). DOE believes that, if it were able to monetize the increased value to consumers of the rebound effect, this value would be similar in value to the foregone energy savings. Therefore, the economic impacts on consumers with or without the rebound effect are the same, so DOE does not adjust operating cost savings in the NIA.

10.6.6 Discount Factor

DOE multiplied monetary values in future years by a discount factor to determine the present value. The discount factor (DF) is described by the equation:

$$DF = \frac{1}{(1+r)^{(y-y_P)}}$$

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.

DOE estimated NPV using both a 3-percent and a 7-percent real discount rate, in accordance with the Office of Management and Budget's guidance to Federal agencies on the development of regulatory analysis, particularly section E therein: Identifying and Measuring Benefits and Costs.[6] DOE defined the present year as 2014.

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 base 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, 2021, through 2050). DOE calculated annual increases in installed cost as the difference in total installed cost for new products purchased each year, multiplied by the shipments in the standards case.

The present value of annual savings in operating cost is the difference between the base case and each standards case discounted to the present and summed throughout the period from the compliance date, 2021, to the time when the last unit installed in 2021-2050 is retired from service.

Savings represent decreases in operating cost (including energy, repair, and maintenance) associated with the more energy efficient product purchased in each standards case compared to the base 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 RESULTS

This section presents the NES and NPV results for the considered TSLs for NWGFs and MHGFs. The results include the impacts of the fuel switching estimated to occur under each standards case. The amount of switching for each TSL is described in chapter 9.

10.7.1 National Energy Savings

This section provides the national energy savings that DOE calculated for each of the TSLs analyzed for NWGFs and MHGFs. See Table 10.7.1 for primary energy savings and Table 10.7.2 for FFC energy savings; in the case of standby and off mode results, see Table 10.7.3 for primary energy savings and Table 10.7.4 for FFC energy savings. DOE based 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. The energy savings reflect application of a rebound effect.

Table 10.7.1 National Energy Savings (Primary) for Non-Weatherized Gas Furnaces and Mobile Home Gas Furnaces

Product Class	Trial Standard Levels				
	1	2	3	4	5
	quads				
Non-Weatherized Gas Furnaces	1.004	1.756	2.124	3.263	4.364
Mobile Home Gas Furnaces	0.062	0.066	0.127	0.131	0.142
Total	**1.066**	**1.821**	**2.251**	**3.394**	**4.507**

Table 10.7.2 National Energy Savings (Full-Fuel-Cycle) for Non-Weatherized Gas Furnaces and Mobile Home Gas Furnaces

Product Class	Trial Standard Levels				
	1	2	3	4	5
	quads				
Non-Weatherized Gas Furnaces	1.222	2.054	2.638	3.963	5.322
Mobile Home Gas Furnaces	0.069	0.073	0.141	0.146	0.159
Total	**1.291**	**2.126**	**2.780**	**4.110**	**5.481**

Table 10.7.3 National Energy Savings (Primary) for Non-Weatherized Gas Furnaces and Mobile Home Gas Furnaces - Standby and Off Mode

Product Class	Trial Standard Levels		
	1	2	3
	quads		
Non-Weatherized Gas Furnaces	0.147	0.176	0.264
Mobile Home Gas Furnaces	0.0002	0.0002	0.0003
Total	**0.147**	**0.176**	**0.264**

Table 10.7.4 National Energy Savings (Full-Fuel-Cycle) for Non-Weatherized Gas Furnaces and Mobile Home Gas Furnaces - Standby and Off Mode

Product Class	Trial Standard Levels		
	1	2	3
	quads		
Non-Weatherized Gas Furnaces	0.154	0.184	0.276
Mobile Home Gas Furnaces	0.0002	0.0002	0.0003
Total	**0.154**	**0.185**	**0.277**

10.7.2 Net Present Value of Consumer Benefit

This section provides results of calculating the NPV for each candidate standard level considered for NWGFs and MHGFs. 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 and Table 10.7.6 for 7-percent discount rate, as well as, for standby results Table 10.7.7

for 3-percent discount rate and Table 10.7.8 for 7-percent discount rate. DOE based the inputs to the NIA model on weighted-average values, yielding results that are discrete point values, rather than a distribution of values 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 efficiency level exceed the savings.

Table 10.7.5 Net Present Value (NPV) of Consumer Benefit for Non-Weatherized Gas Furnaces and Mobile Home Gas Furnaces, Discounted at 3 Percent

Product Class	**Trial Standard Level**				
	1	**2**	**3**	**4**	**5**
	billion 2013$				
Non-Weatherized Gas Furnaces	8.1	13.5	15.1	20.4	24.1
Mobile Home Gas Furnaces	0.6	0.7	1.0	1.1	1.2
Total	**8.6**	**14.1**	**16.1**	**21.5**	**25.3**

Table 10.7.6 Net Present Value (NPV) of Consumer Benefit for Non-Weatherized Gas Furnaces and Mobile Home Gas Furnaces, Discounted at 7 Percent

Product Class	**Trial Standard Level**				
	1	**2**	**3**	**4**	**5**
	billion 2013$				
Non-Weatherized Gas Furnaces	1.9	3.3	2.8	3.7	3.3
Mobile Home Gas Furnaces	0.2	0.2	0.3	0.3	0.3
Total	**2.1**	**3.6**	**3.1**	**4.0**	**3.7**

Table 10.7.7 Net Present Value (NPV) of Consumer Benefit for Non-Weatherized Gas Furnaces and Mobile Home Gas Furnaces, Discounted at 3 Percent - Standby and Off Mode

Product Class	**Trial Standard Level**		
	1	**2**	**3**
	billion 2013$		
Non-Weatherized Gas Furnaces	2.1	2.0	3.3
Mobile Home Gas Furnaces	0.002	0.002	0.003
Total	**2.1**	**2.0**	**3.3**

Table 10.7.8 Net Present Value (NPV) of Consumer Benefit for Non-Weatherized Gas Furnaces and Mobile Home Gas Furnaces, Discounted at 7 Percent - Standby and Off Mode

Product Class	**Trial Standard Level**		
	1	**2**	**3**
Non-Weatherized Gas Furnaces	0.7	0.6	1.0
Mobile Home Gas Furnaces	0.001	0.001	0.001
Total	**0.7**	**0.6**	**1.0**

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5. U.S. Department of Energy-Energy Information Administration, *Annual Energy Outlook 2014 with Projections to 2040*, 2014. Washington, DC. <www.eia.gov/forecasts/aeo/>

6. U.S. Office of Management and Budget (OMB), *Circular A-4: Regulatory Analysis,* 2003. (Posted September 17, 2003) (Last accessed April, 2013.) <www.whitehouse.gov/sites/default/files/omb/assets/regulatory_matters_pdf/a-4.pdf>

APPENDIX 10A. USER INSTRUCTIONS FOR NATIONAL IMPACT ANALYSIS SPREADSHEET MODEL

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10A.1 USER INSTRUCTIONS

The results obtained in this analysis can be examined and reproduced using the Microsoft Excel® spreadsheets accessible on the Internet from the Department of Energy's (DOE's) residential boiler rulemaking page: www1.eere.energy.gov/buildings/appliance_standards/product.aspx/productid/72. From that page, follow the links to the NOPR phase of the rulemaking and then to the analytical tools.

10A.2 STARTUP

The NIA spreadsheets enable the user to perform a National Impact Analysis (NIA) for residential boilers. To utilize the spreadsheet, the Department assumes that the user has access to a PC with a hardware configuration capable of running Windows 2003 or later. To use the NIA spreadsheets, the user requires Microsoft Excel® 2003 or later installed under the Windows operating system.

10A.3 DESCRIPTION OF NATIONAL IMPACT ANALYSIS 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 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 base case can then be compared and the overall energy savings and net present values determined. The NIA spreadsheets consist of the following worksheets:

Introduction	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, product cost and energy use in 2021 for each product class.
Summary by TSL	Contains site energy savings results and net present values at the given TSL, application sector, and region.
NWGF	Contains non-weatherized gas furnace NIA calculations.
MHGF	Contains mobile home gas furnace NIA calculations.
LCC Output	Contains energy use, electricity use, total installed price, annual repair, maintenance costs, energy price, electricity price, price trends, and savings by the standby mode for each product class.
Energy Prices	Contains energy prices for each product class by year.
Price Trend	Includes the learning multipliers to adjust the manufacturer's cost over the entire analysis period.

Price Elasticity	The price elasticity is defined as the change in the percentage of consumers acquiring a furnace relative to the change in the price of the furnace.
Energy Use Trend	Contains look-up tables to adjust for the climate conditions and building shell characteristics during the analysis period.
Base Case Eff. Distr. Trend	Contains look-up table presenting the market share for residential furnaces during the analysis period.
Switching Trend	Contains the fractions of NWGF that will be switched to other products at each standard level. Also contains energy use and product cost differentials between NWGF and other space heating products, energy use and product cost differentials between water heating products, and energy use and product cost differentials between cooling products.
Shipments	Contains historical shipment and the annual shipment forecast results for plotting.
Historical Shipments	Includes historical shipments data for each product class.
AEO Housing Forecast	Includes Annual Energy Outlook (AEO) forecasts of housing stocks and housing starts for both residential and commercial buildings.
New Saturation	Contains market saturation data for each product class in new homes.
Lifetime	Includes the lifetime and the retirement function for each product class.
Labels	Contains labels and definitions used throughout the spreadsheet – Also, worksheet where the ELs used in the analysis are defined
Supplementary Worksheets	Worksheets used for generating outputs for documentation and downstream analysis.

10A.4 BASIC INSTRUCTIONS FOR OPERATING THE NATIONAL IMPACT ANALYSIS SPREADSHEETS

Basic instructions for operating the NIA spreadsheets are as follows:

1. Once the NIA spreadsheet file has been downloaded from the Department’s web site, open the file using MS Excel. Click “Enable Macro” when prompted and then click on the tab for the worksheet User Inputs.

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.

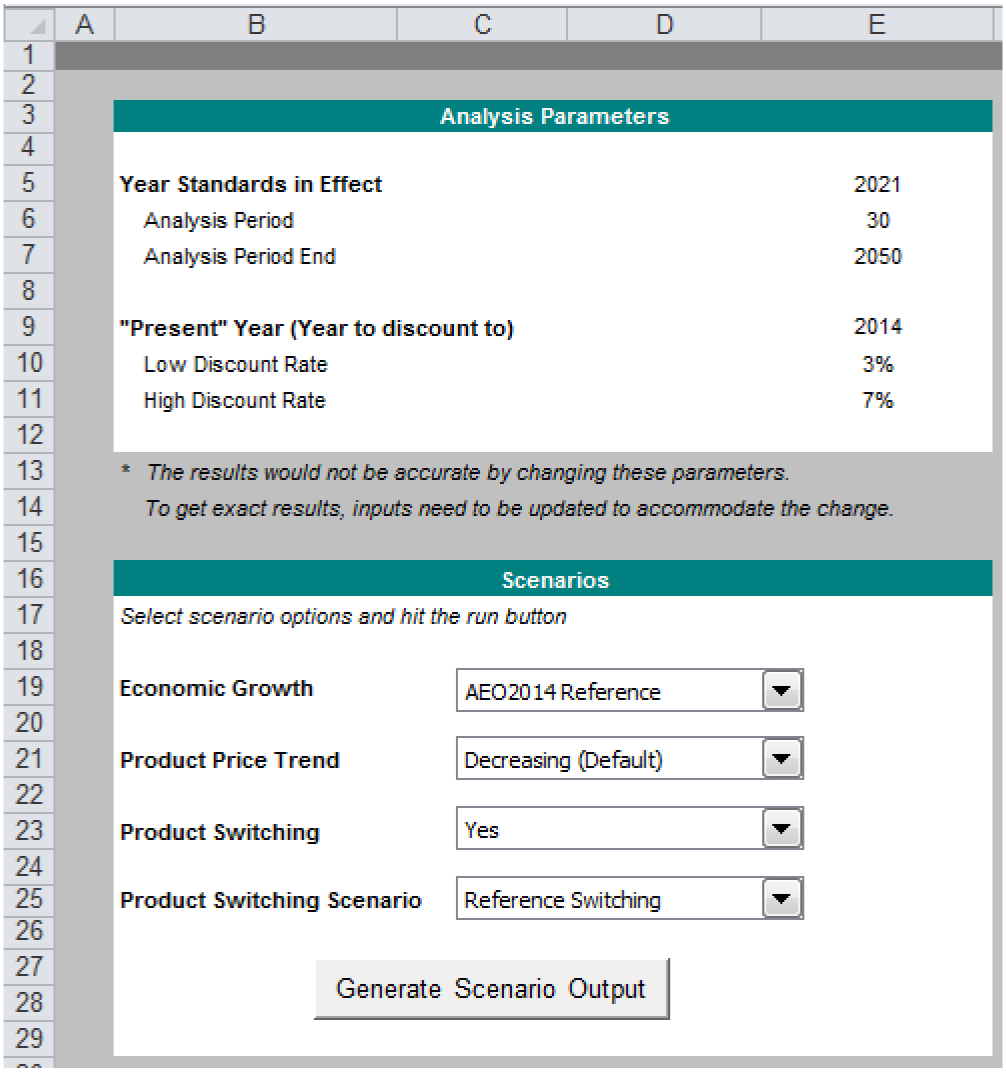
3. The analysis parameters are shown in the sheet “NIA Summary”. The default parameters (shown in Figure 10A.4.1) are:

    a. Year Standards in Effect: Set to 2021.

    b. Analysis period: Set to 30.

c. Discount Rates: Set to 3% (low) and 7% (high).

d. Discount Year: Set to 2014.



Analysis Parameters

Year Standards in Effect	2021
Analysis Period	30
Analysis Period End	2050
"Present" Year (Year to discount to)	2014
Low Discount Rate	3%
High Discount Rate	7%

* *The results would not be accurate by changing these parameters.*
To get exact results, inputs need to be updated to accommodate the change.

Scenarios

Select scenario options and hit the run button

Economic Growth	AEO2014 Reference
Product Price Trend	Decreasing (Default)
Product Switching	Yes
Product Switching Scenario	Reference Switching

Figure 10A.4.1 Default User Input Parameters

4. The user can change the "Scenarios" parameters:

   a. Economic Growth Scenario: Set to "AEO2014 Reference". To change value, click on the pull down menu next to cell B19 "Economic Growth Scenario" and change to desired scenario.

   b. Product Price Trend Scenario: Set to "Default". To change value, click on the pull down menu next to cell B21 "Product Price Trend" and change to desired scenario.

c. Product Switching: Set to “Yes”. To change value, click on the pull down menu next to cell B25 “Product switching” and change to desired scenario.

d. Product Switching Scenario: Set to “Reference Switching”. To change value, click on the pull down menu next to cell B25 “Product Switching Scenario” and change to desired scenario.

5. The button “Generate Scenario Output” updates the analysis results based on user inputs: National Energy Savings and Net Present Values by trial standard level (TSL), in cells H5 to T15; Rest of Country (South) Energy Savings and Net Present Values by TSL, in cells H20 to T29; North Energy Savings and Net Present Values by TSL, in cells H35 to T44; National Energy Savings and Net Present Values by standby and off mode TSL, in cells X5 to AD15; Rest of Country (South) Energy Savings and Net Present Values by standby and off mode TSL, in cells X20 to AD30; South Energy Savings and Net Present Values by standby and off mode TSL, in cells X35 to AD45; and intermediate results, in cells AG5 to AS72 .

6. The user can view the results by TSL, application sector and region in the sheet “Summary by TSL” (shown in Figure 10A.4.2).[a]

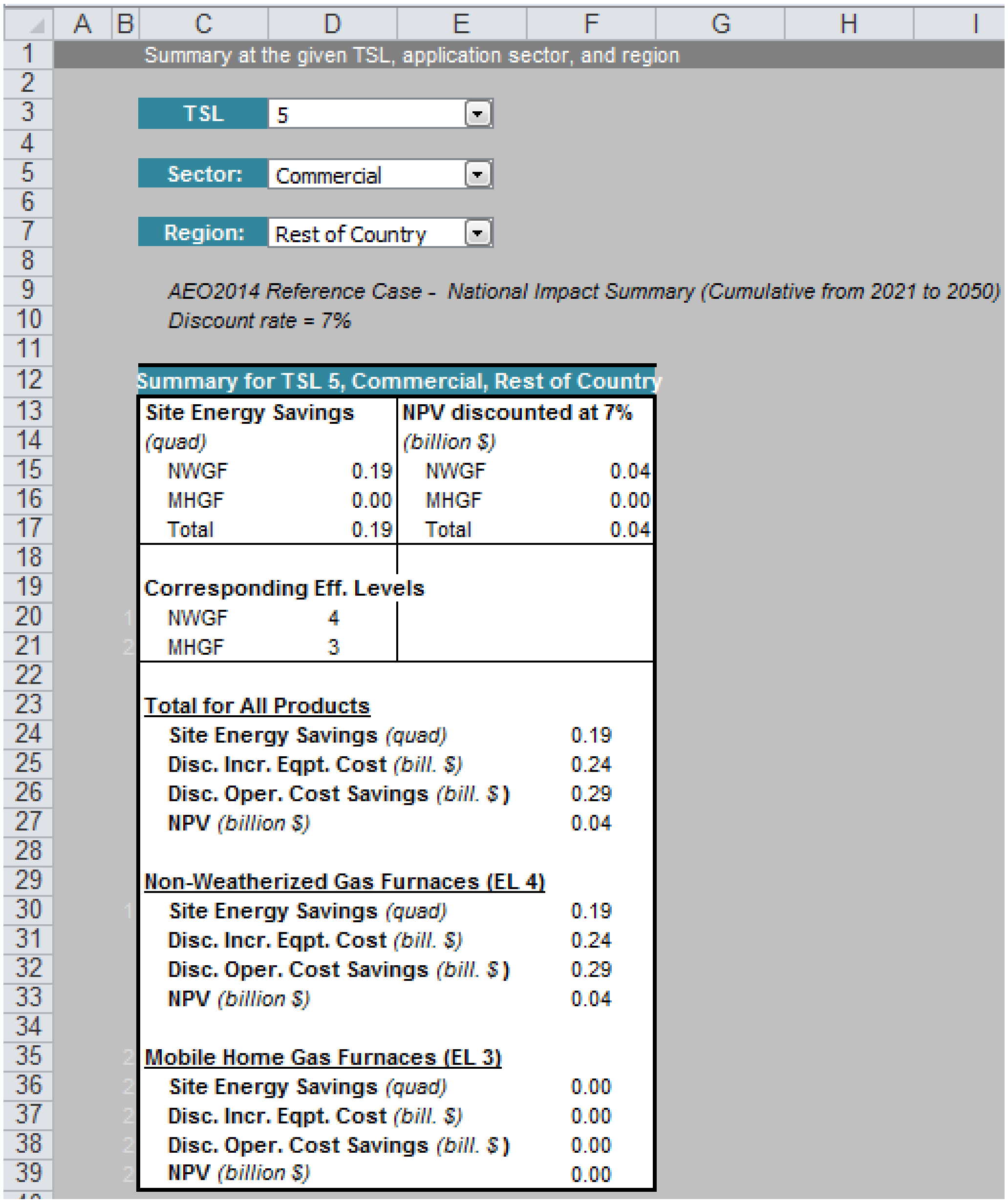
   a) TSL: initially set to “5”. To change, click on the drop down menu next to cell C3 “TSL” and change to desired TSL. You can see the TSL to efficiency level and TSL to AFUE mapping in cells C42 to H75 (see Figure 10A.4.3). The selected TSL is highlighted in orange.

   b) Application sector: initially set to “Commercial”. To change, click on the drop down menu next to cell C5 “Sector” and change to desired application sector.

   c) Region: initially set to “Rest of Country”. To change, click on the drop down menu next to cell C7 “Region” and change to desired region.

---

[a] Note that changing the parameters here will update the annual shipment, unit energy use, product cost of residential furnaces at base case and higher efficiency levels under the selected application sector and region in the accounting worksheets named by product classes, namely “NWGF” and “MHGF”.



Summary at the given TSL, application sector, and region

TSL 5

Sector: Commercial

Region: Rest of Country

AEO2014 Reference Case - National Impact Summary (Cumulative from 2021 to 2050)

Discount rate = 7%

Summary for TSL 5, Commercial, Rest of Country

Site Energy Savings *(quad)*		**NPV discounted at 7%** *(billion $)*	
NWGF	0.19	NWGF	0.04
MHGF	0.00	MHGF	0.00
Total	0.19	Total	0.04

Corresponding Eff. Levels

NWGF	4
MHGF	3

Total for All Products

Site Energy Savings *(quad)*	0.19
Disc. Incr. Eqpt. Cost *(bill. $)*	0.24
Disc. Oper. Cost Savings *(bill. $)*	0.29
NPV *(billion $)*	0.04

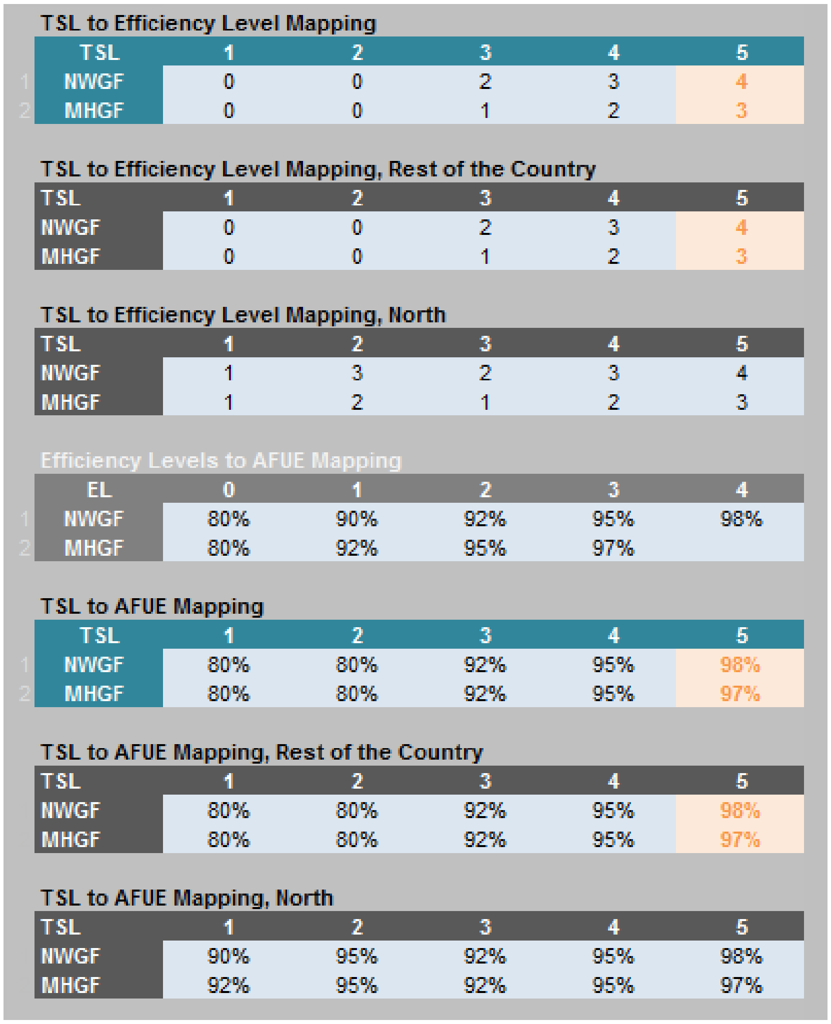
Non-Weatherized Gas Furnaces (EL 4)

Site Energy Savings *(quad)*	0.19
Disc. Incr. Eqpt. Cost *(bill. $)*	0.24
Disc. Oper. Cost Savings *(bill. $)*	0.29
NPV *(billion $)*	0.04

Mobile Home Gas Furnaces (EL 3)

Site Energy Savings *(quad)*	0.00
Disc. Incr. Eqpt. Cost *(bill. $)*	0.00
Disc. Oper. Cost Savings *(bill. $)*	0.00
NPV *(billion $)*	0.00

Figure 10A.4.2 Default User Input Parameters (Summary by TSL)



TSL to Efficiency Level Mapping

TSL	1	2	3	4	5
NWGF	0	0	2	3	4
MHGF	0	0	1	2	3

TSL to Efficiency Level Mapping, Rest of the Country

TSL	1	2	3	4	5
NWGF	0	0	2	3	4
MHGF	0	0	1	2	3

TSL to Efficiency Level Mapping, North

TSL	1	2	3	4	5
NWGF	1	3	2	3	4
MHGF	1	2	1	2	3

Efficiency Levels to AFUE Mapping

EL	0	1	2	3	4
NWGF	80%	90%	92%	95%	98%
MHGF	80%	92%	95%	97%	

TSL to AFUE Mapping

TSL	1	2	3	4	5
NWGF	80%	80%	92%	95%	98%
MHGF	80%	80%	92%	95%	97%

TSL to AFUE Mapping, Rest of the Country

TSL	1	2	3	4	5
NWGF	80%	80%	92%	95%	98%
MHGF	80%	80%	92%	95%	97%

TSL to AFUE Mapping, North

TSL	1	2	3	4	5
NWGF	90%	95%	92%	95%	98%
MHGF	92%	95%	92%	95%	97%

Figure 10A.4.3 TSL Mapping Tables in Summary by TSL Worksheet

Note: Make sure that the spreadsheet is in automatic calculation mode. The calculation mode can be changed by (shown in Figure 10A.4.4):

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".

The results are automatically updated and are reported in the source energy savings matrix, net present value matrix, and summary table for each product class.

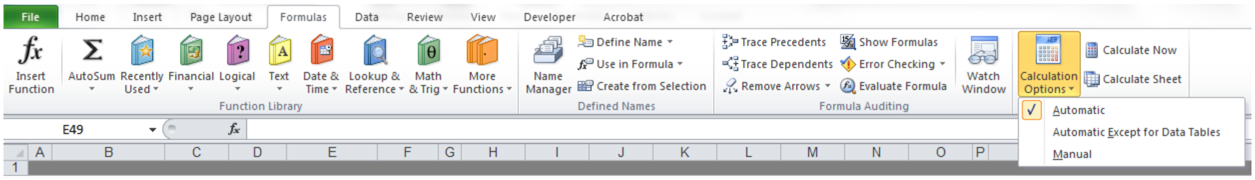


Figure 10A.4.4 Automatic Calculation Mode

APPENDIX 10B. FULL-FUEL-CYCLE MULTIPLIERS

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APPENDIX 10B. FULL-FUEL-CYCLE MULTIPLIERS

10B.1 INTRODUCTION

This appendix summarizes the methods used to calculate full-fuel-cycle (FFC) energy savings expected to result from amended standards. The FFC measure includes point-of-use (site) energy, the energy losses associated with generation, transmission, and distribution of electricity, and the energy consumed in extracting, processing, and transporting or distributing primary fuels. DOE's traditional approach encompassed only site energy and the energy losses associated with generation, transmission, and distribution of electricity. Per DOE's 2011 *Statement of Policy for Adopting Full Fuel Cycle Analyses*, DOE now uses FFC measures of energy use and emissions in its energy conservation standards analyses.[1] This appendix summarizes the methods used to incorporate the full-fuel-cycle impacts into the analysis.

This analysis uses several different terms to reference energy use. The physical sources of energy are the primary fuels such as coal, natural gas, liquid fuels, *etc*. Primary energy is equal to the heat content (Btu) of the primary fuels used to provide an end-use service. Site energy use is defined as the energy consumed at the point-of-use in a building or industrial process. Where natural gas and petroleum fuels are consumed at the site (for example in a furnace), site energy is identical to primary energy, with both equal to the heat content of the primary fuel consumed. For electricity, site energy is measured in kWh. In this case the primary energy is equal to the quads of primary energy required to generate and deliver the site electricity. This primary energy is calculated by multiplying the site kWh times the site-to-power plant energy use factor*,* given in chapter 10. For the FFC analysis, the 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 energy at the site or power plant plus upstream energy use.

Both primary fuels and electricity are used in upstream activities. The treatment of electricity in fuel cycle analysis must distinguish between electricity generated by fossil fuels and uranium, and electricity generated from renewable fluxes (wind, solar and hydro). For the former, the upstream fuel cycle impacts are derived based on 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 is discussed in the paper *A Mathematical Analysis of Full Fuel Cycle Energy Use,*[2] and details on the fuel production chain analysis are presented in the paper *Projections of Full Fuel Cycle Energy and Emissions Metrics*.[3] The text below provides a brief summary of the methods used to calculate FFC energy.

When all energy quantities are normalized to the same units, the FFC energy use can be represented as the product of the primary energy use and an *FFC multiplier*. The FFC multiplier is defined mathematically as a function of a set of parameters representing the energy intensity and material losses at each production stage. These parameters depend only on physical data, so the calculations do not require any assumptions about prices or other economic data. While in general these parameter values may vary by geographic region, for this analysis national averages are used.

In the notation below, the indices *x* and *y* are used to indicate fuel type, with x=c for coal, x=g for natural gas, x=p for petroleum fuels, x=u for uranium and x=r for renewable fluxes. The fuel cycle parameters are:

- 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 transmission and distribution system losses.
- b_y is the amount of grid electricity used in production of fuel y, in MWh per physical unit of fuel y.
- c_{xy} is the amount of fuel x consumed in producing one unit of fuel y.
- q_x is the heat content of fuel x (MBTU/physical unit)
- z_x(s) is the emissions intensity for fuel x (mass of pollutant s per physical unit of x)

The parameters are calculated as a function of time with an annual time step; hence, a time series of annual values is used to estimate the FFC energy and emissions savings in each year of the analysis period. Fossil fuel quantities are converted to energy units using the heat content factors q_x. To convert electricity in kWh to primary energy units, on-site electricity consumption is multiplied by the power sector primary energy use factor indicated in chapter 10. The power sector primary energy use factor is defined as the ratio of the total primary energy consumption by the electric power sector (in quadrillion BTUs) divided by the total electricity generation in each year.

The FFC multiplier is a dimensionless number denoted μ (mu). The upstream component of the energy savings is proportional to (μ-1). A separate multiplier is calculated for each fuel used on site. The fuel type is denoted by a subscript on the multiplier μ. A multiplier is also calculated for electricity reflecting the fuel mix used in its generation.

For DOE’s appliance standards energy savings estimates, the FFC analysis methodology is designed to make use of data and projections published in the Annual Energy Outlook (AEO). Table 10B.2.1 provides a summary of the AEO data used as inputs to the different parameter calculations. 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[3] describes the additional data sources used to complete the analysis. However, the time dependence in the FFC multipliers arises exclusively from variables taken from the AEO. The FFC analysis for this rulemaking used data from *AEO 2014*.[4]

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 power sector energy consumption
b_c, c_{nc}, c_{pc}	coal	Coal Production by Region and Type	Production by coal 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	Crude oil domestic production
c_{nn}	natural gas	Oil and Gas Supply	US 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

10B.3 FULL-FUEL-CYCLE ENERGY MULTIPLIERS

Upstream energy multipliers are presented in Table 10B.3.1 for selected years. For years after 2040 (the last year in the AEO), DOE maintained the 2040 value. The multipliers are applied to site energy. The multiplier for electricity reflects the shares of various primary fuels in total electricity generation over the forecast period.

Table 10B.3.1 Full-Fuel-Cycle Energy Multipliers (Based on AEO 2014)

	2021	2025	2030	2035	2040	2045	2050
Electricity	1.044	1.045	1.046	1.047	1.047	1.047	1.047
Natural Gas	1.110	1.111	1.113	1.114	1.114	1.114	1.114

REFERENCES

1. United States - Office of the Federal Register, *Federal Register, Volume 76, Number 160, August 18, 2011*. UNT Digital Library. Washington D.C. .

2. Coughlin, K., A Mathematical Analysis of Full Fuel Cycle Energy Use. *Energy*, 2012. 37(1): pp. 698-708 <www.sciencedirect.com/science/article/pii/S0360544211006803>

3. Coughlin, K., *Projections of Full-Fuel-Cycle Energy and Emissions Metrics*, 2013. Lawrence Berkeley National Laboratory. Report No. LBNL-6025E.

4. U.S. Department of Energy-Energy Information Administration, *Annual Energy Outlook 2014 with Projections to 2040*, 2014. Washington, DC. <www.eia.gov/forecasts/aeo/>

APPENDIX 10C. NATIONAL NET PRESENT VALUE OF CONSUMER BENEFITS USING ALTERNATIVE PRODUCT PRICE FORECASTS

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APPENDIX 10C. NATIONAL NET PRESENT VALUE OF CONSUMER BENEFITS USING ALTERNATIVE PRODUCT PRICE FORECASTS

10C.1 INTRODUCTION

DOE investigated the impact of different product price trends on the net present value (NPV) for the considered TSLs for non-weatherized gas furnaces (NWGFs) and mobile home gas furnaces (MHGFs) for Annual Fuel Utilization Efficiency (AFUE) standards. The NPV results presented in chapter 10 are based on a product price trend (defined as the fractional reduction in product price expected from each doubling of cumulative production) of 20.0 percent, which is referred to as the "default" learning rate. DOE considered two price trend sensitivities: (1) a high decreasing price trend scenario and (2) a no price trend scenario. This appendix describes the sensitivities and compares NPV results for these scenarios with the default price projection. The NPV results include the impacts of the product switching estimated to occur under each AFUE standard cases for NWGFs.

As explained in chapter 8, DOE did not develop product price trends for standby and off mode standards. Thus, DOE did not conduct a product price sensitivity analysis for standby and off mode standards.

10C.2 ALTERNATIVE RESIDENTIAL FURNACE PRICE TREND SCENARIOS

DOE considered two alternative price trends for the sensitivity analysis. The high decreasing price trend scenario used the same power-law function as the default scenario to fit the warm air furnace PPI during the period of 1990 to 2006. The no price trend scenario assumes zero percent learning rate for all products, implying constant real prices over the entire forecast period.

10C.2.1 Determination of High Decreasing Price Trend Scenario

DOE examined the warm air furnace producer price index (PPI) series from the Bureau of Labor Statistics (BLS) from 1990 to 2006,[a] which demonstrates a steeper downward trend than the full set of data. DOE fit this segment of the data to a power-law function to derive the high decreasing price trend. The inflation-adjusted price index for warm air furnaces was calculated by dividing the PPI series by the gross domestic product-chained price index for the same years, Figure 10C.2.1 presents the nominal and inflation-adjusted PPI trends for warm air furnaces from 1990 to 2006.

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[a] Series ID: PCU333415333415C. Available at www.bls.gov/ppi/.

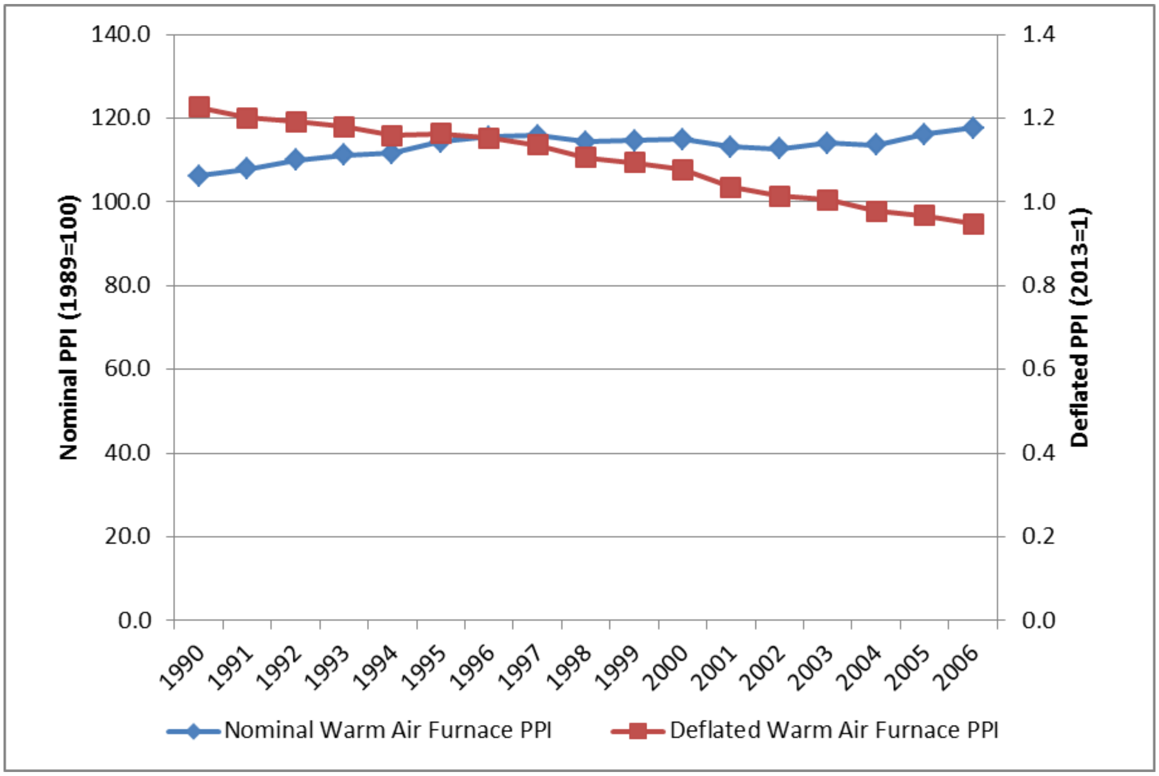

Figure 10C.2.1 Nominal and Deflated Warm Air Furnaces PPI from 1990 to 2006

To estimate a learning rate parameter, a least-squares power-law fit was performed on the unified price index versus corresponding cumulative shipments (Figure 10C.2.2).

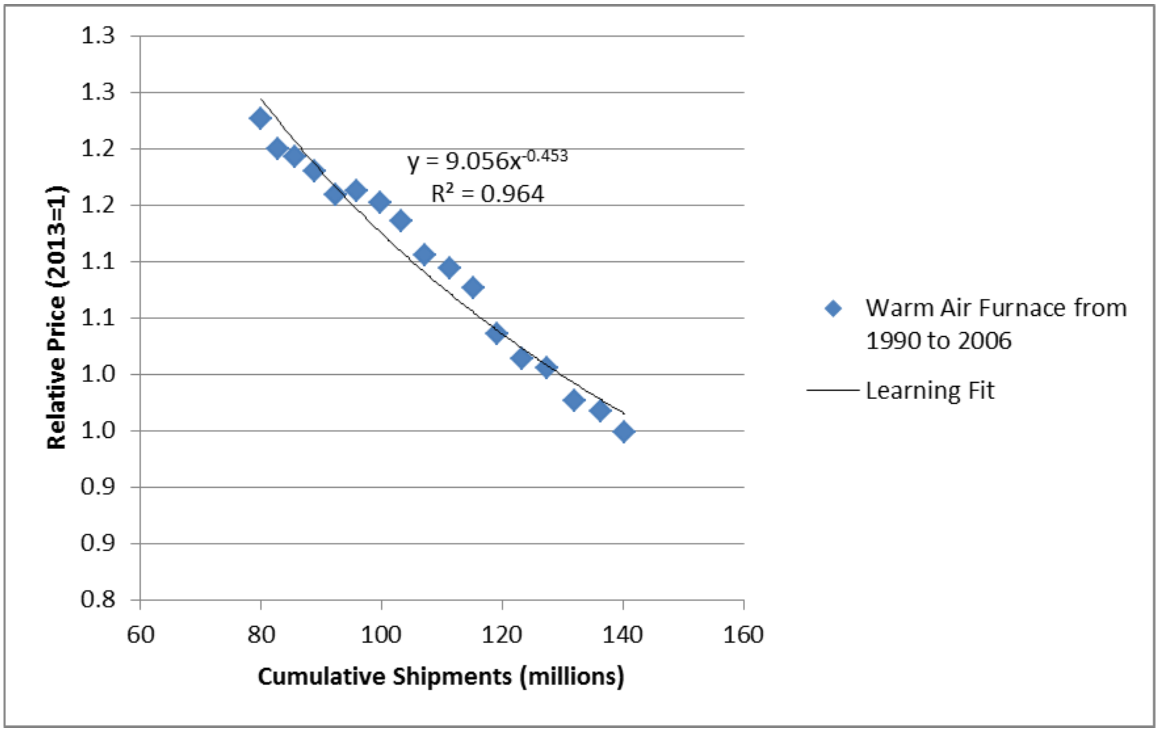

Figure 10C.2.2 **Relative Price versus Cumulative Shipments of Warm Air Furnaces from 1990 to 2006, with Power Law Fit**

The form of the fitting equation is:

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

Eq. 10C.1

where the two parameters, *b* (the learning rate parameter) and P_o (the price or cost of the first unit of production), are obtained by fitting the model to the data.

The parameter values obtained are:

$P_o = 9.056^{+2.30}_{-1.83}$ (95-percent confidence), and
b = 0.453±0.048 (95-percent confidence).

For NWGFs and MHGFs, the estimated high learning rate is $26.9^{+2.4}_{-2.5}$% (95-percent confidence).

10C.2.2 Summary

Table 10C.2.1 shows the summary of the estimated learning rate in each price trend scenario used for NWGFs and MHGFs. Figure 10C.2.3 shows the resulting price forecast indexes.

Table 10C.2.1 Price Trend Sensitivities

Sensitivity	Price Trend	Estimated Learning Rate %
Medium (Default)	Power-law fit to the warm air furnace PPI from 1990 to 2013	20.0
High Decreasing Price Trend Scenario	Power-law fit to the warm air furnace PPI from 1990 to 2006	26.9
No Price Trend Scenario	Constant price projection	0.0

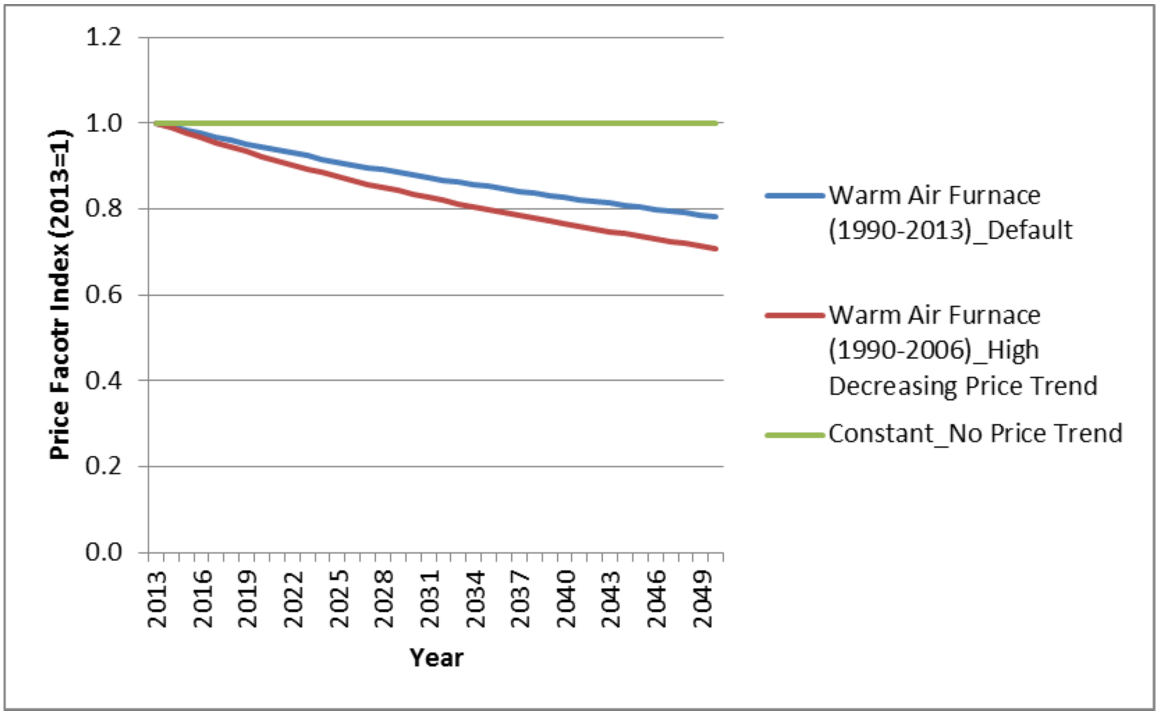

Figure 10C.2.3 Price Forecast Indexes for Non-Weatherized Gas Furnaces and Mobile Home Gas Furnaces

10C.3 NET PRESENT VALUE RESULTS USING ALTERNATIVE PRODUCT PRICE TRENDS

This section presents the NPV results using the alternative product price forecast for each key product class. Table 10C.3.7 compares the total (all classes) NPV using the default product price forecast with the NPV using the alternative product price forecasts. With the high decreasing price trend scenario, the NPV for the highest TSLs rises substantially compared with the reference case; in contrast, it declines with the no price trend scenario.

Table 10C.3.1 Net Present Value (NPV) for AFUE Standards Using Reference Product Price Trend, Discounted at 3 Percent

Product Class	Trial Standard Levels				
	1	2	3	4	5
	billion 2013$				
Non-Weatherized Gas Furnaces	8.1	13.5	15.1	20.4	24.1
Mobile Home Gas Furnaces	0.6	0.7	1.0	1.1	1.2
Total	**8.6**	**14.1**	**16.1**	**21.5**	**25.3**

Table 10C.3.2 Net Present Value (NPV) for AFUE Standards Using Reference Product Price Trend, Discounted at 7 Percent

Product Class	Trial Standard Levels				
	1	2	3	4	5
	billion 2013$				
Non-Weatherized Gas Furnaces	1.9	3.3	2.8	3.7	3.3
Mobile Home Gas Furnaces	0.2	0.2	0.3	0.3	0.3
Total	**2.1**	**3.6**	**3.1**	**4.0**	**3.7**

Table 10C.3.3 Net Present Value (NPV) for AFUE Standards Using Alternative Product Price Trend (High Decreasing Price Trend Scenario), Discounted at 3 Percent

Product Class	Trial Standard Levels				
	1	2	3	4	5
	billion 2013$				
Non-Weatherized Gas Furnaces	8.1	13.7	15.4	21.0	25.2
Mobile Home Gas Furnaces	0.6	0.7	1.0	1.1	1.2
Total	**8.7**	**14.4**	**16.4**	**22.1**	**26.4**

Table 10C.3.4 Net Present Value (NPV) for AFUE Standards Using Alternative Product Price Trend (High Decreasing Price Trend Scenario), Discounted at 7 Percent

Product Class	Trial Standard Levels				
	1	2	3	4	5
	billion 2013$				
Non-Weatherized Gas Furnaces	1.9	3.4	2.9	4.0	3.9
Mobile Home Gas Furnaces	0.2	0.2	0.3	0.3	0.3
Total	**2.1**	**3.7**	**3.2**	**4.3**	**4.2**

Table 10C.3.5 Net Present Value (NPV) for AFUE Standards Using Alternative Product Price Trend (No Price Trend Scenario), Discounted at 3 Percent

Product Class	Trial Standard Levels				
	1	2	3	4	5
	billion 2013$				
Non-Weatherized Gas Furnaces	7.8	12.8	14.2	18.6	20.9
Mobile Home Gas Furnaces	0.6	0.7	1.0	1.1	1.1
Total	**8.4**	**13.5**	**15.2**	**19.7**	**22.0**

Table 10C.3.6 Net Present Value (NPV) for AFUE Standards Using Alternative Product Price Trend (No Price Trend Scenario), Discounted at 7 Percent

Product Class	Trial Standard Levels				
	1	2	3	4	5
	billion 2013$				
Non-Weatherized Gas Furnaces	1.8	3.1	2.4	2.9	1.9
Mobile Home Gas Furnaces	0.2	0.2	0.3	0.3	0.3
Total	**2.0**	**3.3**	**2.7**	**3.2**	**2.2**

Table 10C.3.7 Comparison of Total Net Present Value (NPV) for AFUE Standards Across All Product Classes for Alternative Product Price Trends

Discount Rate	Price Trend Scenario	Trial Standard Level				
		1	2	3	4	5
		billion 2013$				
3%	Reference Case	8.6	14.1	16.1	21.5	25.3
	High Decreasing Price Trend	8.7	14.4	16.4	22.1	26.4
	No Price Trend	8.4	13.5	15.2	19.7	22.0
7%	Reference Case	2.1	3.6	3.1	4.0	3.7
	High Decreasing Price Trend	2.1	3.7	3.2	4.3	4.2
	No Price Trend	2.0	3.3	2.7	3.2	2.2

APPENDIX 10D. NATIONAL IMPACT ANALYSIS USING ALTERNATIVE ECONOMIC GROWTH SCENARIOS FOR RESIDENTIAL FURNACES

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APPENDIX 10D. NATIONAL IMPACT ANALYSIS USING ALTERNATIVE ECONOMIC GROWTH SCENARIOS FOR RESIDENTIAL FURNACES

10D.1 INTRODUCTION

This appendix presents National Impact Analysis (NIA) results using energy price forecasts from alternative economic growth scenarios. The 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 2014* (*AEO 2014*).[1] To estimate energy prices after 2040 in the high and low scenarios, DOE used the growth rate between 2021 and 2040. See appendix 8C for details about alternative economic growth scenarios.

This appendix also describes the High and Low Economic Growth scenarios in further detail. See appendix 10A for details about how to generate NIA results for High Economic Growth and Low Economic Growth scenarios using the NIA spreadsheet.

10D.2 DESCRIPTION OF HIGH AND LOW ECONOMIC SCENARIOS

To generate NIA results reported in chapter 10, DOE uses the Reference case energy price and housing projections from *AEO 2014*. The reference case is a business-as-usual estimate, given known market, demographic, and technological trends. For *AEO 2014*, 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 *AEO 2014* uses High and Low Economic Growth scenarios to project the possible impacts of alternative economic growth assumptions on energy markets.[2]

In general, energy prices are higher in the High Economic Growth scenario and lower in the Low Economic Growth scenario. See appendix 8E for details about the effect of these alternative economic scenarios on energy prices.

Because *AEO 2014* provides the price trends by census division, each sampled household is then matched to the appropriate census division price trend. See chapter 10 for details about how energy price trends by census division are applied in the NIA analysis.

In addition, the High and Low Economic Growth scenarios provide different housing starts projections that affect the furnace shipments projections. Figure 10D.2.1 shows the shipments projections based on the different *AEO 2014* scenarios.

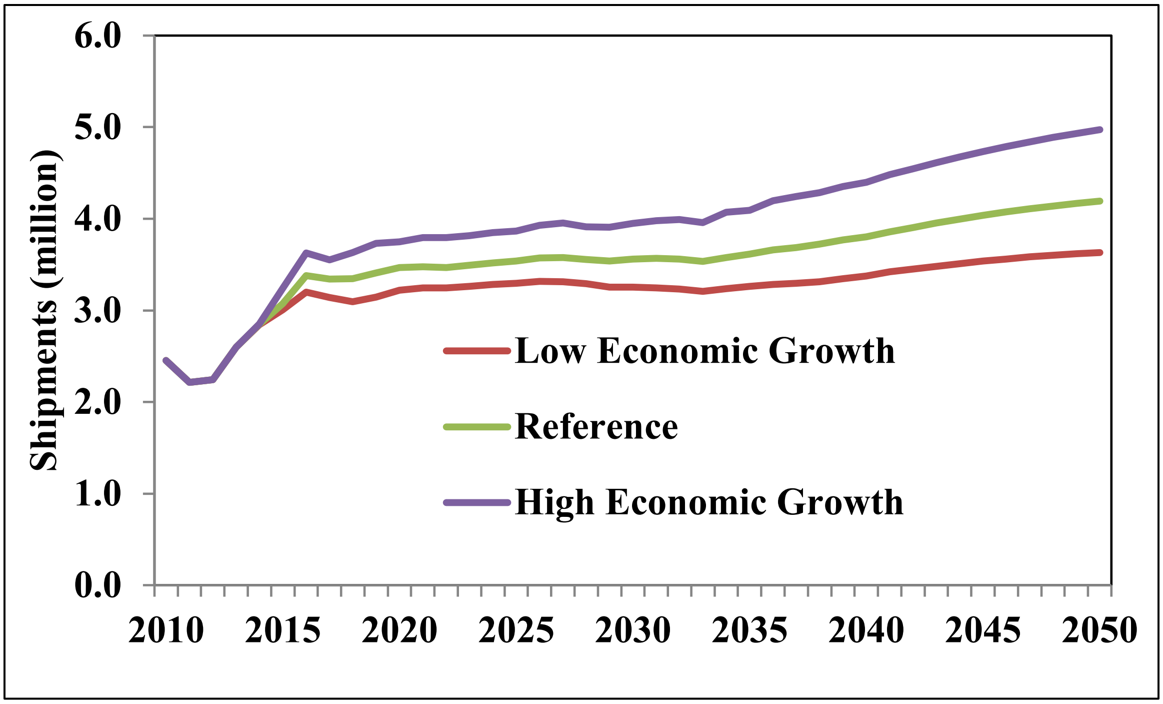

Figure 10D.2.1 **Shipment Projections for Reference Case and High and Low Economic Growth Scenarios (Base Case)**

10D.3 RESULTS

This section presents the national energy savings (NES) and national present value (NPV) results for the considered trial standard levels (TSLs) for non-weatherized gas furnaces (NWGFs) and mobile home gas furnaces (MHGFs) using the Reference Case, High Economic Growth, and Low Economic Growth scenarios. The results include the impacts of the fuel switching estimated to occur under each standards case.

10D.3.1 National Energy Savings

For AFUE standards, Table 10D.3.1 through Table 10D.3.3 show the NES results for each TSL analyzed for NWGFs and MHGFs under different economic growth scenarios. Similarly, Table 10D.3.4 through Table 10D.3.6 show NES results for standby mode and off mode standards.

Table 10D.3.1 National Energy Savings (Primary) for AFUE Standards – Reference Case

Product Classes	Trial Standard Levels				
	1	2	3	4	5
	quads				
Non-Weatherized Gas Furnace	1.004	1.756	2.124	3.263	4.364
Mobile Home Gas Furnace	0.062	0.066	0.127	0.131	0.142
Total – All Classes	**1.066**	**1.821**	**2.251**	**3.394**	**4.507**

Table 10D.3.2 National Energy Savings (Primary) for AFUE Standards – High Economic Growth

Product Classes	Trial Standard Levels				
	1	2	3	4	5
	quads				
Non-Weatherized Gas Furnace	1.075	1.923	2.360	3.635	4.863
Mobile Home Gas Furnace	0.104	0.110	0.192	0.199	0.216
Total – All Classes	**1.179**	**2.033**	**2.551**	**3.834**	**5.080**

Table 10D.3.3 National Energy Savings (Primary) for AFUE Standards – Low Economic Growth

Product Classes	Trial Standard Levels				
	1	2	3	4	5
	quads				
Non-Weatherized Gas Furnace	0.951	1.630	1.943	2.980	3.986
Mobile Home Gas Furnace	0.048	0.050	0.105	0.108	0.116
Total – All Classes	**0.999**	**1.680**	**2.048**	**3.087**	**4.103**

Table 10D.3.4 National Energy Savings (Primary) for Standby Mode and Off Mode Standards – Reference Case

Product Classes	Trial Standard Levels		
	1	2	3
	quads		
Non-Weatherized Gas Furnace	0.147	0.176	0.264
Mobile Home Gas Furnace	0.000	0.000	0.000
Total – All Classes	**0.147**	**0.176**	**0.264**

Table 10D.3.5 National Energy Savings (Primary) for Standby Mode and Off Mode Standards – High Economic Growth

Product Classes	Trial Standard Levels		
	1	2	3
	quads		
Non-Weatherized Gas Furnace	0.166	0.199	0.299
Mobile Home Gas Furnace	0.000	0.000	0.000
Total – All Classes	**0.166**	**0.200**	**0.300**

Table 10D.3.6 National Energy Savings (Primary) for Standby Mode and Off Mode Standards – Low Economic Growth

Product Classes	Trial Standard Levels		
	1	2	3
	quads		
Non-Weatherized Gas Furnace	0.132	0.159	0.238
Mobile Home Gas Furnace	0.000	0.000	0.000
Total – All Classes	**0.132**	**0.159**	**0.238**

10D.3.2 Net Present Value of Consumer Impacts

For AFUE standards, Table 10D.3.7 through Table 10D.3.12 show the NPV results for each of the TSLs analyzed for NWGFs and MHGFs under different economic growth scenarios. Similarly, Table 10D.3.13 through Table 10D.3.18 show NPV results for standby mode and off mode standards. A negative NPV indicates that the costs of a standard at a given efficiency level exceed the savings.

Table 10D.3.7 Net Present Value, Discounted at 3 Percent for AFUE Standards – Reference Case

Product Class	Trial Standard Levels				
	1	2	3	4	5
	billion 2013$				
Non-Weatherized Gas Furnace	8.06	13.46	15.09	20.36	24.08
Mobile Home Gas Furnace	0.58	0.67	1.00	1.13	1.17
Total – All Classes	**8.63**	**14.13**	**16.09**	**21.50**	**25.26**

Table 10D.3.8 Net Present Value, Discounted at 7 Percent for AFUE Standards – Reference Case

Product Class	Trial Standard Levels				
	1	2	3	4	5
	billion 2013$				
Non-Weatherized Gas Furnaces	1.88	3.34	2.77	3.67	3.34
Mobile Home Gas Furnaces	0.19	0.22	0.32	0.34	0.33
Total	**2.07**	**3.56**	**3.09**	**4.01**	**3.67**

Table 10D.3.9 Net Present Value, Discounted at 3 Percent for AFUE Standards – High Economic Growth

Product Class	Trial Standard Levels				
	1	2	3	4	5
	billion 2013$				
Non-Weatherized Gas Furnaces	9.26	15.43	18.27	24.30	28.19
Mobile Home Gas Furnaces	0.93	1.09	1.55	1.75	1.82
Total	**10.19**	**16.52**	**19.81**	**26.06**	**30.01**

Table 10D.3.10 Net Present Value, Discounted at 7 Percent for AFUE Standards – High Economic Growth

Product Class	Trial Standard Levels				
	1	2	3	4	5
	billion 2013$				
Non-Weatherized Gas Furnaces	2.23	3.86	3.74	4.73	4.19
Mobile Home Gas Furnaces	0.31	0.35	0.49	0.53	0.52
Total	**2.54**	**4.21**	**4.23**	**5.25**	**4.70**

Table 10D.3.11 Net Present Value, Discounted at 3 Percent for AFUE Standards – Low Economic Growth

Product Class	Trial Standard Levels				
	1	2	3	4	5
	billion 2013$				
Non-Weatherized Gas Furnaces	5.92	10.30	10.04	13.99	16.26
Mobile Home Gas Furnaces	0.39	0.45	0.73	0.82	0.84
Total	**6.31**	**10.75**	**10.77**	**14.81**	**17.09**

Table 10D.3.12 Net Present Value, Discounted at 7 Percent for AFUE Standards – Low Economic Growth

Product Class	Trial Standard Levels				
	1	2	3	4	5
	billion 2013$				
Non-Weatherized Gas Furnaces	1.23	2.43	1.23	1.84	1.25
Mobile Home Gas Furnaces	0.13	0.15	0.23	0.25	0.23
Total	**1.37**	**2.58**	**1.47**	**2.09**	**1.49**

Table 10D.3.13 Net Present Value, Discounted at 3 Percent for Standby Mode and Off Mode Standards – Reference Case

Product Class	Trial Standard Levels		
	1	2	3
	billion 2013$		
Non-Weatherized Gas Furnace	2.12	2.01	3.27
Mobile Home Gas Furnace	0.00	0.00	0.00
Total – All Classes	**2.12**	**2.01**	**3.27**

Table 10D.3.14 Net Present Value, Discounted at 7 Percent for Standby Mode and Off Mode Standards – Reference Case

Product Class	Trial Standard Levels		
	1	2	3
	billion 2013$		
Non-Weatherized Gas Furnace	0.73	0.61	1.03
Mobile Home Gas Furnace	0.00	0.00	0.00
Total – All Classes	**0.73**	**0.61**	**1.03**

Table 10D.3.15 Net Present Value, Discounted at 3 Percent for Standby Mode and Off Mode Standards – High Economic Growth

Product Class	Trial Standard Levels		
	1	2	3
	billion 2013$		
Non-Weatherized Gas Furnace	2.49	2.38	3.86
Mobile Home Gas Furnace	0.00	0.00	0.01
Total – All Classes	**2.49**	**2.39**	**3.86**

Table 10D.3.16 Net Present Value, Discounted at 7 Percent for Standby Mode and Off Mode Standards – High Economic Growth

Product Class	Trial Standard Levels		
	1	2	3
	billion 2013$		
Non-Weatherized Gas Furnace	0.84	0.71	1.20
Mobile Home Gas Furnace	0.00	0.00	0.00
Total – All Classes	**0.84**	**0.71**	**1.21**

Table 10D.3.17 Net Present Value, Discounted at 3 Percent for Standby Mode and Off Mode Standards – Low Economic Growth

Product Class	Trial Standard Levels		
	1	2	3
	billion 2013$		
Non-Weatherized Gas Furnace	1.90	1.79	2.92
Mobile Home Gas Furnace	0.00	0.00	0.00
Total – All Classes	**1.90**	**1.79**	**2.92**

Table 10D.3.18 Net Present Value, Discounted at 7 Percent for Standby Mode and Off Mode Standards – Low Economic Growth

Product Class	Trial Standard Levels		
	1	2	3
	billion 2013$		
Non-Weatherized Gas Furnace	0.66	0.55	0.93
Mobile Home Gas Furnace	0.00	0.00	0.00
Total – All Classes	**0.66**	**0.55**	**0.93**

10D.3.3 Summary

Table 10D.3.19 and Table 10D.3.20 show the NES and NPV results for AFUE standards for each of the TSL under different economic growth scenarios. Similarly, Table 10D.3.21 and Table 10D.3.22 show the NPV results for standby mode and off mode standards. NES and NPV results are larger for High Economic Growth scenario and smaller for Low Economic Growth scenario compared to Reference Case.

Table 10D.3.19 Comparison of National Energy Savings Results for AFUE Standards for Reference Case and High and Low Economic Growth Scenarios

Scenarios	Trial Standard Level				
	1	2	3	4	5
	quads				
Reference Case	1.066	1.821	2.251	3.394	4.507
High Economic Growth	1.179	2.033	2.551	3.834	5.080
Low Economic Growth	0.999	1.680	2.048	3.087	4.103

Table 10D.3.20 Comparison of Net Present Value Results for AFUE Standards for Reference Case and High and Low Economic Growth Scenarios

Discount Rate	Scenarios	Trial Standard Level				
		1	2	3	4	5
		billion 2013$				
3%	Reference Case	8.63	14.13	16.09	21.50	25.26
	High Economic Growth	10.19	16.52	19.81	26.06	30.01
	Low Economic Growth	6.31	10.75	10.77	14.81	17.09
7%	Reference Case	2.07	3.56	3.09	4.01	3.67
	High Economic Growth	2.54	4.21	4.23	5.25	4.70
	Low Economic Growth	1.37	2.58	1.47	2.09	1.49

Table 10D.3.21 Comparison of National Energy Savings Results for Standby Mode and Off Mode Standards for Reference Case and High and Low Economic Growth Scenarios

Scenarios	Trial Standard Level				
	1	2	3	4	5
	quads				
Reference Case	0.147	0.176	0.264	0.147	0.176
High Economic Growth	0.166	0.200	0.300	0.166	0.200
Low Economic Growth	0.132	0.159	0.238	0.132	0.159

Table 10D.3.22 Comparison of Net Present Value Results for Standby Mode and Off Mode Standards for Reference Case and High and Low Economic Growth Scenarios

Discount Rate	Scenarios	Trial Standard Level				
		1	2	3	4	5
		billion 2013$				
3%	Reference Case	2.12	2.01	3.27	2.12	2.01
	High Economic Growth	2.49	2.39	3.86	2.49	2.39
	Low Economic Growth	1.90	1.79	2.92	1.90	1.79
7%	Reference Case	0.73	0.61	1.03	0.73	0.61
	High Economic Growth	0.84	0.71	1.21	0.84	0.71
	Low Economic Growth	0.66	0.55	0.93	0.66	0.55

REFERENCES

1. U.S. Department of Energy-Energy Information Administration, *Annual Energy Outlook 2014 with Projections to 2040*, 2014. Washington, DC. <www.eia.gov/forecasts/aeo/>

2. Energy Information Administration, *Macroeconomic Activity Module for Annual Energy Outlook 2014*, 2014. Washington, DC. <www.eia.gov/forecasts/aeo/assumptions/pdf/macroeconomic.pdf>

APPENDIX 10E. NATIONAL IMPACT ANALYSIS USING ALTERNATIVE PRODUCT SWITCHING SCENARIOS FOR RESIDENTIAL FURNACES

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10E.1 INTRODUCTION

DOE investigated the impact of different product switching scenarios on the national impact analysis (NIA) results for the considered trial standard levels (TSLs) for non-weatherized gas furnaces (NWGFs) and mobile home gas furnaces (MHGFs) for Annual Fuel Utilization Efficiency (AFUE) standards. The scenarios are based on the different product switching cases. Four product switching scenarios were analyzed: Reference Case, No Product Switching, Low Product Switching, and High Product Switching. DOE did not consider product switching for MHGF AFUE standards or for NWGFs and MHGFs standby and off mode standards. The MHGF results for AFUE standards, which are not impacted by product switching, are shown to compare the total impact of product switching on the NIA results for AFUE standards.

Table 10E.1.1 shows the total fraction of product switching from NWGFs to electric furnaces (EFs) or heat pumps (HPs) by TSL for NWGFs. See appendix 8J for details about alternative product switching scenarios.

Table 10E.1.1 Total Fraction of Product Switching from NWGFs to Electric Furnaces and Heat Pumps under Reference Case and No, High, and Low Product Switching Scenarios

Product Switching Scenario	**Trial Standard Levels**				
	1	**2**	**3**	**4**	**5**
	*Fraction of Product Switching to EF or HP**				
Reference Case	2.1%	2.4%	10%	12%	16%
No Product Switching	0.0%	0.0%	0.0%	0.0%	0.0%
Low Product Switching	1.6%	1.8%	7.4%	9.0%	12%
High Product Switching	2.6%	3.1%	12%	14%	19%

* Includes households that also switch from NWGF to EF or HP as well as from a gas water heater to an electric water heater. These fractions do not include a small fraction of households that switch from a gas water heater to an electric water heater, but do not switch from NWGF to EF or HP.

10E.2 RESULTS

10E.2.1 National Energy Savings

Table 10E.2.1 through Table 10E.2.3 show the national energy savings (NES) results for each of the TSLs analyzed for NWGFs and MHGFs[a] using the Reference Case, No Product Switching, Low Product Switching, and High Product Switching scenarios.

Table 10E.2.1 National Energy Savings (Primary) for AFUE Standards – Reference Case

Product Classes	Trial Standard Levels				
	1	2	3	4	5
	quads				
Non-Weatherized Gas Furnace	1.004	1.756	2.124	3.263	4.364
Mobile Home Gas Furnace	0.062	0.066	0.127	0.131	0.142
Total – All Classes	**1.066**	**1.821**	**2.251**	**3.394**	**4.507**

Table 10E.2.2 National Energy Savings (Primary) for AFUE Standards – No Product Switching Scenario

Product Classes	Trial Standard Levels				
	1	2	3	4	5
	quads				
Non-Weatherized Gas Furnace	1.824	2.549	4.604	6.163	7.959
Mobile Home Gas Furnace	0.062	0.066	0.127	0.131	0.142
Total – All Classes	**1.886**	**2.614**	**4.731**	**6.295**	**8.102**

Table 10E.2.3 National Energy Savings (Primary) for AFUE Standards – Low Product Switching Scenario

Product Classes	Trial Standard Levels				
	1	2	3	4	5
	quads				
Non-Weatherized Gas Furnace	1.200	1.951	2.769	4.054	5.304
Mobile Home Gas Furnace	0.062	0.066	0.127	0.131	0.142
Total – All Classes	**1.262**	**2.017**	**2.896**	**4.186**	**5.446**

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[a] The MHGF results for AFUE standards, which are not impacted by product switching, are shown to able to compare the total impact of the product switching scenarios on NIA results for AFUE standards.

Table 10E.2.4 National Energy Savings (Primary) for AFUE Standards – High Product Switching Scenario

Product Classes	Trial Standard Levels				
	1	2	3	4	5
	quads				
Non-Weatherized Gas Furnace	0.854	1.537	1.476	2.429	3.418
Mobile Home Gas Furnace	0.062	0.066	0.127	0.131	0.142
Total – All Classes	**0.916**	**1.602**	**1.603**	**2.560**	**3.560**

10E.2.2 Net Present Value of Consumer Impacts

Table 10E.2.5 through Table 10E.2.10 show the net present value (NPV) results for each of the TSLs analyzed for NWGFs and MHGFs[b] using the Reference Case, No Product Switching, Low Product Switching, and High Product Switching scenarios. A negative NPV indicates that the costs of a standard at a given efficiency level exceed the savings.

Table 10E.2.5 Net Present Value (NPV) for AFUE Standards, Discounted at 3 Percent – Reference Case

Product Class	Trial Standard Levels				
	1	2	3	4	5
	billion 2013$				
Non-Weatherized Gas Furnace	8.06	13.46	15.09	20.36	24.08
Mobile Home Gas Furnace	0.58	0.67	1.00	1.13	1.17
Total – All Classes	**8.63**	**14.13**	**16.09**	**21.50**	**25.26**

Table 10E.2.6 Net Present Value (NPV) for AFUE Standards, Discounted at 7 Percent – Reference Case

Product Class	Trial Standard Levels				
	1	2	3	4	5
	billion 2013$				
Non-Weatherized Gas Furnaces	1.88	3.34	2.77	3.67	3.34
Mobile Home Gas Furnaces	0.19	0.22	0.32	0.34	0.33
Total	**2.07**	**3.56**	**3.09**	**4.01**	**3.67**

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[b] The MHGF results for AFUE standards, which are not impacted by product switching, are shown to able to compare the total impact of the product switching scenarios on NIA results for AFUE standards.

Table 10E.2.7 Net Present Value (NPV) for AFUE Standards, Discounted at 3 Percent – No Product Switching Scenario

Product Class	Trial Standard Levels				
	1	2	3	4	5
	billion 2013$				
Non-Weatherized Gas Furnaces	6.90	12.38	19.28	25.84	30.66
Mobile Home Gas Furnaces	0.58	0.67	1.00	1.13	1.17
Total	**7.48**	**13.05**	**20.28**	**26.98**	**31.84**

Table 10E.2.8 Net Present Value (NPV) for AFUE Standards, Discounted at 7 Percent – No Product Switching Scenario

Product Class	Trial Standard Levels				
	1	2	3	4	5
	billion 2013$				
Non-Weatherized Gas Furnaces	1.53	3.01	4.18	5.51	5.48
Mobile Home Gas Furnaces	0.19	0.22	0.32	0.34	0.33
Total	**1.73**	**3.23**	**4.50**	**5.85**	**5.81**

Table 10E.2.9 Net Present Value (NPV) for AFUE Standards, Discounted at 3 Percent – Low Product Switching Scenario

Product Class	Trial Standard Levels				
	1	2	3	4	5
	billion 2013$				
Non-Weatherized Gas Furnaces	8.60	14.08	18.86	24.62	29.25
Mobile Home Gas Furnaces	0.58	0.67	1.00	1.13	1.17
Total	**9.17**	**14.75**	**19.86**	**25.76**	**30.42**

Table 10E.2.10 Net Present Value (NPV) for AFUE Standards, Discounted at 7 Percent – Low Product Switching Scenario

Product Class	Trial Standard Levels				
	1	2	3	4	5
	billion 2013$				
Non-Weatherized Gas Furnaces	2.09	3.57	4.05	5.12	5.07
Mobile Home Gas Furnaces	0.19	0.22	0.32	0.34	0.33
Total	**2.28**	**3.79**	**4.37**	**5.46**	**5.40**

Table 10E.2.11 Net Present Value (NPV) for AFUE Standards, Discounted at 3 Percent – High Product Switching Scenario

Product Class	Trial Standard Levels				
	1	2	3	4	5
	billion 2013$				
Non-Weatherized Gas Furnaces	7.51	12.97	10.93	15.56	18.76
Mobile Home Gas Furnaces	0.58	0.67	1.00	1.13	1.17
Total	**8.09**	**13.64**	**11.93**	**16.69**	**19.93**

Table 10E.2.12 Net Present Value (NPV) for AFUE Standards, Discounted at 7 Percent – High Product Switching Scenario

Product Class	Trial Standard Levels				
	1	2	3	4	5
	billion 2013$				
Non-Weatherized Gas Furnaces	1.67	3.13	1.30	1.98	1.46
Mobile Home Gas Furnaces	0.19	0.22	0.32	0.34	0.33
Total	**1.86**	**3.35**	**1.62**	**2.32**	**1.79**

10E.2.3 Summary

Table 10E.2.13 and Table 10E.2.14 show the NES and NPV results for each of the TSL for the Reference Case, No Product Switching, High Product Switching, and Low Product Switching scenarios. NES results are larger for No Product Switching and Low Product Switching scenario and smaller for High Product Switching scenario compared to the Reference case. NPV results are larger for No Product Switching (TSL 3 though TSL 5) and Low Product Switching scenarios and smaller for No Product Switching (TSL 1 and TSL 2) and High Product Switching scenarios compared to the Reference case.

Table 10E.2.13 Comparison of National Energy Savings (Primary) Results for AFUE Standards under Reference Case and No Switching and High and Low Product Switching Scenarios

Scenarios	Trial Standard Level				
	1	2	3	4	5
	quads				
Reference Case	1.066	1.821	2.251	3.394	4.507
No Product Switching	1.886	2.614	4.731	6.295	8.102
Low Product Switching	1.262	2.017	2.896	4.186	5.446
High Product Switching	0.916	1.602	1.603	2.560	3.560

Table 10E.2.14 Comparison of Net Present Value (NPV) Results for AFUE Standards under Reference Case and No Switching and High and Low Product Switching Scenarios

Discount Rate	**Scenarios**	**Trial Standard Level**				
		1	**2**	**3**	**4**	**5**
		billion 2013$				
3%	Reference Case	8.63	14.13	16.09	21.50	25.26
	No Product Switching	7.48	13.05	20.28	26.98	31.84
	Low Product Switching	9.17	14.75	19.86	25.76	30.42
	High Product Switching	8.09	13.64	11.93	16.69	19.93
7%	Reference Case	2.07	3.56	3.09	4.01	3.67
	No Product Switching	1.73	3.23	4.50	5.85	5.81
	Low Product Switching	2.28	3.79	4.37	5.46	5.40
	High Product Switching	1.86	3.35	1.62	2.32	1.79

CHAPTER 11. CONSUMER SUBGROUP ANALYSIS

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CHAPTER 11. CONSUMER SUBGROUP ANALYSIS

11.1 INTRODUCTION

The consumer subgroup analysis evaluates impacts on groups or customers who may be disproportionately affected by any national energy conservation standard. The U.S. Department of Energy (DOE) evaluates impacts on particular subgroups of consumers by analyzing the life-cycle cost (LCC) impacts and payback period (PBP) for those consumers from the considered energy efficiency levels. DOE determined the impact on consumer subgroups using the LCC spreadsheet models for non-weatherized gas furnaces (NWGFs) and mobile home gas furnaces (MHGFs). Chapter 8 explains in detail the inputs to the models used in determining LCC impacts and PBPs.

DOE evaluated the impacts of the considered energy efficiency levels for NWGFs and MHGFs on low-income households and households occupied solely by senior citizens (*i.e.*, senior-only households).

This chapter describes the subgroup identification in further detail and gives the results of the LCC and PBP analyses for the considered subgroups.

11.2 SUBGROUPS DEFINITION

11.2.1 Low-Income Households

As defined in the RECS survey, low-income households are those at or below the "poverty line." The poverty line varies with household size, head of household age, and family income and in RECS encompasses a group of households with incomes below the poverty level in 2009 as defined by the U.S. Bureau of the Census[1] (see Table 11.2.1). The RECS survey classifies approximately 15 percent of U.S. households as low-income.

Table 11.2.1 RECS 2009 Definitions of Low-Income Households by Yearly Income

Household Size	**Weighted Average Threshold** ***2009$***
1	10,956
2	13,991
3	17,098
4	21,954
5	25,991
6	29,405
7	33,372
8	37,252
9+	44,366

11.2.2 Senior-Only Households

Senior-only households have occupants who are all at least 65 years of age. Based on the Energy Information Administration's 2009 Residential Energy Consumption Survey (RECS 2009),[2] senior-only households comprise 17 percent of the country's households.

11.2.3 Distribution of Subgroup Households with Residential Furnaces

Of the 12,083 households in the 2009 RECS database, 5,700 have NWGFs and 195 have MHGFs. Table 11.2.2 shows the household sample sizes for all gas furnaces.

Table 11.2.2 Household Population Data for all Gas Furnace Products

Region	**General Population**		**Low-Income Households**		**Senior-Only Households**	
	No. of Records	**Number of Houses**	**No. of Records**	**Number of Houses**	**No. of Records**	**Number of Houses**
Households with Non-Weatherized Gas Furnaces						
Nation	5700	53,737,696	494	4,907,938	843	8,472,597
North	3301	30,808,874	275	2,825,101	483	4,925,907
South	2399	22,928,822	219	2,082,837	360	3,546,690
Households with Mobile Home Gas Furnaces						
Nation	195	2,512,951	37	536,311	38	553,245
North	123	1,537,735	22	286,132	24	362,163
South	72	975,216	15	250,178	14	191,082

11.3 RESULTS

Table 11.3.1 through Table 11.3.16 summarize the LCC and PBP results for NWGFs and MHGFs for low-income and senior-only households for AFUE standards and standby and off mode standards. Table 11.3.17 and Table 11.3.20 compare the LCC savings and simple payback period for these subgroups with those for all households.

11.3.1 Low-Income Subgroup Results

Table 11.3.1 Average LCC and PBP Results by Efficiency Level for Non-Weatherized Gas Furnaces for Low-Income Households for AFUE Standards

Efficiency Level	AFUE	Average Costs 2013$				Simple Payback years	Average Lifetime
		Installed Cost	First Year's Operating Cost	Lifetime Operating Cost	LCC		
National							
0	80%	$1,983	$654	$10,641	$12,625	--	21.5
1	90%	$2,498	$600	$9,720	$12,218	9.6	21.5
2	92%	$2,512	$591	$9,562	$12,074	8.3	21.5
3	95%	$2,618	$577	$9,328	$11,945	8.3	21.5
4	98%	$2,776	$561	$9,012	$11,789	8.5	21.5
North							
0	80%	$2,185	$853	$14,029	$16,215	--	21.5
1	90%	$2,823	$783	$12,864	$15,687	9.1	21.5
2	92%	$2,838	$770	$12,649	$15,487	7.8	21.5
3	95%	$2,964	$751	$12,328	$15,291	7.6	21.5
4	98%	$3,149	$724	$11,861	$15,010	7.5	21.5
Rest of Country							
0	80%	$1,745	$419	$6,647	$8,392	--	21.5
1	90%	$2,115	$385	$6,012	$8,127	10.8	21.5
2	92%	$2,128	$379	$5,922	$8,049	9.6	21.5
3	95%	$2,210	$372	$5,790	$8,000	10.0	21.5
4	98%	$2,338	$368	$5,654	$7,991	11.7	21.5

*AFUE = annual fuel utilization efficiency.

Note: The results for each EL are calculated assuming that all consumers use products with that efficiency level. The PBP is measured relative to the baseline product.

Table 11.3.2 LCC Savings Relative to the Base Case Efficiency Distribution for Non-Weatherized Gas Furnaces for Low-Income Households for AFUE Standards

Efficiency Level	AFUE	Life-Cycle Cost Savings	
		% of Consumers that Experience Net Cost	Average LCC Savings* 2013$
National			
0	80%	--	--
1	90%	26%	$176
2	92%	23%	$247
3	95%	26%	$330
4	98%	43%	$485
North			
0	80%	--	---
1	90%	14%	$148
2	92%	11%	$228
3	95%	14%	$346
4	98%	37%	$624
Rest of Country			
0	80%	--	---
1	90%	41%	$209
2	92%	39%	$269
3	95%	40%	$312
4	98%	50%	$321

* The calculation includes buildings with zero LCC savings (no impact).

Table 11.3.3 Average LCC and PBP Results by Efficiency Level for Mobile Home Gas Furnaces for Low-Income Households for AFUE Standards

Efficiency Level	AFUE	Average Costs 2013$				Simple Payback years	Average Lifetime
		Installed Cost	First Year's Operating Cost	Lifetime Operating Cost	LCC		
National							
0	80%	$1,555	$684	$10,711	$12,266	--	21.5
1	92%	$1,718	$609	$9,544	$11,262	2.2	21.5
2	95%	$1,864	$593	$9,290	$11,155	3.4	21.5
3	97%	$1,980	$585	$9,170	$11,150	4.3	21.5
North							
0	80%	$1,594	$817	$12,755	$14,349	--	21.5
1	92%	$1,752	$727	$11,360	$13,112	1.8	21.5
2	95%	$1,898	$707	$11,043	$12,941	2.8	21.5
3	97%	$2,013	$697	$10,889	$12,902	3.5	21.5
Rest of Country							
0	80%	$1,497	$483	$7,630	$9,127	--	21.5
1	92%	$1,667	$431	$6,807	$8,474	3.3	21.5
2	95%	$1,814	$421	$6,648	$8,462	5.1	21.5
3	97%	$1,930	$417	$6,578	$8,508	6.5	21.5

*AFUE = annual fuel utilization efficiency.

Note: The results for each EL are calculated assuming that all consumers use products with that efficiency level. The PBP is measured relative to the baseline product.

Table 11.3.4 LCC Savings Relative to the Base Case Efficiency Distribution for Mobile Home Gas Furnaces for Low-Income Households for AFUE Standards

Efficiency Level	AFUE	Life-Cycle Cost Savings	
		% of Consumers that Experience Net Cost	Average LCC Savings* 2013$
National			
0	80%	0%	--
1	92%	9%	$677
2	95%	16%	$763
3	97%	27%	$768
North			
0	80%	0%	--
1	92%	4%	$746
2	95%	9%	$882
3	97%	21%	$921
Rest of Country			
0	80%	0%	--
1	92%	17%	$572
2	95%	27%	$583
3	97%	34%	$537

* The calculation includes buildings with zero LCC savings (no impact).

Table 11.3.5 Average LCC and PBP Results by Efficiency Level for Non-Weatherized Gas Furnaces for Low-Income Households for Standby and Off-Mode Standards

Efficiency Level	Design Type	Average Costs 2013$				Simple Payback years
		Installed Cost	First Year's Operating Cost	Lifetime Operating Cost	LCC	
0	Linear Power Supply	$0	$11	$161	$161	--
1	Linear Power Supply with LLTX	$2	$9	$139	$141	1.3
2	Switching Mode Power Supply	$17	$9	$135	$152	9.5
3	Switching Mode Power Supply with LLTX	$18	$8	$125	$143	7.3

Note: The results for each EL are calculated assuming that all consumers use products with that efficiency level. The PBP is measured relative to the baseline product.

Table 11.3.6 LCC Savings Relative to the Base Case Efficiency Distribution for Non-Weatherized Gas Furnaces for Low-Income Households for Standby and Off-Mode Standards

Efficiency Level	Design Type	Life-Cycle Cost Savings	
		% of Consumers that Experience Net Cost	Average LCC Savings* 2013$
0	Linear Power Supply	--	--
1	Linear Power Supply with LLTX	0.3%	$12
2	Switching Mode Power Supply	1.5%	$6
3	Switching Mode Power Supply with LLTX	1.0%	$13

* The calculation includes buildings with zero LCC savings (no impact).

Table 11.3.7 Average LCC and PBP Results by Efficiency Level for Mobile Home Gas Furnaces for Low-Income Households for Standby and Off-Mode Standards

Efficiency Level	Design Type	Average Cost 2013$				Simple Payback years
		Installed Cost	First Year's Operating Cost	Lifetime Operating Cost	LCC	
0	Linear Power Supply	$0	$10	$147	$147	--
1	Linear Power Supply with LLTX	$2	$8	$127	$129	1.3
2	Switching Mode Power Supply	$16	$8	$123	$139	10.0
3	Switching Mode Power Supply with LLTX	$17	$7	$114	$130	7.7

Note: The results for each EL are calculated assuming that all consumers use products with that efficiency level. The PBP is measured relative to the baseline product.

Table 11.3.8 LCC Savings Relative to the Base Case Efficiency Distribution for Mobile Home Gas Furnaces for Low-Income Households for Standby and Off-Mode Standards

Efficiency Level	Design Type	Life-Cycle Cost Savings	
		% of Consumers that Experience Net Cost	Average LCC Savings* 2013$
0	Linear Power Supply	--	--
1	Linear Power Supply with LLTX	0.1%	$1.0
2	Switching Mode Power Supply	0.2%	$0.6
3	Switching Mode Power Supply with LLTX	0.1%	$1.2

* The calculation includes buildings with zero LCC savings (no impact).

11.3.2 Senior-Only Subgroup Results

Table 11.3.9 Average LCC and PBP Results by Efficiency Level for Non-Weatherized Gas Furnaces for Senior Only for AFUE Standards

Efficiency Level	AFUE	Average Costs 2013$				Simple Payback years	Average Lifetime
		Installed Cost	First Year's Operating Cost	Lifetime Operating Cost	LCC		
National							
0	80%	$2,094	$715	$11,513	$13,607	--	21.5
1	90%	$2,582	$652	$10,444	$13,026	7.8	21.5
2	92%	$2,596	$641	$10,263	$12,859	6.8	21.5
3	95%	$2,708	$626	$9,987	$12,695	6.9	21.5
4	98%	$2,872	$611	$9,707	$12,579	7.5	21.5
North							
0	80%	$2,206	$903	$14,624	$16,830	--	21.5
1	90%	$2,851	$822	$13,271	$16,121	7.9	21.5
2	92%	$2,867	$807	$13,036	$15,903	6.9	21.5
3	95%	$2,992	$786	$12,687	$15,679	6.7	21.5
4	98%	$3,175	$766	$12,334	$15,509	7.1	21.5
Rest of Country							
0	80%	$1,960	$489	$7,776	$9,736	--	21.5
1	90%	$2,259	$449	$7,049	$9,307	7.5	21.5
2	92%	$2,271	$442	$6,932	$9,203	6.7	21.5
3	95%	$2,367	$433	$6,743	$9,110	7.3	21.5
4	98%	$2,509	$425	$6,551	$9,060	8.6	21.5

*AFUE = annual fuel utilization efficiency.

Note: The results for each EL are calculated assuming that all consumers use products with that efficiency level. The PBP is measured relative to the baseline product.

Table 11.3.10 LCC Savings Relative to the Base Case Efficiency Distribution for Non-Weatherized Gas Furnaces for Senior Only Households for AFUE Standards

Efficiency Level	AFUE	Life-Cycle Cost Savings	
		% of Consumers that Experience Net Cost	Average Savings* 2013$
National			
0	80%	0%	--
1	90%	21%	$255
2	92%	19%	$326
3	95%	23%	$427
4	98%	39%	$542
North			
0	80%	0%	--
1	90%	10%	$223
2	92%	8%	$293
3	95%	11%	$405
4	98%	35%	$573
Rest of Country			
0	80%	0%	--
1	90%	35%	$293
2	92%	32%	$367
3	95%	37%	$454
4	98%	44%	$504

* The calculation includes buildings with zero LCC savings (no impact).

Table 11.3.11 Average LCC and PBP Results by Efficiency Level for Mobile Home Gas Furnaces for Senior Only Households for AFUE Standards

Efficiency Level	AFUE	Average Costs 2013$ Installed Cost	 First Year's Operating Cost	 Lifetime Operating Cost	 LCC	Simple Payback years	Average Lifetime
National							
0	80%	$1,555	$519	$8,245	$9,801	--	21.5
1	92%	$1,776	$465	$7,387	$9,163	4.1	21.5
2	95%	$1,918	$454	$7,207	$9,125	5.5	21.5
3	97%	$2,033	$450	$7,133	$9,166	6.8	21.5
North							
0	80%	$1,586	$673	$10,572	$12,158	--	21.5
1	92%	$1,822	$600	$9,433	$11,255	3.2	21.5
2	95%	$1,963	$585	$9,187	$11,150	4.3	21.5
3	97%	$2,077	$578	$9,073	$11,151	5.2	21.5
Rest of Country							
0	80%	$1,508	$287	$4,721	$6,229	--	21.5
1	92%	$1,707	$261	$4,288	$5,995	7.6	21.5
2	95%	$1,850	$256	$4,208	$6,058	11.0	21.5
3	97%	$1,966	$255	$4,193	$6,158	14.5	21.5

*AFUE = annual fuel utilization efficiency.

Note: The results for each EL are calculated assuming that all consumers use products with that efficiency level. The PBP is measured relative to the baseline product.

Table 11.3.12 LCC Savings Relative to the Base Case Efficiency Distribution for Mobile Home Gas Furnaces for Senior Only Households for AFUE Standards

Efficiency Level	AFUE	Life-Cycle Cost Savings	
		% of Consumers that Experience Net Cost	Average Savings* 2013$
National			
0	80%	0%	--
1	92%	13%	$429
2	95%	23%	$455
3	97%	40%	$415
North			
0	80%	0%	--
1	92%	4%	$586
2	95%	9%	$670
3	97%	28%	$669
Rest of Country			
0	80%	0%	--
1	92%	26%	$192

* The calculation includes buildings with zero LCC savings (no impact).

Table 11.3.13 Average LCC and PBP Results by Efficiency Level for Non-Weatherized Gas Furnaces for Senior Only Households for Standby and Off-Mode Standards

Efficiency Level	Design Type	Average Costs 2013$				Simple Payback years
		Installed Cost	First Year's Operating Cost	Lifetime Operating Cost	LCC	
0	Linear Power Supply	$0	$11	$161	$161	--
1	Linear Power Supply with LLTX	$2	$9	$139	$141	1.3
2	Switching Mode Power Supply	$17	$9	$135	$152	9.5
3	Switching Mode Power Supply with LLTX	$18	$8	$124	$143	7.3

Note: The results for each EL are calculated assuming that all consumers use products with that efficiency level. The PBP is measured relative to the baseline product.

Table 11.3.14 LCC Savings Relative to the Base Case Efficiency Distribution for Non-Weatherized Gas Furnaces for Senior Only Households for Standby and Off-Mode Standards

Efficiency Level	Design Type	Life-Cycle Cost Savings	
		% of Consumers that Experience Net Cost	Average Savings* 2013$
0	Linear Power Supply	--	--
1	Linear Power Supply with LLTX	0.3%	$12
2	Switching Mode Power Supply	2.1%	$6
3	Switching Mode Power Supply with LLTX	1.3%	$13

* The calculation includes buildings with zero LCC savings (no impact).

Table 11.3.15 Average LCC and PBP Results by Efficiency Level for Mobile Home for Senior Only Households for Standby and Off-Mode Standards

Efficiency Level	Design Type	Average Cost 2013$				Simple Payback years
		Installed Cost	First Year's Operating Cost	Lifetime Operating Cost	LCC	
0	Linear Power Supply	$0	$11	$165	$165	--
1	Linear Power Supply with LLTX	$2	$10	$142	$144	1.1
2	Switching Mode Power Supply	$16	$9	$138	$154	8.6
3	Switching Mode Power Supply with LLTX	$17	$9	$127	$144	6.7

*AFUE = annual fuel utilization efficiency.

Note: The results for each EL are calculated assuming that all consumers use products with that efficiency level. The PBP is measured relative to the baseline product.

Table 11.3.16 LCC Savings Relative to the Base Case Efficiency Distribution for Mobile Home Gas Furnaces for Senior Only Households for Standby and Off-Mode Standards

Efficiency Level	Design Type	Life-Cycle Cost Savings	
		% of Consumers that Experience Net Cost	Average Savings* 2013$
0	Linear Power Supply	--	--
1	Linear Power Supply with LLTX	0.1%	$1.1
2	Switching Mode Power Supply	0.2%	$0.6
3	Switching Mode Power Supply with LLTX	0.1%	$1.2

* The calculation includes buildings with zero LCC savings (no impact).

11.3.3 Comparison of Senior-Only and Low-Income to the General Population

Table 11.3.17 and Table 11.3.20 compare the LCC savings and simple payback period for these subgroups with those for all households for AFUE standards and standby and off mode standards. Overall, the senior-only households show similar or higher LCC savings and shorter PBPs from purchasing more-efficient NWGFs for AFUE standards than the general population; however, they show reduced LCC savings and longer PBPs from purchasing more-efficient MHGFs than the general population. Low-income households show reduced LCC savings from more-efficient NWGFs for AFUE standards than the general population and longer PBPs than the general population at all ELs in all regions except for Northern households at the max tech EL, which show slightly higher LCC savings and shorter PBPs. Low-income households also show slightly reduced LCC savings and similar PBPs from more-efficient MHGFs for AFUE standards than the general population except households in the Rest of Country, which have somewhat higher LCC savings than the general population. The standby and off mode standards results are very similar between the senior-only households, low income households, and general population.

Table 11.3.17 Comparison of Average LCC Savings for Consumer Subgroups and All Households for Non-Weatherized Gas Furnaces AFUE Standards

EL	AFUE	Average Life-Cycle Cost Savings 2013$			Simple Payback Period years		
		Senior-Only	Low-Income	All Consumers	Senior-Only	Low-Income	All Consumers
National							
1	90%	$255	$176	$236	7.8	9.6	8.2
2	92%	$326	$247	$305	6.8	8.3	7.2
3	95%	$427	$330	$388	6.9	8.3	7.4
4	98%	$542	$485	$441	7.5	8.5	8.3
North							
1	90%	$223	$148	$208	7.9	9.1	8.3
2	92%	$293	$228	$277	6.9	7.8	7.2
3	95%	$405	$346	$374	6.7	7.6	7.2
4	98%	$573	$624	$467	7.1	7.5	7.7
Rest of Country							
1	90%	$293	$209	$267	7.5	10.8	8.1
2	92%	$367	$269	$336	6.7	9.6	7.1
3	95%	$454	$312	$404	7.3	10.0	7.9
4	98%	$504	$321	$412	8.6	11.7	9.6

Note: The average life-cycle cost savings is measured relative to the base case efficiency distribution. The Simple PBP is measured relative to the baseline product.

Table 11.3.18 Comparison of Average LCC Savings for Consumer Subgroups and All Households for Mobile Home Gas Furnaces AFUE Standards

EL	AFUE	Average Life-Cycle Cost Savings 2013$			Simple Payback Period Years		
		Senior-Only	Low-Income	All Consumers	Senior-Only	Low-Income	All Consumers
National							
1	92%	$429	$677	$691	4.1	2.2	2.2
2	95%	$455	$763	$778	5.5	3.4	3.3
3	97%	$415	$768	$784	6.8	4.3	4.2
North							
1	92%	$586	$746	$770	3.2	1.8	1.8
2	95%	$670	$882	$902	4.3	2.8	2.8
3	97%	$669	$921	$941	5.2	3.5	3.5
Rest of Country							
1	92%	$192	$572	$565	7.6	3.3	3.2
2	95%	$130	$583	$579	11.0	5.1	5.0
3	97%	$29	$537	$533	14.5	6.5	6.4

Note: The average life-cycle cost savings is measured relative to the base case efficiency distribution. The Simple PBP is measured relative to the baseline product.

Table 11.3.19 Comparison of Average LCC Savings for Consumer Subgroups and All Households for Non-Weatherized Gas Furnaces Standby and Off-Mode Standards

EL	Design Type	Average Life-Cycle Cost Savings 2013$			Simple Payback Period years		
		Senior-Only	Low-Income	All Consumers	Senior-Only	Low-Income	All Consumers
1	Linear Power Supply with LLTX	$12	$12	$12	1.3	1.3	1.3
2	Switching Mode Power Supply	$6	$6	$6	9.5	9.5	9.7
3	Switching Mode Power Supply with LLTX	$13	$13	$13	7.3	7.3	7.5

Note: The average life-cycle cost savings is measured relative to the base case efficiency distribution. The Simple PBP is measured relative to the baseline product.

Table 11.3.20 Comparison of Average LCC Savings for Consumer Subgroups and All Households for Mobile Home Gas Furnaces Standby and Off-Mode Standards

EL	Design Type	Average Life-Cycle Cost Savings 2013$			Simple Payback Period years		
		Senior-Only	Low-Income	All Consumers	Senior-Only	Low-Income	All Consumers
1	Linear Power Supply with LLTX	$1.1	$1.0	$0.9	1.1	1.3	1.2
2	Switching Mode Power Supply	$0.6	$0.6	$0.5	8.6	10.0	9.2
3	Switching Mode Power Supply with LLTX	$1.2	$1.2	$0.9	6.7	7.7	7.1

Note: The average life-cycle cost savings is measured relative to the base case efficiency distribution. The Simple PBP is measured relative to the baseline product.

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2. U.S. Department of Energy: Energy Information Administration, *Residential Energy Consumption Survey (RECS): 2009 RECS Survey Data,* 2009. (Last accessed January 7, 2015.) <www.eia.gov/consumption/residential/data/2009/>

CHAPTER 12. MANUFACTURER IMPACT ANALYSIS

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CHAPTER 12. MANUFACTURER IMPACT ANALYSIS

12.1 INTRODUCTION

In determining whether an energy conservation 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 residential furnaces, 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 that would be subject to this rulemaking. The GRIM inputs include information on industry cost structure, shipments, and manufacturer production costs. 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 base case (without new or amended standards) 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, cumulative regulatory burden, 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 residential gas-fired furnace 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 residential gas-fired furnace 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 residential gas-fired furnace 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 residential gas-fired furnace 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 residential gas-fired furnace 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) stock reports,[2] market research tools (*e.g.,* Hoovers[3]), corporate annual reports, and the U.S. Census Bureau's 2011 *Annual Survey of Manufacturers (ASM)*.[4] DOE also characterized these industries using information from its engineering analysis and the life-cycle cost 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 residential gas-fired furnaces. 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 residential gas-fired furnace 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 base-case projections for the industry. The financial impact of amended energy conservation standards is the difference between the discounted annual cash flows in the base 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 included (1) key issues, (2) engineering, (3) company overview and organizational characteristics, (4) markups and profitability, (5) unit warehousing costs, (6) shipment projections and market shares, (7) financial parameters, (8) conversion costs, (9) cumulative regulatory burden, (10) employment, (11) capacity, (12) industry consolidation,; (13) regional energy conservation standards, (14) impacts on small businesses, and (15) shipping costs. A redacted version of the interview guide can be found in Appendix 12B of this TSD.

12.2.3 Phase III: Subgroup Analysis

For its GRIM analysis, DOE presented the impacts on non-weatherized gas-fired furnaces and mobile home gas fired furnaces. 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 residential gas-fired furnace 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 residential gas-fired furnace 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.[5] 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
Air−Conditioning and Warm Air Heating Products and Commercial and Industrial Refrigeration Products Manufacturing	N/A	750	333415

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 the residential gas-fired furnaces 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

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[a] Based on listings in the CCMS directory accessed on October, 15 2013 (Available at: http://www.regulations.doe.gov/certification-data/).

[b] Hoovers Company Information Industry Information Lists, D&B (2014) (Available at: http://www.hoovers.com/) (Last accessed August 29, 2014).

manufacturer of covered residential gas-fired furnaces. 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 three 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 residential gas-fired furnace manufacturers in section 12.6.

12.2.3.5 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 residential gas-fired furnaces 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.

12.2.3.6 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 products (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.

12.2.3.7 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 residential gas-fired furnaces 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 feel 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 Replacement Market

Multiple manufacturers noted that an energy conservation standard set at 90 percent annual fuel utilization efficiency (AFUE) or above would make it difficult to replace substantial portions of the installed base of existing residential furnaces. They noted that some consumers may be faced with significant installation or home renovation costs when for replacing non-condensing furnaces with new condensing units due to the challenges of disposing of condensate from furnaces with efficiencies above 80 percent AFUE.

12.3.2 Product Switching

Several manufacturers stated that gas-fired furnaces may not be economically justified for certain customers, depending on the level of the amended energy conservation standard for residential furnaces. According to the manufacturers, those customers may be forced to seek alternatives with lower upfront costs. Manufacturers expressed concern that customers may opt to buy alternative products, such as heat pumps, water heater systems, or electric furnaces. Such substitutions could decrease shipments of gas-fired furnaces, which in turn would reduce industry revenue.

12.3.3 Regional Enforcement

Several manufacturers expressed concern about the potential complications of implementing and enforcing regional standards. Without a clear enforcement plan for regional standards, manufacturers were concerned about the potential burdens and impacts on their residential furnace product lines. The manufacturers noted that any amended standard should provide enough lead time between the announcement date and effective date to comply with the increased burden of a regional standard.

12.3.4 Negative Impacts on Industry Profitability

During interviews, all manufacturers agreed that if DOE set amended energy conservation standards too high, increased standards could limit their ability to differentiate residential furnace products based on efficiency. As the standard approaches max tech, manufacturers stated that there would be fewer performance differences and operating cost savings between baseline and premium products. They were concerned the drop in differentiation would lead to an erosion of markups for top efficiency products. Thus, the manufacturers' profitability would decrease with compressed product offerings and markups.

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, 2014, and continuing to 2050. The model calculates the INPV by summing the stream of annual discounted cash flows during this period and adding a discounted terminal value.[6]

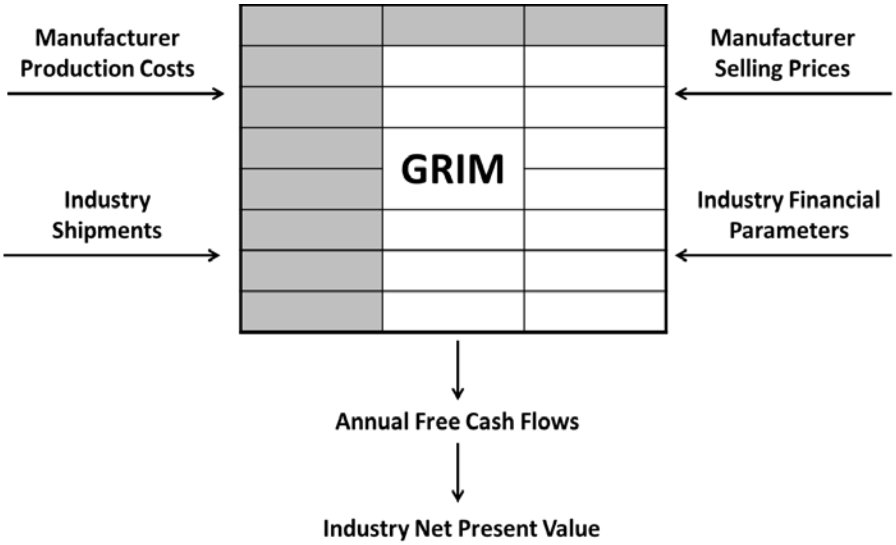

Figure 12.4.1 Using the GRIM to Calculate Cash Flow

The GRIM projects cash flows using standard accounting principles and compares changes in INPV between the base-case scenario and the standards-case scenario induced by amended energy conservation standards. The difference in INPV between the base case and the standards case(s) represents the estimated financial impact of the amended energy conservation standard on manufacturers. Appendix 12A provides more technical details and user information for the GRIM.

12.4.2 Sources for GRIM Inputs

The GRIM uses several different sources for data inputs in determining industry cash flow. These sources include prior company profiles, census data, rulemaking financial metrics, the shipments model, the engineering analysis, and the manufacturer interviews.

12.4.2.1 Corporate Annual Reports

Corporate annual reports to the U.S. Securities and Exchange Commission (SEC10-K reports) 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 residential gas-fired furnaces. 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 base 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 residential gas-fired furnaces 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;
- and possible profitability impacts.

12.4.3 Financial Parameters

Table 12.4.1 provides financial parameters for six public companies engaged in manufacturing and selling residential gas-fired furnaces. The values listed are averages over a seven-year period (2007 to 2013).

Table 12.4.1 Financial Parameters used for Residential Gas-Fired Furnaces GRIM

Parameter	Industry-Weighted Average	Manufacturers					
		A	B	C	D	E	F
Tax Rate (% of Taxable Income)	29.1	27.4	34.9	35.3	40.5	17.0	13.9
Working Capital (% of Revenue)	23.5	36.8	22.0	10.1	14.4	16.0	19.6
SG&A (% of Revenue)	15.0	11.2	18.0	19.7	21.2	19.0	11.6
R&D (% of Revenues)	2.1	3.4	0.0	1.6	1.8	1.7	0.5
Depreciation (% of Revenues)	2.2	2.4	2.3	1.7	2.9	2.3	1.5
Capital Expenditures (% of Revenues)	1.7	2.0	1.6	1.8	1.2	1.5	1.2
Net Property, Plant, and Equipment (% of Revenues)	15.9	24.2	24.0	10.2	10.6	12.6	9.0

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 Base Case Markup

	Manufacturer					
	A	B	C	D	E	F
Average Net Revenues ($Million)	56,611.29	202.52	3,164.29	2,139.26	12,299.97	1,888.08
Corporate Gross Margin (%)	27.2	23.1	26.8	27.8	28.0	26.1
Markup	1.37	1.30	1.37	1.39	1.39	1.35

Table 12.4.2 lists the average net revenues, estimated corporate gross margin, and estimated manufacturer markup for the years 2007 to 2013 for the six manufacturers. The weighted average of the estimated manufacturer markup based on public filings by these six companies is 1.37. To further refine the base 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 Base Case Manufacturer Markups

Equipment	Markup
Non-Weatherized Gas Furnace – North	1.34
Non-Weatherized Gas Furnace – Rest of Country	1.34
Mobile Home Gas Furnace - North	1.27
Mobile Home Gas Furnace – Rest of Country	1.27

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 residential gas-fired furnace industry based on six representative companies, using the following formula:

$$WACC = After\text{-}Tax\ Cost\ of\ Debt \times (Debt\ Ratio) + Cost\ of\ Equity \times (Equity\ Ratio)$$

The cost of equity is the rate of return that equity investors (including, potentially, the company) expect to earn on a company's stock. These expectations are reflected in the market price of the company's stock. The Capital Asset Pricing Model (CAPM) provides one widely used means to estimate the cost of equity. According to the CAPM, the cost of equity (expected return) is:

$$Cost\ of\ Equity = Riskless\ Rate\ of\ Return + \beta \times Risk\ Premium$$

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 residential gas-fired furnace industry is 12.82 percent (Table 12.4.4).

Table 12.4.4 Cost of Equity Calculation

Parameter	**Industry Weighted Average**	**A**	**B**	**C**	**D**	**E**	**F**
(1) Average Beta	1.2	1.1	0.2	1.4	0.9	1.7	-
(2) Average Yield on 10-Year Bonds (1928-2012) (%)	5.1						
(3) Market Risk Premium (%)	6.4						
Cost of Equity (2)+[(1)*(3)](%)	12.8						
Equity/Total Capital(%)	64.4	62.7	92.2	67.6	75.9	69.3	53.1

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 5.12 percent, which is the average 10-year Treasury bond rate between 1928 and 2013.

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 5.12 percent to determine the gross cost of debt for each company. It then calculated an industry weighted average gross cost of debt of 7.2 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

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[c] For one of the six manufacturers, S&P bond ratings were not available. In these cases, DOE estimated the companies' synthetic bond ratings based on their 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: http://www.stern.nyu.edu/~adamodar/pc/ratings.xls

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	D	E	F
S&P Bond Rating		BB+	BB+	BB+	BB+	BB+	BB+
(1) Avg. Yield on 10-Yr Bonds (1928-2012) (%)	5.1						
(2) Gross Cost of Debt (%)	7.2	6.2	5.7	6.8	10.2	6.8	8.2
(3) Tax Rate (%)	29.1	27.4	34.9	35.3	40.5	17.0	32.9
Net Cost of Debt (2) x [1-(3)] (%)	5.1						
Debt/Total Capital (%)	35.6	37.3	7.8	32.4	24.1	30.7	54.1

Using public information for these six companies, the initial estimate for the industry's nominal WACC was approximately 10.1 percent. Subtracting an inflation rate of 3.06 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 7.01 percent. DOE also asked for feedback on the discount rate during manufacturer interviews. Based on this feedback, DOE used a discount rate of 6.4 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 groupings of efficiency levels for all products types. Table 12.4.6 presents the TSLs used for energy efficiency analysis in the GRIM.

Table 12.4.6 Trial Standard Levels for Energy Efficiency Analysis of Residential Gas-Fired Furnaces

Products Class	Baseline	TSL1	TSL2	TSL3	TSL4	TSL5
Non-Weatherized Gas Furnace – North	Baseline	EL 1	EL 3	EL 2	EL 3	EL 4
Non-Weatherized Gas Furnace – Rest of Country	Baseline	Baseline	Baseline	EL 2	EL 3	EL 4
Mobile Home Gas Furnace - North	Baseline	EL 1	EL 2	EL 1	EL 2	EL 3
Mobile Home Gas Furnace – Rest of Country	Baseline	Baseline	Baseline	EL 1	EL 2	EL 3

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 standard level 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 base 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 2021 and beyond. The NIA assumes that product efficiencies in the base 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 base case who purchase units above the standard level are not affected as they are assumed to continue to purchase the same base case unit in the standards case. See chapter 11 of this TSD for more information on the residential gas-fired furnaces 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 manufacture than baseline products (as shown in chapter 5 of this TSD). 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. DOE used two sets of MPCs in the GRIM. Both sets were derived from the engineering analysis. One set of MPCs was applied in the years 2014 to 2018, before the furnace fan energy conservation standard goes into effect. The second set of MPCs was applied from 2019 onward, after the furnace fan energy conservation standard goes into effect. The primary driver of cost differences between the sets of MPCs is the cost of the furnace fan motor as well as the addition of multi-stage combustion. Furthermore, to be consistent with assumptions in the NIA, the MPCs presented in the engineering analysis were supplemented with market share weighted price adders to reflect the current portion of the market using electronically commutated motors and the portion of the market requiring low NOx burner technology.

To calculate baseline MSP, DOE followed a two-step process. First, DOE derived MPCs from the engineering and teardown analyses. Second, DOE applied a manufacturer markup, which varies with the markup scenario (discussed in detail in section 12.4.9) to the MPCs. Table 12.4.7 through Table 12.4.10 shows the base case preservation of gross profit margin scenario to calculate the baseline MSP.

Table 12.4.7 Pre-2019 Manufacturer Production Cost Breakdown ($2013) for NWGFs

Efficiency Level	Materials	Labor	Depreciation	Overhead	MPC	Markup	MSP
Baseline	$253.49	$24.13	$8.26	$9.05	$294.93	1.34	$395.21
EL 1	$328.14	$34.01	$10.69	$8.94	$381.78	1.34	$511.58
EL 2	$335.59	$35.71	$10.93	$8.22	$390.45	1.34	$523.20
EL 3	$448.62	$48.26	$14.64	$11.16	$522.68	1.34	$700.40
EL 4	$558.74	$57.87	$18.16	$13.85	$648.63	1.34	$869.16

Table 12.4.8 Pre-2019 Manufacturer Production Cost Breakdown ($2013) for MHGF

Efficiency Level	Materials	Labor	Depreciation	Overhead	MPC	Markup	MSP
Baseline	$262.32	$28.28	$12.92	$13.14	$316.70	1.27	$402.21
EL 1	$352.16	$35.55	$10.23	$16.36	$414.30	1.27	$526.16
EL 2	$395.19	$43.72	$12.46	$18.76	$470.13	1.27	$597.07
EL 3	$459.17	$50.80	$10.34	$15.54	$535.85	1.27	$680.53

Table 12.4.9 Manufacturer Production Cost Breakdown ($2013) for NWGFs

Efficiency Level	Materials	Labor	Depreciation	Overhead	MPC	Markup	MSP
Baseline	$326.58	$31.09	$10.64	$11.66	$379.97	1.34	$509.16
EL 1	$401.23	$41.59	$13.07	$10.93	$466.82	1.34	$625.54
EL 2	$408.68	$43.49	$13.31	$10.01	$475.49	1.34	$637.15
EL 3	$469.88	$50.55	$15.33	$11.69	$547.46	1.34	$733.59
EL 4	$558.74	$57.87	$18.16	$13.85	$648.63	1.34	$869.16

Table 12.4.10 Manufacturer Production Cost Breakdown ($2013) for MHGF

Efficiency Level	Materials	Labor	Depreciation	Overhead	MPC	Markup	MSP
Baseline	$267.38	$28.83	$13.17	$13.40	$322.81	1.27	$409.97
EL 1	$357.35	$36.07	$10.38	$16.61	$420.41	1.27	$533.92
EL 2	$422.26	$46.72	$13.31	$20.04	$502.33	1.27	$637.96
EL 3	$486.76	$53.85	$10.96	$16.47	$568.05	1.27	$721.42

DOE also calculated additive costs for meeting standby and off mode efficiency levels. Table 12.4.11 presents DOE's estimates of the incremental MPCs of each standby mode and off mode efficiency level for this rulemaking. These MPC adders were the same for NWGF and MHGF product classes.

Table 12.4.11 Incremental Manufacturer Production Cost for Non-Weatherized Gas-Fired and Mobile Home Gas-Fired Furnaces Standby Mode and Off Mode

Efficiency Level	Standby Mode and Off Mode Power Consumption (W)	Incremental MPC ($)
Baseline	11	0
EL1	9.5	1.00

EL2	9.2	10.47
EL3	8.5	11.12

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

Capital Conversion Cost by Efficiency Level

To estimate capital conversion costs, DOE used a top-down approach that began by interviewing manufacturers and learning what each manufacturer estimated to be level of investment to meet the proposed efficiency levels. The manufacturers' estimates were aggregated into a market share weighted average at each efficiency level. This per-manufacturer conversion costs were then multiplied by the number of manufacturers in the industry to determine cumulative capital conversion cost at each efficiency level for the industry. DOE's analysis found ten NWGF manufacturers and five MHGF manufacturers.

Table 12.4.12 NWGF Industry Capital Conversion Cost by Efficiency Level ($MM)

Efficiency Level	Cumulative Capital Conversion Cost
EL 1	29.55
EL 2	33.53
EL 3	60.81
EL 4	189.94

Table 12.4.13 MHGF Industry Capital Conversion Cost by Efficiency Level ($MM)

Efficiency Level	Cumulative Capital Conversion Cost
EL 1	5.00
EL 2	5.00
EL 3	10.00

Capital Conversion Cost by TSL

DOE evaluates regional standards in TSL 1 and TSL 2. DOE assumed that capital conversion costs would scale with regional shipments. For example, a national standard at 95-percent AFUE would require greater conversion costs than regional standard at 95-percent AFUE for the North and 80-percent AFUE for the Rest of Country. A national condensing standard would require the industry to add more secondary heat exchanger capacity than a regional condensing standard for a portion of the country. DOE used a North/Rest-of-Country shipment weighting to estimate conversion costs for regional standards. The shipment volume breakdowns by region for 2014 are shown below in table Table 12.4.14. The cumulative capital conversion costs by TSL and product class are listed below in Table 12.4.15.

Table 12.4.14 Shipment Weightings for Capital Conversion Costs

Product Class	Shipment Volume Breakdowns by Region and Product Class
NWGF - North	52%
NWGF- Rest of Country	48%
MHGF - North	31%
MHGF- Rest of Country	69%

Table 12.4.15 NWGF Cumulative Capital Conversion Costs by TSL ($MM)

TSL	NWGF	MHGF
TSL 1	15.40	1.55
TSL 2	31.68	1.55
TSL 3	33.53	5.00
TSL 4	60.81	5.00
TSL 5	189.94	10.00

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 at each efficiency level as a starting point for the derived product conversion costs. The estimates were then aggregated into market share weighted averages by efficiency level. The per-manufacturer cumulative product conversion costs were then multiplied by the number of manufacturers in each respective industry to determine cumulative capital conversion cost at each efficiency level for the industry.

DOE's analysis found ten NWGF manufacturers. The per-manufacturer product conversion cost for each efficiency level was multiplied by ten to estimate industry cumulative product conversions. NWGF industry cumulative product conversion costs are shown below in Table 12.4.16.

Table 12.4.16 NWGF Cumulative Product Conversion Costs ($MM)

Efficiency Level	Cumulative Capital Conversion Cost
EL 1	13.77
EL 2	14.47
EL 3	21.00
EL 4	60.36

DOE's analysis found five MHGF manufacturers. The per-manufacturer cumulative conversion cost was multiplied by five to derive industry product conversion cost by efficiency level. MHGF industry cumulative product conversion costs are shown below in Table 12.4.17.

Table 12.4.17 MHGF Cumulative Product Conversion Costs ($MM)

Efficiency Level	Cumulative Capital Conversion Cost
EL 1	2.00
EL 2	2.00
EL 3	4.00

Product Conversion Cost by TSL

DOE determined that product conversion costs do not scale by sales volume. A regional condensing standard would require the same R&D investments as a national condensing standard, as manufacturers seek to design a cost-optimized product based on the proposed standard level. Product conversion costs by TSL are shown below in Table 12.4.18.

Table 12.4.18 Cumulative Product Conversion Cost by TSL ($MM)

TSL	NWGF	MHGF
TSL 1	13.77	2.00
TSL 2	21.00	2.00
TSL 3	14.47	2.00
TSL 4	21.00	2.00
TSL 5	60.36	4.00

Standby Mode and Off Mode Conversion Costs

Standby mode and off mode conversion costs represent the costs associated with reducing electrical energy consumption during periods when the furnace is in standby mode or off mode. DOEs analysis determined that there would be minimal capital conversion costs necessary to meet standby and off mode efficiency levels. DOE did determine that there would be product conversion costs associated with standby mode and off mode efficiency levels.

Standby mode and off mode product conversion costs were derived with a Bottom-Up approach that examined the number of product platforms requiring redesign at various efficiency levels. DOE estimated an approximate per-platform product conversion cost of $45,000, which incorporated R&D, testing, and marketing material changes. DOE multiplied the per-platform standby mode product conversion cost by the number of platforms that would require redesign to arrive at the conversion costs in Table 12.4.19.

Table 12.4.19 Standby Mode and Off Mode Cumulative Conversion Cost by TSL ($MM)

TSL	NWGF	MHGF
TSL 1	2.98	0.057
TSL 2	2.98	0.057
TSL 3	3.83	0.073

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 base case, DOE used the same markups applied in the engineering analysis. In the standards case, DOE modeled three 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, (2) a preservation of operating profit scenario, and (3) a three-tiered 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. DOE assumed the non-production cost markup—which includes SG&A expenses, R&D expenses, interest, and profit— to be 1.34 for NWGFs and 1.27 for MHGFs in the base 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.

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 one year after the compliance date of the new energy conservation standards is the same as in the base case. 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 base-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 base case and standards case.

12.4.9.3 Three-Tiered Scenario

DOE also modeled a second lower bound profitability scenario, a three-tiered markup scenario, which represents the most severe impacts on industry net present value. DOE implemented the three-tiered markup scenario because multiple manufacturers stated during interviews that they offer three tiers of equipment lines that are differentiated, in part, by efficiency levels that represent "good, better, and best" product line offerings. The high efficiency tiers typically earn a premium over the baseline efficiency tier. In the three-tiered markup scenario, the "good" markup aligns with a baseline offering and increases through the manufacturer's highest efficiency offering which receives a "best" markup.

In the standards case, the three tier scenario modeled the situation in which product offering reduction squeezes the margin of high efficiency equipment as it becomes the new baseline, and presumably higher volume product. Table 12.4.20 and Table 12.4.21 show the representative units DOE analyzed with the corresponding three-tier markups at each selected EL.

Table 12.4.20 Three-Tiered Markups for Non-Weatherized Gas Furnaces

EL	Markups by Selected EL				
	Baseline	EL 1	EL 2	EL 3	EL 4
Baseline	1.293				
EL 1	1.364	1.293			
EL 2	1.364	1.293	1.293		
EL 3	1.364	1.364	1.364	1.293	
EL 4	1.466	1.466	1.466	1.364	1.293

Table 12.4.21 Three Tiered Markups for Mobile Home Gas Furnaces

EL	Markups by Selected EL			
	Baseline	EL 1	EL 2	EL 3
Baseline	1.266			
EL 1	1.277	1.266		
EL 2	1.277	1.277	1.266	
EL 3	1.397	1.397	1.277	1.266

12.5 INDUSTRY FINANCIAL IMPACTS

Using the inputs and scenarios described in the previous sections, the GRIM estimated indicators of financial impacts on the residential gas-fired furnace industry. The following sections detail additional inputs and assumptions for residential gas-fired furnaces. 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.

12.5.1 Introduction

The INPV measures the industry value and is used in the MIA to compare the economic impacts of different TSLs in the standards case. The INPV is different from DOE's 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 2014 to 2050, 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 (2014 – 2020) and a long-term assessment over the analysis period used in the NIA (2021 – 2050).

In the MIA, DOE compares the INPV of the base case (no amended energy conservation standards) to that of each TSL in the standards case. The difference between the base-case and a standards-case INPV is an estimate of the economic 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 one or two years could strain the industry's access to capital. Consequently, the sharp drop in financial performance could cause investors to flee, even 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, 2014. 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.

12.5.2 Impacts on Residential Gas-Fired Furnace Industry Net Present Value

The markup scenarios modeled yield three sets of results: (1) preservation of gross Margin, (2) per unit preservation of operating profit, and (3) three tier scenario. 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 three tier scenario show in Table 12.5.3. The middle of the range of impacts is the per unit preservation of operating profit scenario shown in Table 12.5.2. The upper bound of the range of impacts is the preservation of gross margin scenario shown in Table 12.5.1.

Table 12.5.1 Preservation of Gross Margin Percentage Scenario: Impacts in INPV

	Units	Base Case	Trial Standard Level				
			1	2	3	4	5
INPV	2013($ MM)	1,055.13	1,049.23	1,063.76	1,064.35	1,103.17	1,084.42
Change in INPV	2013($ MM)	-	(5.91)	8.63	9.21	48.04	29.28
	(%)	-	(0.56)	0.82	0.87	4.55	2.78

Table 12.5.2 Preservation of Per Unit Operating Profit Scenario: Impacts in INPV

	Units	Base Case	Trial Standard Level				
			1	2	3	4	5
INPV	2013($ MM)	1,055.13	1,032.62	1,011.02	1,037.84	992.20	801.00
Change in INPV	2013($ MM)	-	(22.52)	(44.11)	(17.30)	(62.94)	(254.14)
	(%)	-	(2.13)	(4.18)	(1.64)	(5.96)	(24.09)

Table 12.5.3 Three Tier Scenario: Impacts in INPV

	Units	Base Case	Trial Standard Level				
			1	2	3	4	5
INPV	2013$ MM	1,055.13	990.91	825.40	972.99	742.42	548.11
Change in INPV	2013$ MM	-	(64.23)	(229.73)	(82.14)	(312.71)	(507.03)

	(%)	-	(6.09)	(21.77)	(7.79)	(29.64)	(48.05)

12.5.3 Impacts on Residential Gas-Fired Furnace 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 one or two years could strain the industry's access to capital. Consequently, the sharp drop in financial performance could cause investors to flee, even 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 12.5.3 below present the annual free cash flows from 2013 through 2050 for the base case and different TSLs in the standards case.

Annual cash flows are discounted to the base year, 2014. Between 2014 and the 2021 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.

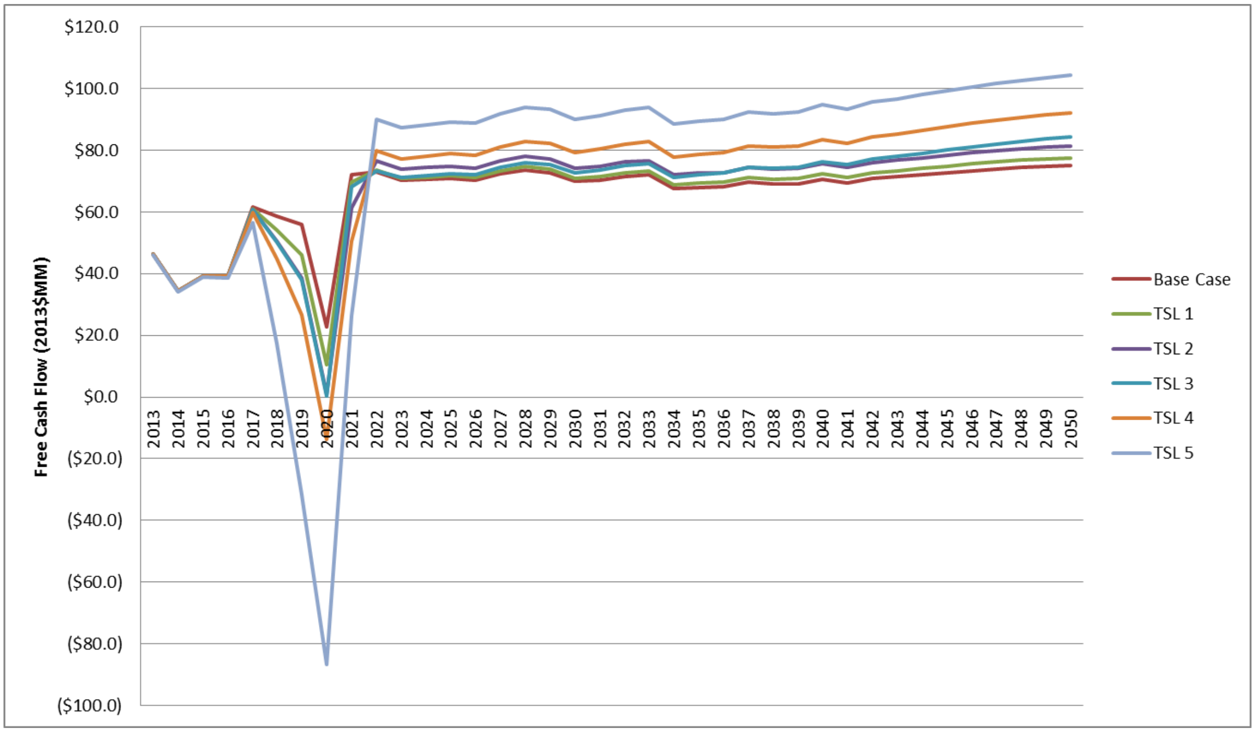

Figure 12.5.1 Annual Industry Free Cash Flows for Residential Gas-Fired Furnaces – Preservation of Gross Margin Markup Scenario

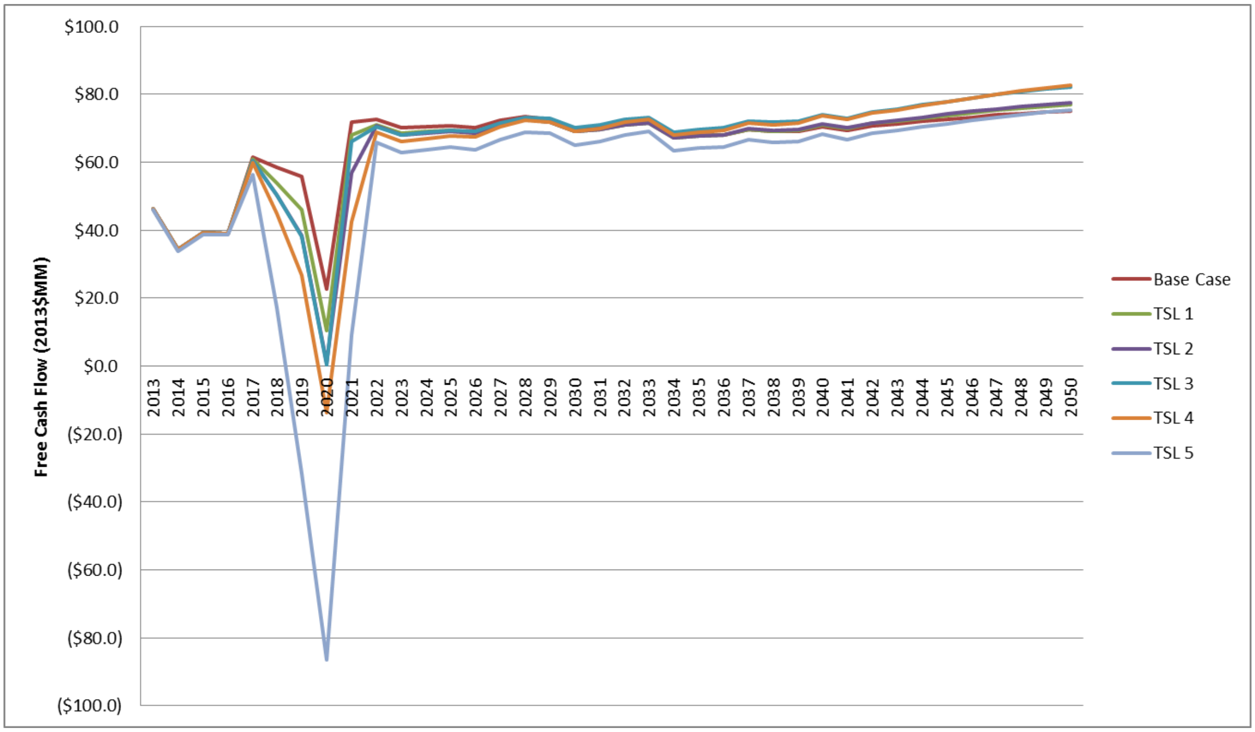

Figure 12.5.2 Annual Industry Free Cash Flows for Residential Gas-Fired Furnaces – Per Unit Preservation of Operating Profit Markup Scenario

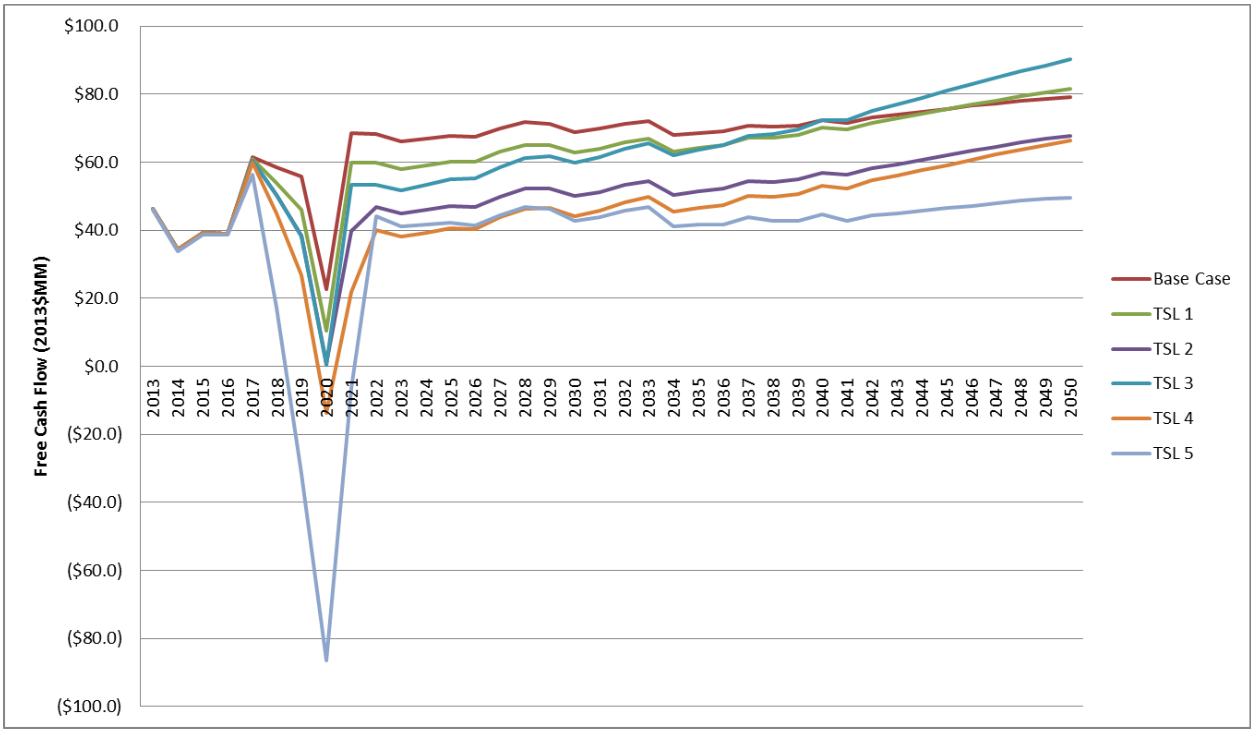

Figure 12.5.3 Annual Industry Free Cash Flows for Residential Gas-Fired Furnaces – Three Tier Markup Scenario

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 NWGF and MHGF 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 NWGF and MHGF 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. Out of 12 manufacturers DOE was able to identify, 4 manufacturers were classified as meeting the SBA's definition of a "small business" that manufactures products covered by this rulemaking. Three of those small manufacturers were domestic companies.

DOE attempted to contact all the small domestic business manufacturers of NWGFs and MHGFs it had identified. None of the small businesses consented to formal MIA interviews. DOE also attempted to obtain information about small business impacts while interviewing large manufacturers.

Of the three small domestic manufacturers identified, one manufacturer was a NWGF manufacturer and two manufacturers were MHGF manufacturers. The small domestic NWGF manufacturer focuses on the residential furnace market and accounts for approximately 7 percent of the listings in the DOE Certification Compliance Database. This small manufacturer has condensing furnace product offerings, with 9 percent of its models meeting the proposed national standard level of 92-percent AFUE. In comparison, the NWGF industry as a whole has 46 percent of listings at or above 92-percent AFUE.

DOE made several key assumptions to estimate the conversion costs for small NWGF manufacturers. First, DOE assumed that conversion costs scaled with the number of model listings. Second, DOE assumed that small manufacturers accounted for 2 percent of NWGF industry revenues based on a 2003 market research report[d]. Using these assumptions, DOE estimates the impacts on small manufacturer relative to large manufacturers in Table 12.6.1.

Table 12.6.1 Impacts on Small Manufacturers Relative to Large Manufacturers

	Total Conversion Cost as a Percentage of Revenue	Total Conversion Cost as a Percentage of EBIT	Capital Conversion Cost as a Percentage of Annual Capex	Product Conversion Cost as a Percentage of Annual R&D

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[d] The Share-of-Market Picture for 2003. Appliance Magazine, 2004.61(9): pp. 65.

Average Small Manufacturer	18%	304%	605%	148%
Average Large Manufacturer	3%	60%	99%	50%

These results suggest that small NWGF manufacturers could be at a disadvantage relative to the large NWGF manufacturers. In general, small manufacturers must make many of the same product redesign and cost optimization investments as their larger competitors. However, for the small manufacturer these upfront investments are spread over a smaller volume of shipments and smaller revenue base, making cost recovery more difficult.

The two small manufacturers producing MHGFs together account for approximately 32 percent of MHGF listings in the DOE Certification Compliance Database. These two manufacturers have zero listings at or above 92-percent AFUE, the proposed national standard level. In comparison, the MHGF industry as a whole has 58 percent of listings at or above 92-percent AFUE. These two small MHGF manufacturers would thus need to upgrade all product lines to remain in the industry. DOE estimates industry average conversion costs of approximately $0.9 million per company at this the proposed standard level. However, these estimates are driven by feedback from manufacturers who have condensing products today. Given that the two small manufacturers will need to develop a condensing product line from scratch, they may face substantially higher conversion costs for R&D and, perhaps, for tooling-up production of secondary heat exchangers. At the proposed AFUE standard level, the two small manufacturers may re-evaluate the cost-benefit of staying in the MHGF market.

DOE has tentatively concluded that the impacts of the standby mode and off mode requirements on small business are small relative to the AFUE standard impacts. Based on the engineering analysis, the cost of standby mode and off mode components are small to the overall cost of a residential furnace. DOE estimates that the standby mode and off mode requirements would add between $1 to $10 to the MPC of NWGF products (which ranges from $380 to $650) and to the MPC of MHGF products (which range from $323 to $568). The engineering analysis suggests that the design paths required to meet the standby mode and off mode requirements consist of relatively straight-forward component swaps. Additionally, the INPV and short-term cash flow impacts of the standby mode and off mode requirements are dwarfed by the impacts of the AFUE standard. In general, the impacts of the standby and off mode standard are significantly smaller than the impacts of the AFUE standard. For this reason, the IRFA focuses on the impacts of the AFUE standard.

12.7 OTHER IMPACTS

12.7.1 Impacts on Direct Employment

To quantitatively assess the potential impacts of amended energy conservation standards on direct employment in the residential furnaces industry, DOE used the GRIM to estimate the domestic labor expenditures and number of direct employees in the base case and at each standards case (TSL) from 2014 through 2050. DOE used statistical data from the U.S. Census Bureau's 2011 Annual Survey of Manufacturers,[e] 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 2011 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 NWGFs and MHGFs, as compared to the base case. Table 12.7.1 shows the range of impacts of a potential amended energy conservation standard on U.S. production workers of residential gas-fired furnace products.

Table 12.7.1. Potential Changes in the Total Number of Production Workers in the Residential Gas-Fired Furnace Industry in 2020

	Trial Standard Level					
	Base Case	**1**	**2**	**3**	**4**	**5**
Total Number of Domestic Production Workers in 2020 (without changes in production locations)	2706	2758	2849	2982	3081	3299
Potential Changes in Domestic Production Workers in 2020*	-	(2706) to 52	(2706) to 143	(2706) to 276	(2706) to 375	(2706) to 593

* DOE presents a range of potential employment impacts. Numbers in parentheses indicate negative values.

In the absence of amended energy conservation standards, DOE estimates that the residential gas-fired furnace industry would employ 2,706 domestic production workers in 2020. The upper end of the range estimates the maximum increase in the number of production workers in the residential gas-fired furnace industry after implementation of an energy conservation standard at each TSL. It assumes manufacturers would continue to produce the same scope of covered products within the United States and would require some additional labor to produce more-efficient products. To establish a conservative lower bound, DOE assumes

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[e] U.S. Census Bureau, Annual Survey of Manufacturers: General Statistics: Statistics for Industry Groups and Industries (2011) (Available at http://www.census.gov/manufacturing/asm/index.html).

the entire industry shifts production to foreign countries. Some large manufacturers have already begun moving production to lower-cost countries, and an amended standard that necessitates large increases in labor content or that requires large expenditures to re-tool facilities could cause other manufacturers to re-evaluate production siting options.

DOE notes that its estimates of the impacts on direct employment are based on the analysis of amended AFUE energy efficiency standards only. Standby mode and off mode technology options considered in the engineering analysis would result in component swaps, which would not make the product significantly more complex and would not be difficult to implement. While some product development effort would be required, DOE does not expect the standby mode and off mode standard to meaningfully affect the amount of labor required in production. Consequently, DOE does not anticipate that the proposed standby mode and off mode standards will have a significant impact on direct employment.

These employment impact conclusions are independent of conclusions regarding indirect employment impacts in the broader United States economy, which are discussed in chapter 15 of this TSD.

12.7.2 Impacts on Manufacturing Capacity

According to residential gas-fired furnace manufacturers interviewed, production facilities as they are today may not be able to accommodate a large shift to condensing furnaces, if such shift were mandated by an energy conservation standard. However, manufacturers would be able to add capacity and adjust product designs between the announcement year of the standard and the compliance year of the standard. DOE interviewed manufacturers representing over 50 percent of industry sales. None of the interviewed manufacturers expressed concern over the industry's ability to ramp up production lines at TSL 1 to TSL 4 to meet consumer demand. At TSL 5, technical uncertainty was expressed by manufacturers that do not offer 98-percent AFUE products today, as they were unsure what production lines changes would be needed to meet a standard set at max-tech.

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 NWGF and MHGF manufacturers that will take effect approximately three years before or after the 2021 compliance date of amended energy conservation standards for NWGF and

MHGF. In interviews, manufacturers cited Federal regulations on equipment other than NWGF and MHGF 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 12.7.2.

Table 12.7.2 Compliance Dates and Expected Conversion Expenses of Federal Energy Conservation Standards Affecting NWGF and MHGF Manufacturers

Federal Energy Conservation Standards	Approximate Compliance Date	Estimated Total Industry Conversion Expense
Commercial Packaged Air Conditioners and Heat Pumps* 79 FR 58948 (September, 30, 2014)	2018	$226.4M (2013$)
Commercial Warm-Air Furnaces* 80 FR 6182 (February 4, 2015).	2018	$19.9M (2013$)
2014 Furnace Fans 79 FR 38130 (July 3, 2014)	2019	$40.6M (2013$)
Miscellaneous Residential Refrigeration*	2019	TBD
Single Packaged Vertical Units* 79 FR 78614 (December 30, 2014)	2019	$7.2M (2013$)
Commercial Water Heaters*	2019	TBD
Commercial Packaged Boilers*	2020	TBD
Residential Water Heaters*	2021	TBD
Clothes Dryers*	2022	TBD
Central Air Conditioners*	2022	TBD
Room Air Conditioners*	2022	TBD
Commercial Packaged Air Conditioning and Heating Equipment (Evaporatively and Water Cooled) *	2023	TBD

*The final rule for these energy conservation standards 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.)

DOE notes that furnace fans standard creates a unique cumulative burden because today's proposed residential furnace standard and the furnace fans standard impact the same products (i.e., residential furnaces), affect the same group of manufacturers, and go into effect in a similar timeframe. The furnace fans standard goes into effect in 2019 and the residential furnaces standard is expected to have an effective date in 2021. A detailed summary of manufacturer impacts from the furnace fans final rule can be found in Table 12.7.3. DOE explicitly notes the additional burdens of the furnace fan rule when weighing the benefits and costs of the trial standard levels in Section V.C.1 of the residential furnaces notice.

Table 12.7.3 Summary of Manufacturer Financial Impacts from the Furnace Fans Final Rule

	Units	Furnace Fans Final Rule
INPV	$M	290.6 to 397.8
Change in INPV	$M	(59.0) to 48.2
	(%)	(16.9) to (13.8)

Product Conversion Costs	$M	25.5
Capital Conversion Costs	$M	15.1
Total Conversion Costs	$M	40.6

*Values in parentheses are negative values.

12.8 CONCLUSION

The following section summarizes the impacts for the scenarios DOE believes are most likely to capture the range of impacts on manufacturers of residential gas-fired furnaces 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. Active mode results are shown below in 12.8.1 and standby mode results are shown in 12.8.2.

12.8.1 Active Mode Results

Table 12.8.1 summarizes the upper and lower bound active mode INPV impacts and conversion costs projected to result from each of the trial standard levels analyzed.

Table 12.8.1 AFUE Standards Results for Active Mode Residential Gas-Fired Furnaces

	Units	Base Case	Trial Standard Level*				
			1	2	3	4	5
INPV	$MM	1055.13	990.43 to 1048.71	825.26 to 1063.45	971.41 to 1061.65	740.79 to 1099.24	548.20 to 1080.94
Change in INPV	$MM	-	(64.71) to (6.42)	(229.87) to 8.32	(83.72) to 6.52	(314.34) to 44.10	(506.94) to 25.80
	%	-	(6.13) to (0.61)	(21.79) to 0.79	(7.93) to 0.62	(29.79) to 4.18	(48.04) to 2.45
2020 Free Cash Flow (FCF)	$MM	22.55	10.32	0.88	0.41	(13.78)	(86.21)
Change in 2020 FCF	$MM	-	(12.23)	(21.67)	(22.15)	(36.33)	(108.76)
	%	-	(54.22)	(96.09)	(98.19)	(161.08)	(482.22)
Product Conversion Costs	$MM	-	15.77	23.00	16.47	23.00	64.36
Capital Conversion Costs	$MM	-	16.95	33.24	38.53	65.81	199.94

At TSL 1, DOE estimates the change in INPV to range from -$64.71 million to -6.42 million, or a change of -6.13 percent to -0.61 percent. At this level, industry free cash flow in 2020 (the year before the compliance date) is estimated to decrease to $10.32 million, or a change of -54.22 percent compared to the base-case value of $22.55 million.

TSL 1 proposes regional standards, requiring products the North to meet an efficiency level above the baseline while the Rest of Country remains at the current Federal minimum of 80-percent AFUE. NWGF products in the North would be required to meet a minimum efficiency of 90-percent AFUE while MHGF products in the North would be required to meet a minimum efficiency of 92-percent AFUE. Conversion costs are driven by the need for manufacturers to add a secondary condensing heat exchanger production capacity. Today, approximately 39 percent of NWGF shipments and 17 percent of MHGF shipments are sold at condensing levels. When the standard goes into effect, an additional 23 percent of NWGF shipments and 22 percent of MHGF will require secondary heat exchangers, requiring manufacturers to add capacity to their secondary heat exchanger production lines. Manufacturers will also incur product conversion costs driven by the development necessary to create compliant, cost competitive products. DOE estimates total conversion costs to be $32.72 million for the industry.

At TSL 2, DOE estimates the change in INPV to range from -$229.87 million to $8.32 million, or a change in INPV of -21.79 percent to -0.79 percent. At this level, free cash flow in 2020 is estimated to decrease to $0.88 million, or a decrease of 96.09 percent compared to the base-case value of $22.55million in the year 2020.

TSL 2 is a regional standard requiring the North to meet efficiency levels above the baseline while the Rest of Country remains at baseline. NWGFs and MHGFs in the North would be required to meet a minimum efficiency of 95-percent AFUE. Manufacturer feedback in interviews indicated that capital conversion costs ramp up significantly at 95-precent AFUE. DOE estimates total conversion costs to be $56.24 million for the industry.

Furthermore, most 95-percent AFUE products today are premium offerings that are sold at a higher markup than baseline products. Once 95-percent AFUE becomes the amended baseline standard in the North, manufacturers would need to investment engineering resources to create baseline, cost-optimized 95-percent AFUE models that are competitive at reduced markups. Additionally, manufacturers may find markups for products above 95-percent AFUE in the North are reduced, as there is less opportunity for differentiation based on efficiency between baseline products and premium products. This general reduction in markups in the North leads to reduced profitability for manufacturers and a potential drop in INPV.

At TSL 3, DOE estimates the change in INPV to range from -$83.72 million to $6.52 million, or a change in INPV of -7.93 percent to 0.62 percent. At this level, free cash flow is estimated to decrease to $0.41 million, or a change of -98.19 percent compared to the base-case value of $22.55 million in the year 2020.

TSL 3 represents a national standard at 92-percent AFUE for both NWGF and MHGF products. With a national condensing standard, an additional 61 percent of NWGF and an additional 83 percent of MHGF industry shipments would need condensing heat exchangers. That increase would require manufacturers to add significant secondary heat exchanger capacity to their operations. Models accounting for 65 percent of NWGF shipments and 83 percent of MHGF shipments would need to be redesigned. Industry conversion costs reach $55 million.

At 92-percent AFUE, the industry faces some compression of markups. However, on the whole, manufacturers are still able to maintain three tiers of markups with efficiency as a differentiator. As a result, even though TSL 3 conversion costs as similar to those at TSL 2, the INPV impacts are not as severe.

At TSL 4, DOE estimates the change in INPV to range from -$314.34 million to $44.10 million, or a change in INPV of -29.79 percent to 4.18 percent. At this level, free cash flow is estimated to decrease to -$13.78 million, or a change of -161.08 percent compared to the base-case value of $22.55 million in the year 2020.

TSL 4 represents a national standard at 95-percent AFUE for both NWGF and MHGF products. Manufacturers would need to add significant secondary heat exchanger capacity. Additionally, manufacturers would need to redesign a models accounting for 79 percent of NWGF shipments and 92 percent of MHGF shipments. Industry conversion costs reach $88.81 million. These conversion costs are a significant drain on industry cash flow and could results in manufacturers seeking outside capital to finance the conversion expenses.

At 95-percent AFUE, the industry faces significant compression of markups. As noted at TSL 2, most 95-percent AFUE products today are premium offerings that are sold at a higher markup than baseline products. Once 95-percent AFUE becomes the amended baseline standard, manufacturers would need to investment engineering resources to create baseline, cost-optimized 95-percent AFUE models that are competitive at reduced markups. Additionally, there is less opportunity for differentiation between baseline products and premium products, resulting in reduced markups for products that have premium efficiencies. This reduction in markups leads to reduced profitability for manufacturers and a potential drop in INPV.

At TSL 5, DOE estimates the change in INPV to range from -$506.94 million to $25.80 million, or a change in INPV of -48.04 percent to 2.45 percent. At this level, free cash flow is estimated to decrease to -$86.21 million, or a decrease of 482.22 percent compared to the base-case value of $22.55 million in the year 2020. TSL 5 represents the max-tech standard level.

Some manufacturers expressed great concern about the state of technology at max tech. They had concerns about the ability to deliver cost effectiveness of these products for their customers at such a high efficiency level. They also cited high conversion costs and large investment in R&D to produce all products at this level. Total conversion costs are expected to reach $264.30 million for the industry. Additionally at max-tech, there is no opportunity for product differentiation based on efficiency. DOE models all shipments as having a baseline product markup. This results in a large drop in profitability for manufacturers in the tiered markup scenario.

12.8.2 Standby mode results

Table 12.8.2 summarizes the upper and lower bound standby and off mode INPV impacts and conversion costs projected to result from the each of the trial standard levels analyzed.

Table 12.8.2 AFUE Standards Results for Standby and Off Mode Residential Gas-Fired Furnaces

	Units	Base Case	Trial Standard Level*		
			1	2	3
INPV	$MM	1055.13	1053.41 to 1054.61	1046.10 to 1055.58	1042.97 to 1055.99
Change in INPV	$MM	-	(1.72) to (0.52)	(9.03) to 0.45	(12.16) to 0.85
	%	-	(0.16) to (0.05)	(0.86) to 0.04	(1.15) to 0.08
2020 Free Cash Flow (FCF)	$MM	22.55	22.16	22.16	22.16
Change in 2020 FCF	$MM	-	(0.39)	(0.39)	(0.39)
	%	-	(1.75)	(1.75)	(1.75)
Product Conversion Costs	$MM	-	1.35	1.35	1.35
Capital Conversion Costs	$MM	-	-	-	-

At TSL 1, DOE estimates impacts on INPV for residential gas-fired furnace manufacturers to decrease by less than one percent in both markup scenarios (preservation of gross margin and per-unit preservation of operating profit). At this potential standard level, industry free cash flow is estimated to decrease by less than two percent, compared to the base-case value of $22.55 million in 2020. DOE expects conversion costs for standby and off mode to be $1.35 million.

At TSL 2, DOE estimates impacts on INPV for residential gas-fired furnace manufacturers to range from a decrease of 0.86 percent to an increase of 0.04 percent. At this potential standard level, industry free cash flow is estimated to decrease by less than two percent, compared to the base-case value of $22.55 million in 2020. DOE expects conversion costs for standby and off mode to be $1.35 million.

At TSL 3, DOE estimates impacts on INPV for residential gas-fired furnace manufacturers to range from a decrease of 1.15 percent to an increase of 0.08 percent, or a change in INPV of -$12.16 million to $0.85 million. At this potential standard level, industry free cash flow is estimated to decrease by less than two percent compared to the base-case value of $22.55 million in 2020. DOE expects conversion costs for standby mode and off mode to be $1.35 million.

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APPENDIX 12A. GOVERNMENT REGULATORY IMPACT MODEL (GRIM) OVERVIEW

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12A.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 products with regulations taking effect over a period of time, and of multiple regulations on the same products.

Industry net present value is defined, for the purpose of this analysis, as the discounted sum of industry free cash flows plus a discounted terminal value. The model calculates the actual cash flows by year and then determines the present value of those cash flows both without an energy conservation standard (*i.e.*, the base case) and under different trial standard levels (*i.e.*, the standards case).

Output from the model consists of summary financial metrics, graphs of major variables, and, when appropriate, access to the complete cash flow calculation.

12A.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 “BASE DCF” and “STANDARDS CASE DCF” sheets of the GRIM.

(1) ***Revenues:*** Annual revenues – computed by multiplying products’ 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) ***Materials:*** The portion of COGS that includes materials.

(4) ***Labor:*** The portion of cost of goods sold (COGS) that includes direct labor, commissions, dismissal pay, bonuses, vacation, sick leave, social security contributions, fringe, and assembly labor up-time.

(5) ***Depreciation:*** The portion of overhead that includes an allowance for the total amount of fixed assets used to produce that one unit. Annual depreciation is computed as a percentage of ***COGS.*** While included in overhead, the depreciation is shown as a separate line item.

(6) ***Overhead:*** The portion of COGS that includes indirect labor, indirect material, energy use, maintenance, depreciation, property taxes, and insurance related to assets. While included in overhead, the depreciation is shown as a separate line item.

(7) ***Standard SG&A:*** Selling, general, and administrative costs are computed as a percentage of ***Revenues (1)***.

(8) ***R&D:*** GRIM separately accounts for ordinary research and development (R&D) as a percentage of ***Revenues (1)***.

(9) ***Product Conversion Costs:*** Product conversion costs are one-time investments in research, development, testing, marketing, and other costs focused on making products designs comply with the new energy conservation standard. The GRIM allocates these costs over the period between the standard's announcement and compliance dates.

(10) ***Stranded Assets:*** In the year the standard becomes effective, a one-time write-off of stranded assets is accounted for.

(11) ***Earnings Before Interest and Taxes (EBIT):*** Includes profits before deductions for interest paid and taxes.

(12) ***EBIT as a Percentage of Sales (EBIT/Revenues):*** GRIM calculates EBIT as a percentage of sales to compare with the industry's average reported in financial statements.

(13) ***Taxes:*** Taxes on ***EBIT (12)*** are calculated by multiplying the tax rate contained in Major Assumptions by ***EBIT (12)***.

(14) ***Net Operating Profits After Taxes (NOPAT):*** Computed by subtracting ***Cost of Goods Sold ((3) to (6))***, ***SG&A (7)***, ***R&D (8)***, ***Product Conversion Costs (9)***, and ***Taxes (13)*** from ***Revenues (1)***.

(15) ***NOPAT repeated***: NOPAT is repeated in the Statement of Cash Flows.

(16) ***Depreciation repeated***: Depreciation and Stranded Assets are added back in the Statement of Cash Flows because they are non-cash expenses.

(17) ***Change in Working Capital***: Change in cash tied up in accounts receivable, inventory, and other cash investments necessary to support operations is calculated by multiplying working capital (as a percentage of revenues) by the change in annual revenues.

(18) ***Cash Flow From Operations***: Calculated by taking ***NOPAT (15)***, adding back non-cash items such as a ***Depreciation (16)***, and subtracting the ***Change in Working Capital (17)***.

(19) ***Ordinary Capital Expenditures:*** Ordinary investments in property, plant, and equipment to maintain and replace existing production assets, computed as a percentage of ***Revenues (1)***.

(20) ***Capital Conversion Costs:*** Capital conversion costs are one-time investments in property, plant, and equipment to adapt or change existing production facilities so that new product designs can be fabricated and assembled under the new regulation. The GRIM allocates these costs over the period between the standard's announcement and compliance dates.

(21) ***Capital Investment:*** Total investments in property, plant, and equipment are computed by adding ***Ordinary Capital Expenditures (19)*** and ***Capital Conversion Costs (20)***.

(22) ***Free Cash Flow:*** Annual cash flow from operations and investments; computed by subtracting ***Capital Investment (21)*** from ***Cash Flow from Operations (18)***.

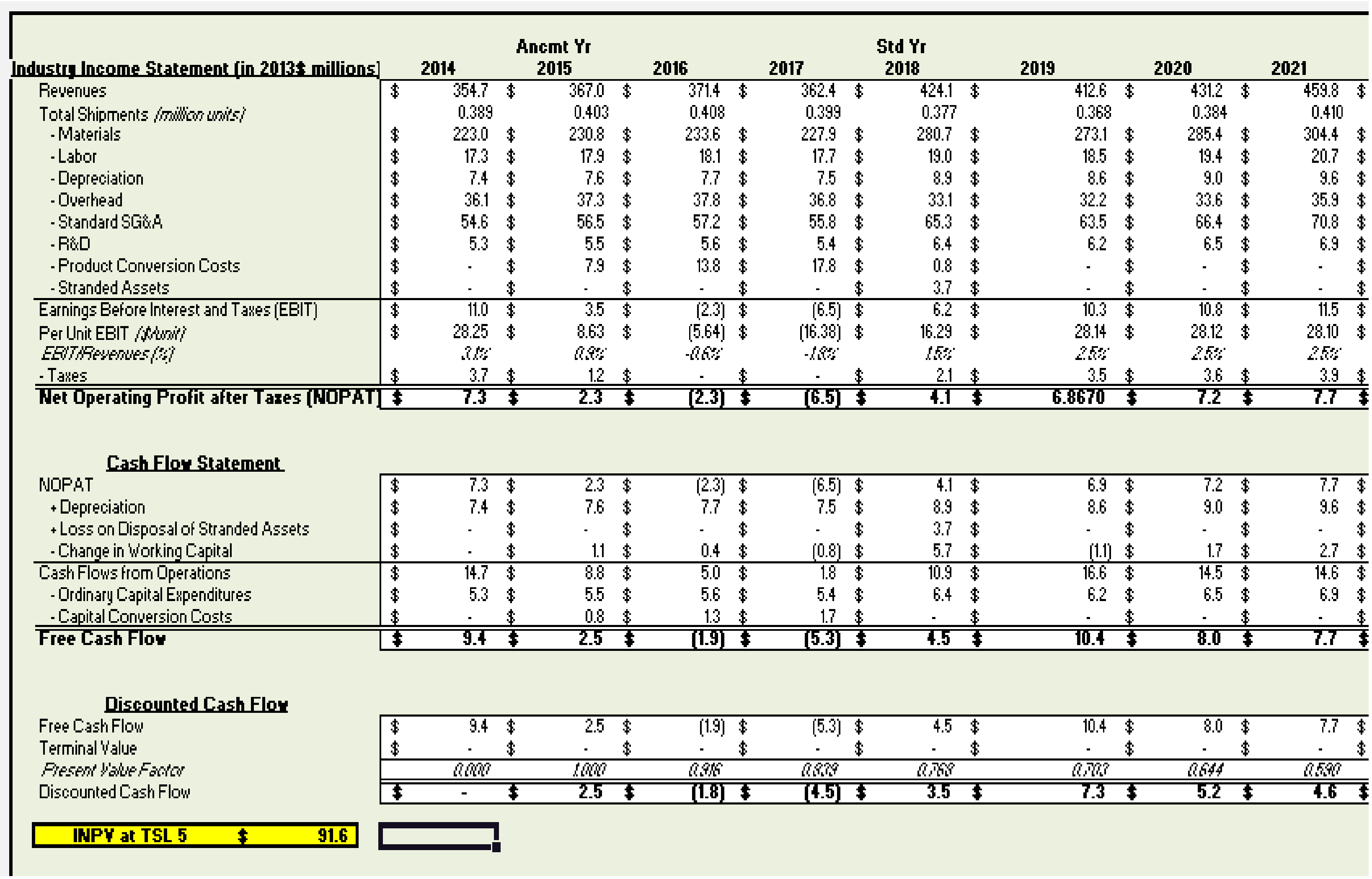
(23) ***Terminal Value:*** Estimate of the continuing value of the industry after the analysis period. Computed by growing the Free Cash Flow at the beginning of 2048 at a constant rate in perpetuity.

(24) ***Present Value Factor:*** Factor used to calculate an estimate of the present value of an amount to be received in the future.

(25) ***Discounted Cash Flow: Free Cash Flows (22)*** multiplied by the ***Present Value Factor (24)***. For the final year of analysis, the discounted cash flow includes the discounted ***Terminal Value (23)***.

(26) ***Industry Net Present Value (INPV):*** The sum of ***Discounted Cash Flows (25)*** over the analysis period.

Table 12A.2.1 Detailed Cash Flow Example



		Ancmt Yr			Std Yr			
Industry Income Statement (in 2013$ millions)	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**
Revenues	$ 354.7	$ 367.0	$ 371.4	$ 362.4	$ 424.1	$ 412.6	$ 431.2	$ 459.8
Total Shipments *(million units)*	0.389	0.403	0.408	0.399	0.377	0.368	0.384	0.410
- Materials	$ 223.0	$ 230.8	$ 233.6	$ 227.9	$ 280.7	$ 273.1	$ 285.4	$ 304.4
- Labor	$ 17.3	$ 17.9	$ 18.1	$ 17.7	$ 19.0	$ 18.5	$ 19.4	$ 20.7
- Depreciation	$ 7.4	$ 7.6	$ 7.7	$ 7.5	$ 8.9	$ 8.6	$ 9.0	$ 9.6
- Overhead	$ 36.1	$ 37.3	$ 37.8	$ 36.8	$ 33.1	$ 32.2	$ 33.6	$ 35.9
- Standard SG&A	$ 54.6	$ 56.5	$ 57.2	$ 55.8	$ 65.3	$ 63.5	$ 66.4	$ 70.8
- R&D	$ 5.3	$ 5.5	$ 5.6	$ 5.4	$ 6.4	$ 6.2	$ 6.5	$ 6.9
- Product Conversion Costs	$ -	$ 7.9	$ 13.8	$ 17.8	$ 0.8	$ -	$ -	$ -
- Stranded Assets	$ -	$ -	$ -	$ -	$ 3.7	$ -	$ -	$ -
Earnings Before Interest and Taxes (EBIT)	$ 11.0	$ 3.5	$ (2.3)	$ (6.5)	$ 6.2	$ 10.3	$ 10.8	$ 11.5
Per Unit EBIT *($/unit)*	$ 28.25	$ 8.63	$ (5.64)	$ (16.38)	$ 16.29	$ 28.14	$ 28.12	$ 28.10
EBIT/Revenues (%)	*3.1%*	*0.9%*	*-0.6%*	*-1.8%*	*1.5%*	*2.5%*	*2.5%*	*2.5%*
- Taxes	$ 3.7	$ 1.2	$ -	$ -	$ 2.1	$ 3.5	$ 3.6	$ 3.9
Net Operating Profit after Taxes (NOPAT)	**$ 7.3**	**$ 2.3**	**$ (2.3)**	**$ (6.5)**	**$ 4.1**	**$ 6.8670**	**$ 7.2**	**$ 7.7**
Cash Flow Statement								
NOPAT	$ 7.3	$ 2.3	$ (2.3)	$ (6.5)	$ 4.1	$ 6.9	$ 7.2	$ 7.7
+ Depreciation	$ 7.4	$ 7.6	$ 7.7	$ 7.5	$ 8.9	$ 8.6	$ 9.0	$ 9.6
+ Loss on Disposal of Stranded Assets	$ -	$ -	$ -	$ -	$ 3.7	$ -	$ -	$ -
- Change in Working Capital	$ -	$ 1.1	$ 0.4	$ (0.8)	$ 5.7	$ (1.1)	$ 1.7	$ 2.7
Cash Flows from Operations	$ 14.7	$ 8.8	$ 5.0	$ 1.8	$ 10.9	$ 16.6	$ 14.5	$ 14.6
- Ordinary Capital Expenditures	$ 5.3	$ 5.5	$ 5.6	$ 5.4	$ 6.4	$ 6.2	$ 6.5	$ 6.9
- Capital Conversion Costs	$ -	$ 0.8	$ 1.3	$ 1.7	$ -	$ -	$ -	$ -
Free Cash Flow	**$ 9.4**	**$ 2.5**	**$ (1.9)**	**$ (5.3)**	**$ 4.5**	**$ 10.4**	**$ 8.0**	**$ 7.7**
Discounted Cash Flow								
Free Cash Flow	$ 9.4	$ 2.5	$ (1.9)	$ (5.3)	$ 4.5	$ 10.4	$ 8.0	$ 7.7
Terminal Value	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Present Value Factor	*0.000*	*1.000*	*0.916*	*0.839*	*0.768*	*0.703*	*0.644*	*0.590*
Discounted Cash Flow	**$ -**	**$ 2.5**	**$ (1.8)**	**$ (4.5)**	**$ 3.5**	**$ 7.3**	**$ 5.2**	**$ 4.6**

INPV at TSL 5 $ 91.6

APPENDIX 12B. MANUFACTURER IMPACT ANALYSIS INTERVIEW GUIDE

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Appendix 12B. Manufacturer Impact Analysis Interview Guide

12B.1 MANUFACTURER IMPACT ANALYSIS INTERVIEW GUIDE FOR RESIDENTIAL FURNACES

The recent 2014 court settlement agreement remands the 2011 direct final rule for non-weatherized gas furnaces. Department of Energy (DOE) is conducting a manufacturer impact analysis (MIA) to re-evaluate energy conservation standards for non-weatherized gas furnaces. In the MIA, DOE uses publicly available information and information provided by manufacturers during interviews to assess possible impacts on manufacturers due to changes to the 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 residential gas furnace 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 generic questions intended to solicit qualitative comments. Topics covered will include:

- Key Issues
- Engineering Topics
- Company Overview And Organizational Characteristics
- Markups And Profitability
- Unit Warehousing Costs
- Shipment Projections And Market Shares
- Product Mix
- Financial Parameters
- Conversion Costs
- Cumulative Regulatory Burden
- Direct Employment Impact Assessment
- Capacity / Exports / Foreign Competition / Outsourcing
- Regional Energy Conservation Standard Impacts
- Impacts On Small Businesses
- Shipping Costs

The following questions cover two different product classes of furnaces.

Furnace Product Classes:

- Non-weatherized Gas Furnaces (NWGF)
- Mobile Homes Furnaces (MHF)

In responding to this questionnaire, please refer to the efficiency levels in the tables below:

Efficiency Levels (AFUE) under consideration for Residential Furnace products:

Efficiency Level	NWGF	MHGF
Baseline	80%	80%
EL 1	90%	92%
EL 2	92%	95%
EL 3	95%	97%
EL 4	98%	

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 when conducting the Manufacturer Impact Analysis.

1.1 In general, what are the key concerns for your company regarding this residential furnaces rulemaking? Please reference the specific product classes to which your comments apply.

1.2 For the issues identified, how significant are they at each listed efficiency level?

1.3 How would amended energy conservation standards affect your ability to compete in the marketplace?

2 Engineering Topics

Covered products include:

Product Classes for Residential Furnaces under Consideration for the Rulemaking

Furnace Type	Characteristics
Non-Weatherized Gas Furnaces	Gas-fired furnace intended for indoor installation; input capacity no greater than 225,000 Btu/h.
Mobile Home Gas Furnaces	Gas-fired furnace subject to size constraints and special venting/ducting requirements in order to meet demands of indoor mobile home installation; input capacity no greater than 225,000 Btu/h.

2.1 Baseline Products and Design Options

2.1.1. DOE has preliminarily identified the following design features as those that impact energy use and are generally incorporated into "baseline" residential furnaces in each product class. Please provide comment.

Table 2-1 Baseline Design Features by Product Class

Product Class	Characteristics	Manufacturer Feedback

Non-Weatherized Gas Furnaces	• Draft inducer • Single-stage burner • Hot surface igniter • Aluminized steel, clamshell or tubular primary heat exchanger • PSC direct-drive blower motor, forward-curved blower impeller with 1200 cfm airflow capacity	
Mobile Home Gas Furnaces	• Draft inducer • Single-stage burner • Hot surface igniter • Aluminized steel, clamshell or tubular primary heat exchanger • PSC direct-drive blower motor, forward-curved blower impeller with 1200 cfm airflow capacity	

2.1.2. DOE is aware that the addition of secondary heat exchangers and heat exchanger improvements (i.e. increased surface area, baffles, surface features) are common design features incorporated into products that result in a direct increase in AFUE. DOE also understands that supplemental technology options may be necessary in tandem with these design features in order to improve user satisfaction or to ensure reliable, safe operation of the furnace at higher efficiencies (i.e., multi-stage or modulating burners, ECM indoor blower and inducer fan motors, corrosion-resistant heat exchanger coatings). Please comment on the use of these technologies as they relate to AFUE improvements. Please provide comment on any other technologies used to improve AFUE that are not mentioned here.

2.1.3. DOE research suggests that 95% AFUE furnaces use either a constant speed ECM motor or a constant torque BPM motor, and furnaces at the max-tech (98% AFUE) level exclusively use constant speed ECM motors. Please comment on the product mix of these two types of motors at the 95% and higher AFUE levels.

2.1.4. DOE has observed the use of corrosion resistant plastic coatings inside some secondary heat exchangers on condensing products as an alternative material to using Al29-4C stainless steel. Please comment on the frequency of use of this design feature among furnace manufacturers, material cost trends, its reliability in preventing heat exchanger corrosion, and any differences in the heat transfer properties of this design feature versus Al29-4C.

2.1.5. Regulations in certain jurisdictions mandate that residential furnaces must not exceed specific limits on NOX emissions (typically 40 nanograms of NOx per joule of useful heat). DOE is aware that furnace manufacturers offer low-NOX products in order to meet these requirements, and has observed the use of low-NO_x baffles at the entry point of heat exchangers as one method of reducing NO_x emissions in non-condensing furnaces. Please comment on this and any other technologies used to reduce NO_x emissions from residential furnaces, as well as any differences in the technologies used between non-condensing and condensing products. Also, please provide comment on the differences between these design features and those needed in order to comply with ultra-low NO_x (14 nanograms/joule of useful heat) emissions standards.

2.1.6. Can you provide data or comment on AFUE improvements attributable to increased secondary heat exchanger area? Also, could you comment on improvements to AFUE from increasing the primary heat exchanger area, and how these improvements differ based on whether aluminized or stainless steel is used as the heat exchanger material?

2.1.7. At which efficiency levels do safety issues, such as condensate formation, require a switch to a stainless steel heat exchanger? What grade of stainless steel do you use in your products?

2.1.8. Have you considered redesigning your furnaces to use a single condensing heat exchanger instead of utilizing separate non-condensing and condensing heat exchanger sections? Would such a furnace allow a wider range of modulation, better AFUE, etc.?

2.1.9. At what AFUE level have you found it to be necessary to use modulating burners as opposed to single-stage burners?

2.1.10. How do installation costs differ between a non-condensing gas furnace and a condensing gas furnace? Maintenance costs? Repair costs? Would you please characterize these cost differences by providing incremental installation, maintenance, and/or repair cost data?

2.1.11. In the condensing range (i.e., 90% AFUE and above), are installation, maintenance, and repair costs a function of furnace efficiency? If so, would you please characterize this relationship by providing incremental installation, maintenance, and/or repair cost data?

2.2 Component Parts and Material Costs

2.2.1. In the following tables, we have compiled estimates for component pricing at high-volume manufacturing. These estimates are based on a number of different sources, most of which are not component suppliers. They are estimates and should NOT be construed as actual quotes for component and raw material prices. We are seeking feedback regarding the likely raw material and purchased part costs.

Table 2-2 Gas Valves, Burners, and Ignition Elements Cost Estimates, as of 5/2014 at 500,000 unit/year purchase volume

Description	**Cost ($/ea)**	**Manufacturer Comments**
24V Gas Valve, up to 150kBtu, Single Stage	[redacted]	
24V Gas Valve, up to 140kBtu, Two-Stage	[redacted]	
24V Gas Valve, 150kBtu, Modulating	[redacted]	
Hot Surface Igniter, Single Rod, 115V	[redacted]	
Spark Igniter with target	[redacted]	
Gas Valve Thermocouple Assy	[redacted]	
Non-condensing Ignition Module, PSC	[redacted]	
Condensing Ignition Module, PSC	[redacted]	
Condensing Ignition Module, 2.3ECM	[redacted]	

Table 2-3 Combustion Fan Motor Assembly Cost Estimates, as of 5/2014 at 500,000 unit/year purchase volume

Non-Condensing/Condensing, # Speeds, Motor Type, Weight	**Cost ($/ea)**	**Manufacturer Comments**
Inducer Fan Motor Assembly, Non-Condensing, 1 Speed, PSC, 5lb	[redacted]	
Inducer Fan Motor Assembly, Condensing, 1 Speed, PSC, 5.8lb	[redacted]	
Inducer Fan Motor Assembly, Non-Condensing, 2 Speed, PSC, 5lb	[redacted]	
Inducer Fan Motor Assembly, Condensing, 2 Speed, PSC, 5.8lb	[redacted]	

Table 2-4 Indoor Fan Motor Cost Estimates, as of 5/2014 at 500,000 unit/year purchase volume

Power Rating, RPM, # Speeds, Voltage, Motor Type, Weight	**Cost ($/ea)**	**Manufacturer Comments**
Indoor Fan Motor, 0.20hp, 1075RPM, 3 Speed, 115V, PSC	[redacted]	
Indoor Fan Motor, 0.33hp, 1075RPM, 3 Speed, 115V, PSC	[redacted]	
Indoor Fan Motor, 0.50hp, 1075RPM, 3 Speed, 115V, PSC	[redacted]	
Indoor Fan Motor, 0.50hp, 1100RPM, 4 Speed, 120V, PSC	[redacted]	
Indoor Fan Motor, 0.50hp, 1075RPM, 3 Speed, 230V, PSC	[redacted]	
Outdoor Fan Motor, 0.50hp, 1100RPM, 3 Speed, 230V, PSC	[redacted]	

Indoor Fan Motor, 0.50hp, 1050RPM, 5 Speed, 115V, Constant Torque a.k.a. X13ECM	[redacted]	
Indoor Fan Motor, 0.75hp, 1050RPM, 5 Speed, 115V, Constant Torque a.k.a. X13ECM	[redacted]	
Indoor Fan Motor, 1hp, 1050RPM, 5 Speed, 115V, Constant Torque a.k.a. X13ECM	[redacted]	
Indoor Fan Motor, 0.50hp, 200-1300RPM, Variable Speed, 120/240V, Constant Speed a.k.a. 2.3ECM	[redacted]	
Indoor Fan Motor, 0.75hp, 200-1300RPM, Variable Speed, 120/240V, Constant Speed a.k.a. 2.3ECM	[redacted]	
Indoor Fan Motor, 1.00hp, 200-1300RPM, Variable Speed, 120/240V, Constant Speed a.k.a. 2.3ECM	[redacted]	

Table 2-5 Fan Blade Cost Estimates, as of 5/2014 at 500,000 unit/year purchase volume

Description	**Cost ($/ea)**	**Manufacturer Comments**
Indoor Blower Wheel, GCRS, 11″ OD, 7″ High	[redacted]	
Indoor Blower Wheel, GCRS, 11″ OD, 8″ High	[redacted]	
Indoor Blower Wheel, GCRS, 11″ OD, 10″ High	[redacted]	
Indoor Blower Wheel, GCRS, 12″ OD, 9″ High	[redacted]	

Table 2-6 Misc. Electrical Part Cost Estimates, as of 5/2014 at 500,000 unit/year purchase volume

Description	**Cost ($/ea)**	**Manufacturer Comments**
35VA Transformer (bare, conductors are extra)	[redacted]	
40VA Transformer (bare, conductors are extra)	[redacted]	
78VA Transformer (bare, conductors are extra)	[redacted]	
40VA Low Loss Transformer (bare, conductors are extra)	[redacted]	
Capacitor, 5uF, 370VAC	[redacted]	
Capacitor, 7.5uF, 370VAC	[redacted]	
Capacitor, 10uF, 370VAC	[redacted]	
Capacitor, 12.5uF, 370VAC	[redacted]	

Table 2-7 Misc. Part Cost Estimates, as of 5/2014 at 500,000 unit/year purchase volume

Description	**Cost ($/ea)**	**Manufacturer Comments**
Air Pressure Switch, single point (prove combustion)	[redacted]	
Air Pressure Switch, 120V, Two-Point	[redacted]	
Thermal Cutout, 250VAC	[redacted]	
Thermal Cutout Switch on Standoff	[redacted]	
Cabinet Switch, low Voltage	[redacted]	

2.2.2. The following chart shows DOE’s assumptions for raw material prices for common metals found in furnaces. Please assume the delivered price at the shipping dock of your facility, inclusive of all processing costs, shipping costs, etc.

Table 2-8 Metal Raw Material Costs, as of 5/2014

Metals	**Five Year Cost Avg. ($/lb 6/2009-5/2014)**	**Cost ($/lb) As of 5/2014**	**Manufacturer Feedback**
Cold Rolled Steel (CRS)	[redacted]	[redacted]	
Aluminized CRS	[redacted]	[redacted]	
Galvanized CRS	[redacted]	[redacted]	
Pre-Painted CRS	[redacted]	[redacted]	
Textured CRS	[redacted]	[redacted]	
Fin Aluminum	[redacted]	[redacted]	
Aluminized CRS Tube	[redacted]	[redacted]	
AL29-4C Stainless Steel	[redacted]	[redacted]	
AL29-4C Tube	[redacted]	[redacted]	

2.2.3. For plastics, as a starting point DOE assumed that most parts are made in-house, including condensate drains, logos, etc., in a variety of injection-molding machines. Please indicate what parts are typically made in-house versus those that are made by outside vendors.

In-House Parts:	Sourced Parts:

2.2.4. Below is an abridged table containing DOE’s cost assumptions for plastic resins. These costs are in rail-car quantities, fully delivered to your shipping dock. Please indicate how the following prices compare to your raw material costs.

Table 2-9 Plastics Raw Material Costs, as of 5/2014

Resin	**Five Year Cost Avg. ($/lb 6/2009-5/2014)**	**Cost ($/lb) As of 5/2014**	**Manufacturer Feedback**
ABS	[redacted]	[redacted]	

Nylon-6	[redacted]	[redacted]	
Polypropylene (PP)	[redacted]	[redacted]	
PP with Glass Fiber	[redacted]	[redacted]	
Polystyrene (PS)	[redacted]	[redacted]	
Noryl with Glass Fiber	[redacted]	[redacted]	
HDPE	[redacted]	[redacted]	
LDPE	[redacted]	[redacted]	
Polycarbonate (PC)	[redacted]	[redacted]	
Styrofoam	[redacted]	[redacted]	
Generic Ether Foam	[redacted]	[redacted]	
PVC (Hard)	[redacted]	[redacted]	
PVC (Flexible)	[redacted]	[redacted]	
High Temperature Silicone	[redacted]	[redacted]	
High Temperature Silicone Foam	[redacted]	[redacted]	
Silicone	[redacted]	[redacted]	
SBR Rubber (Buna)	[redacted]	[redacted]	

2.2.5. A single-material sourced part (such as an injection-molded name decal, for example) is assumed to cost approximately twice the raw material cost of a part made in house. For your sourced parts, please indicate how close that assumption comes to actual part costs (i.e., compare on a $/lb basis to the above raw material costs).

2.2.6. Below are some other raw material costs on which DOE would like feedback. For cardboard and paper, please assume fully converted prices (i.e., printed, folded, etc.) delivered to your shipping dock. The fiberglass is either foil-faced or plain appliance grade.

Table 2-10 Other Raw Material Costs, as of 5/2014

Material Description	Five Year Cost Avg. ($/lb 6/2009-5/2014)	Cost ($/lb) As of 5/2014	Manufacturer Feedback
Plain Cardboard for Shipping	[redacted]	[redacted]	
2-Color Cardboard for Shipping	[redacted]	[redacted]	
Paper	[redacted]	[redacted]	
Wood for Shipping	[redacted]	[redacted]	
Fiberglass Insulation	[redacted]	[redacted]	
Foil Faced Fiberglass	[redacted]	[redacted]	
Fiberfrax	[redacted]	[redacted]	

Durafrax		[redacted]			[redacted]		
Permagum		[redacted]			[redacted]		

2.3 Factory Parameter Assumptions

2.3.1. DOE used information gathered from its analysis of common industry practices to formulate factory parameters for manufacturers. Please comment on the following factory parameter assumptions.

Table 2-11 Residential Furnace Factory Parameter Assumptions

Parameter	Estimate for NWGF and MHF	Manufacturer Feedback
Actual Annual Production Volume (units/year)	350,000	
Work Days Per Year (days)	[redacted]	
Assembly Shifts Per Day (shifts)	[redacted]	
Fabrication Shifts Per Day (shifts)	[redacted]	
Fabrication Labor Wages ($/hr)	[redacted]	
Assembly Labor Wages ($/hr)	[redacted]	
Fringe Benefits Ratio	[redacted]	
Burdened Assembly Labor Wage ($/hr)	[redacted]	
Supervisor Span (workers/supervisor)	[redacted]	
Supervisor Wage Premium (over fabrication and assembly wage)	[redacted]	
Indirect to Direct Labor Ratio	[redacted]	
Length of Shift (hrs)	[redacted]	
Average Worker Downtime per shift	[redacted]	
Average Equipment Installation Cost (% of purchase price)	[redacted]	
Average Scrap Recovery Value (using base material value)	[redacted]	
Production Area Building Cost ($/ft^2)	[redacted]	
Storage Area Building Cost ($)	[redacted]	
Building Life (in years)	[redacted]	

2.4 Manufacturer Production Costs

DOE estimated the *manufacturer production costs* (MPC) of residential furnaces. DOE defines manufacturer production cost as all direct costs associated with manufacturing a product. It includes direct labor, direct materials, and overhead (including depreciation costs). The breakdown of manufacturer production cost has implications for the quantitative impacts on manufacturers of non-weatherized gas furnaces and mobile home furnaces in the manufacturer impact analysis. The per unit production costs are necessary for DOE to estimate labor expenditures and other cash flow calculations.

Manufacturer selling price (MSP) is the average price manufacturers charge their first consumers, but does not include all of the costs along the distribution channels. The manufacturer selling price includes a per unit research and development cost; selling, general, and administrative expense; shipping cost; and profit. The manufacturer markup is a multiplier applied to manufacturer production cost to cover the per-unit research and development, selling, general, and administrative expense, and profit. For residential furnaces, the manufacturer markup does not cover shipping costs. Shipping costs are calculated separately and are shown for each product class in Table 2-1. Section 15 contains additional questions about the shipping assumptions and costs.

DOE estimated an industry-wide markup of 1.35 for gas furnaces (non-weatherized and mobile home). DOE asks a series of questions about the manufacturer markup associated with premium products at higher efficiencies in section 3 of this interview guide. As shown in Equation 2-1 below, the manufacturer production cost multiplied by the manufacturer markup covers all costs in the manufacturer selling price of baseline products except for shipping costs.

Equation 2-1 Calculation of Manufacturer Selling Price

(Manufacturer Production Cost × Manufacturer Markup) + Shipping Cost = Manufacturer Selling Price

2.4.1. Table 2-12 and Table 2-13 provide DOE's estimates of the manufacturer production costs and manufacturer selling prices for residential furnaces at each efficiency level being considered. Would you please comment on the estimated values?

Table 2-12 Estimated Manufacturer Production Costs, Shipping Costs, and Manufacturer Selling Prices for Non-Weatherized Gas Furnaces, 80,000 Btu/h

Efficiency Level (AFUE)	DOE's Manufacturer Production Cost Estimates* (2013$)	DOE's per Unit Shipping Cost Estimates (2013$)	DOE's Manufacturer Selling Price Estimates (2013$)	Manufacturer Comments or Revised Estimates
Baseline Level (80%)	[redacted]	[redacted]	[redacted]	
EL 1 (90%)	[redacted]	[redacted]	[redacted]	
EL 2 (92%)	[redacted]	[redacted]	[redacted]	
EL 3 (95%)	[redacted]	[redacted]	[redacted]	
EL 4 (98%)	[redacted]	[redacted]	[redacted]	

* DOE's manufacturer production cost estimates were developed using a five-year average of raw material prices spanning 2009 to 2013.

Table 2-13 Estimated Manufacturer Production Costs, Shipping Costs, and Manufacturer Selling Prices for Mobile Home Furnace, 80,000 Btu/h

Efficiency Level (AFUE)	DOE's Manufacturer Production Cost Estimates* (2013$)	DOE's per Unit Shipping Cost Estimates (2013$)	DOE's Manufacturer Selling Price Estimates (2013$)	Manufacturer Comments or Revised Estimates
Baseline Level (80%)	[redacted]	[redacted]	[redacted]	
EL 1 (92%)	[redacted]	[redacted]	[redacted]	
EL 2 (95%)	[redacted]	[redacted]	[redacted]	
EL 3 (97%)	[redacted]	[redacted]	[redacted]	

* DOE's manufacturer production cost estimates were developed using a five-year average of raw material prices spanning 2009 to 2013.

2.4.2. Please compare your manufacturer production cost percentages to the estimates tabulated below. The manufacturer production cost breakdown is used to calculate the total cost of goods sold (COGS) for the industry. Having an accurate estimate of the production costs for the industry allows DOE to better examine impacts on profitability and employment due to amended energy conservation standards. Are the different percentages of each cost representative of your company or the NWGF and MHF industries? Please explain any differences.

Table 2-14 Breakdown of Manufacturer Production Costs for Baseline NWGF

Components of Manufacturer Production Costs	DOE's Estimated Percentage of Manufacturer Production Cost	Manufacturer Feedback
Materials	84.4	
Labor	8.9	
Overhead	2.6	
Depreciation	4.2	

Table 2-15 Breakdown of Manufacturer Production Costs for Baseline MHF

Components of Manufacturer Production Costs	DOE's Estimated Percentage of Manufacturer Production Cost	Manufacturer Feedback
Materials	82.0	
Labor	9.6	
Overhead	3.6	
Depreciation	4.8	

2.4.3. Do these percentages change at higher efficiency levels for any of the product classes?

2.5 Standby and Off Mode Power Consumption

Section 310(3) of EISA 2007 amended EPCA to require that a final rule must, if justified by the criteria for adoption of standards in section 325(o) of EPCA, incorporate standby mode and off mode energy use when DOE adopts new or amended standards for certain covered products after July 1, 2010. (42 U.S.C. 6295(gg)(3)) Therefore, DOE will address the standby mode and off mode energy use in this rulemaking as required by EPCA. As proposed in the residential furnace test procedures NOPR published on July 27, 2009, DOE defines standby mode and off mode for residential furnaces as:

- Standby mode means the condition during the heating season in which the furnace is connected to the power source, and neither the burner, electric resistance elements, nor any electrical auxiliaries such as blowers or pumps, are activated.
- Off mode means the condition during the non-heating season in which the furnace is connected to the power source, and neither the burner, electric resistance elements, nor any electrical auxiliaries such as blowers or pumps, are activated. 74 FR 36970.

2.5.1. DOE believes it is reasonable to assume that most consumers are unlikely to set their furnaces to the off mode by use of a seasonal off switch. Hence, DOE is assuming that furnaces will be consuming electricity at their respective standby rates during all non-active mode hours, and, accordingly, off mode power consumption should be assumed to be equivalent to standby mode power consumption.

DOE performed standby testing on a representative subset of commercially-available furnaces. The data from DOE's testing is shown in the table below. Would you please comment on these standby power consumption test results and how they compare to the standby consumption of your company's products?

Table 2-16 Summary of Standby Test Results by Product Class

	DOE Data		Manufacturer Comments	
Product Class	**Range (W)**	**Average (W)**	**Range (W)**	**Average (W)**
Non-Weatherized Gas Furnaces	3.6-9.8	5.8		
Mobile Home Gas Furnaces	4.2-8.8	5.0		

2.5.2. DOE believes that standby power consumption does not correlate with input capacity, but AFUE may have a defined impact (i.e. due to the presence of ECM motors). Please confirm your knowledge of these relationships, and comment on any other performance factors known to impact standby power consumption.

2.5.3. Which components consume power in standby mode (e.g., ignition elements, power supply, transformer, control components/board(s) for the furnace and blower assembly, etc.)?

2.5.4. How much power do integrated controls for modulating components, such as ECM fan motors and modulating gas valves, consume in standby mode?

2.5.5. Based on the test results summarized in Table 2-16, DOE developed estimates for the amount of standby consumption attributable to each component that DOE believes is a major contributor to overall furnace standby consumption. These estimates are displayed in Table 2-17 below. Also included are unit cost estimates for each component and estimates for the cost and standby consumption of components DOE believes could potentially be used to decrease standby consumption in residential furnaces. Would you please comment on the accuracy of these cost and standby consumption estimates? Are there any additional components that you could incorporate into your designs in order to decrease standby power consumption? If so, would you please describe these components, their costs and their estimated standby consumption?

Table 2-17 Estimated Standby Consumption and Cost by Furnace Component

	DOE Estimates		Manufacturer Comments	
Component	**Standby Consumption (W)**	**Cost per unit @ 500,000 units purchased ($)**	**Standby Consumption (W)**	**Cost per unit @ 500,000 units purchased ($)**
Transformer:				
35VA	3.3 - 3.5	[redacted]		
40VA	3.5 - 3.8	[redacted]		
40 VA Low Loss Transformer (LLTX)	.2	[redacted]		
Power Supply:				
Linear	1.5 - 2.5	[redacted]		
Switch Mode	0.5 - 1.0	[redacted]		
Fan Motors:				
ECM Blower Motor	1.0 - 2.0	See Table 2-4		
ECM Inducer Fan Motor	0	See Table 2-4		

2.5.6. According to DOE's research, solid state transformers are typically not used in residential HVAC systems due to cost prohibitions. Please comment on the current feasibility of this design option in residential HVAC systems.

2.5.7. DOE understands that transitioning from 24VAC to 24VDC control systems to save standby power consumption may be undesirable due to the complexities of adjusting certain equipment components and small overall energy savings. Please comment on the feasibility of this and other design options that can potentially reduce standby energy consumption.

3 Company Overview And Organizational Characteristics

Understanding how the manufacturing of residential gas furnaces fits within your larger organization will help DOE better estimate the probable impacts of an amended energy conservation standard. Because many residential furnace manufacturers also produce other products, the details of operations and profitability at the relevant business unit level are typically not available in published literature. Therefore, DOE invites you to provide these details in your own words to the extent possible and practical.

3.1 Do you have a parent company and/or any subsidiary relevant to the residential furnace industry?

3.2 What percentage of your overall revenue is from residential furnace sales?

3.3 What are your product line niches and relative strengths in the residential furnace market?

3.4 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 product class.

Table 3-1 Manufacturing Locations

Facility	Location	Products	Employees (Production)	Employees (Non-production)	Units/Yr Produced
Example	*Jackson, TN*	*NWGF, MHF*	*750*	*25*	*100,000*
Location 1					
Location 2					
Location 3					
Location 4					
Location 5					

3.5 Are higher efficiency products built at different plants than lower efficiency products of the same product class?

3.6 Would you expect your market share to change once amended energy conservation standards become effective?

4 Markups And Profitability

One of the primary objectives of the MIA is to assess the impact of amended energy conservation standards on industry profitability. In this section, DOE would like to understand the current markup structure of the industry and how setting an amended 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. For the residential furnace analysis, the manufacturer markup does not cover shipping costs. The manufacturer production cost multiplied by the manufacturer markup plus the shipping costs cover all costs involved in manufacturing the product.

4.1 Please comment on the baseline markups DOE calculated for the industry as a whole (shown in the table below for each product class).

Table 4-1 Estimated Manufacturer Markups by Product Class

Product Class	Baseline Markup	Manufacturer Comments or Revised Estimates
NWGF	1.35	
MHF	1.35	

4.2 Within each product class, do the per-unit markups vary by efficiency level?

4.3 DOE received comments that the industry typically follows a three-tier "Good, Better, Best" markup structure. Does this structure apply to your business? If so, how would a higher energy conservation standard affect this markup structure?

4.4 What factors other than efficiency affect markups in the same product class?

4.5 Would you expect shipping costs to increase as a result of an amended energy conservation standard?

4.6 How are warranty costs categorized by your accounting procedures and in your financial statements (e.g., in COGS, SG&A, etc.)? Could you please explain how you determine the amount of capital set aside to cover warranty issues?

4.7 Would you expect amended energy conservation standards to affect your profitability? If so, please explain why.

5 Unit Warehousing Costs

An amended energy conservation standard can alter product attributes, such as size and weight, which affect warehousing demands. Having an accurate estimate of these cost changes allows DOE to better examine impacts on profitability due to amended energy conservation standards.

5.1 Increasing the minimum energy conservation standard can have a significant impact of the size and volume of products. For each product class in Table 5-1, would warehousing costs (for manufacturers) significantly increase at any particular efficiency level? If so, please explain why.

Table 5-1 Efficiency Level (AFUE) for Furnaces

Efficiency Level	NWGF	MHGF
Baseline	80%	80%
EL 1	90%	92%
EL 2	92%	95%
EL 3	95%	97%
EL 4	98%	

6 Shipment Projections And Market Shares

An amended energy conservation standard can change overall shipments by altering product attributes, marketing approaches, product availability, and price. DOE's shipments model includes forecasts for the base-case shipments (i.e., total industry shipments absent amended energy conservation standards) and the standards-case shipments (i.e., total industry shipments with amended energy conservation standards).

6.1 For your company, what is the approximate split of shipments sold into the new construction market and sold into the replacement market for each product type?

Figure 6-1 Percentage of Residential Furnaces Sales by Market

Product Class	% New Construction Market	% Replacement Market
Non-weatherized Gas Furnace		
Mobile Home Furnace		

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.

6.2 Does your company offer furnace lines at different efficiency levels? Could you provide a description of your company's furnace lines and their respective efficiency levels?

6.3 In the table below, please estimate the percentage of current furnace shipments that falls in each BTU bin range.

Table 6-1 Percentage of Industry-Wide Shipments in 2009 by Btu Range for Non-Weatherized Gas Furnaces

	40,000-60,000	70,000-80,000	90,000-100,000	110,000-120,000
NWGF				

6.4 Table 6-2 through Table 6-3 show DOE's estimate for the mix of furnace shipments by efficiency today and in 2021, the anticipated compliance date of amended energy conservation standards. Please comment on DOE's estimates based on your knowledge of the industry?

Table 6-2 Percentage of Industry-Wide Shipments by Efficiency Level for Non-weatherized Gas Furnaces Today and in 2021 in the Base Case

EL	AFUE	DOE Estimate 2014	DOE Estimate 2021	Manufacturer Feedback
Baseline	**80%**	58.5%	*48.3%*	
EL 1	**90%**	2.6%	3.2%	
EL 2	**92%**	10.1%	12.5%	
EL 3	**95%**	27.4%	34.1%	
EL 4	**98%**	1.5%	1.9%	
Total		100%	100%	

Table 6-3 Percentage of Industry-Wide Shipments by Efficiency Level for Mobile Home Gas Fired Furnaces Today and in 2021

EL	AFUE	DOE Estimate 2014	DOE Estimate 2021	Manufacturer Feedback
Baseline	**80%**	91.0%	87.8%	
EL 1	**92%**	1.7%	2.3%	
EL 2	**95%**	6.4%	8.7%	
EL 3	**97%**	0.8%	1.1%	
Total		100%	100%	

6.5 In the absence of amended energy conservation standards, would you expect your furnace product mix to change over time? If so, please explain why.

7 Financial Parameters

Navigant Consulting, Inc. (NCI) has developed a "strawman" 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.

7.1 Please compare your company's furnace financial parameters to the GRIM parameters tabulated below.

Table 7-1 Financial Parameters for Residential Furnace Manufacturers

GRIM Input	**Definition**	**Industry Estimated Value**	**Your Actual** (If Significantly Different from DOE's Estimate**)**
Income Tax Rate	Corporate effective income tax paid (percentage of earnings before taxes, EBT)	29.1%	
Discount Rate	Weighted average cost of capital (inflation-adjusted weighted average of corporate cost of debt and expected return on equity)	7.1%	
Working Capital	Current assets less current liabilities (percentage of revenues)	23.5%	
SG&A	Selling, general, and administrative expenses (percentage of revenues)	15%	
R&D	Research and development expenses (percentage of revenues)	2.1%	
Depreciation	Amortization of fixed assets (percentage of revenues)	2.2%	
Capital Expenditures	Outlay of cash to acquire or improve capital assets (percentage of revenues, not including acquisition or sale of business units)	1.7%	
Cost of Goods Sold	Includes material, labor, overhead, and depreciation (percentage of revenues)	72%	

7.2 Are the figures in Table 7-1 representative of the residential furnace industry as a whole? If not, why not?

7.3 If your company manufactures multiple product classes of residential furnaces, do any of the financial parameters in Table 7-1 change based on product? Please describe any differences.

7.4 How would you expect an amended energy conservation standard to impact any of the financial parameters for the residential furnace industry?

8 Conversion Costs

An increase in energy conservation standards may cause the industry to incur capital and product conversion costs to meet the amended energy conservation standard. The MIA considers three types of conversion expenditures:

- Capital conversion costs -- One-time investments in plant, property, and equipment (PPE) necessitated by an amended energy conservation standard. These may be incremental changes to existing PPE or the replacement of existing PPE. Included are expenditures on buildings, equipment, and tooling.

- Product conversion costs – One-time investments in research, product development, testing, marketing and other costs for redesigning products to meet an amended energy conservation standard.

- Stranded assets -- Assets replaced before the end of their useful lives as a direct result of the change in an energy conservation standard.

With a detailed understanding of the conversion costs required by different standard levels, DOE can better model the impact on the residential furnace industry resulting from amendments to the conservation standards.

8.1 At your manufacturing facilities, would potential amended national energy conservation standards be difficult to implement? If so, would your company modify existing facilities or develop new facilities?

8.2 What level of conversion costs do you anticipate incurring at each efficiency level? Please provide dollar amounts as well as descriptions of the investments in the tables below.

Table 8-1 Non Weatherized Gas Furnace Conversion Costs and Descriptions

EL	AFUE	Capital Conversion Cost ($)	Product Conversion Cost ($)	Description
Baseline	80%	*n/a*	*n/a*	*n/a*
EL 1	90%		0	
EL 2	92%		0	
EL 3	95%		0	
EL 4	98%		0	

Table 8-2 Mobile Home Furnace Conversion Costs and Descriptions

EL	AFUE	Capital Conversion Cost	Product Conversion Cost	Description
Baseline	80%	*n/a*	*n/a*	*n/a*
EL 1	92%			
EL 2	95%			
EL 3	97%			

8.3 Please comment on any potential stranded assets that may result from an amended energy conservation standard.

8.4 For any efficiency levels that would require new production equipment, please describe how much downtime would be required. What impact would downtime have on your business?

8.5 Would the redesign of residential furnaces to limit power draw in stand-by mode result in significant conversion cost?

9 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.

9.1 Below is a preliminary list of regulations that could possibly affect manufacturers of residential furnaces. Are there other recent or impending standards that residential furnace manufacturers face from DOE, other US federal agencies, State regulators, foreign government agencies, or other standard setting bodies? If so, please identify the regulation and the corresponding possible compliance dates for those regulations. Please provide any comments and expected expenditures for the listed regulations, as well as additional regulations or standards that should be considered.

Table 9-1 Other Regulations Identified by DOE

Federal Energy Conservation Standards	Approximate Compliance Date	Comments
2007 Residential Furnaces & Boilers 72 FR 65136 (Nov. 19, 2007)	2015	
2011 Residential Furnaces 76 FR 37408 (June 27, 2011); 76 FR 67037 (Oct. 31, 2011)	2015	
2011 Residential Central Air Conditioners and Heat Pumps 76 FR 37408 (June 27, 2011); 76 FR 67037 (Oct. 31, 2011)	2015	
2010 Gas Fired and Electric Storage Water Heaters 75 FR 20112 (April 16, 2010)	2015	
Commercial Packaged Air-Conditioning and Heating Equipment	2018	
Commercial and Industrial Fans and Blowers	2018	
Furnace Fans	2019	
Packaged Terminal Air Conditioners and Heat Pumps	2019	
Residential Boilers	2019	
Commercial Boilers	2019	
Walk-in Coolers and Freezers	2014	
Dishwashers***	2018	
Commercial Packaged Air Conditioners and Heat Pumps	2018	
Commercial Warm-Air Furnaces	2018	
Miscellaneous Residential Refrigeration	2019	
Single Package Vertical Air Conditioners and Heat Pumps	2019	
Commercial Water Heaters	2019	
Kitchen Ranges and Ovens	2020	
Commercial Packaged Boilers	2020	
Direct Heating Equipment/Pool Heaters	2021	
Residential Water Heaters	2021	
Clothes Dryers	2022	
Central Air Conditioners	2022	
Residential Refrigerators and Freezers	2022	

Room Air Conditioners	2022	

Other Regulations:

9.2 Are there any additional regulatory burdens that DOE should take into consideration?

9.3 Under what circumstances would you be able to coordinate expenditures related to these other regulations with an amended energy conservation standard, thereby lessening the cumulative burden?

10 Direct Employment Impact Assessment

The impact of amended energy conservation standards on employment is an important consideration in the rulemaking process. This section of the interview guide seeks to explore current trends in residential furnace production employment and solicit manufacturer views on how domestic employment patterns might be affected by amended energy conservation standards.

10.1 Would amended energy conservation standards impact your domestic vs. foreign manufacturing decision? 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.

10.2 Would amended energy conservation standards require extensive retraining or replacement of employees at your manufacturing facilities?

11 Capacity / Exports / Foreign Competition / Outsourcing

Disparity between domestic and foreign energy conservation standards could impact exports or imports. Labor content and material changes resulting from amended energy conservation standards may impact sourcing decisions.

11.1 How would amended energy conservation standards impact your company's manufacturing capacity?

11.2 What percentage of your company's residential furnace sales is domestic?

11.3 What percentage of the U.S. market for residential furnaces is imported? Would amended energy conservation standards have an impact on foreign competition?

11.4 Absent amended energy conservation standards, are production facilities being relocated to foreign countries?

12 Consolidation

Amended energy conservation standards can alter the competitive dynamics of the market. This can include prompting companies to enter or exit the market, or to merge. DOE and the Department of Justice are both interested in any potential reduction in competition that would result from an amended energy conservation standard.

12.1 Please comment on industry consolidation and related trends over the last 10 years.

12.2 In the absence of amended energy conservation standards, do you expect any industry consolidation or fragmentation? Please describe your expectations.

12.3 How would industry competition change as a result of amended conservation standards?

12.4 To your knowledge, are there any niche manufacturers for which the adoption of amended energy conservation standards would have a particularly severe impact?

12.5 To your knowledge, are there any component manufacturers for which the adoption of amended energy conservation standards would have a particularly severe impact?

13 Regional Energy Conservation Standard Impacts

The Energy Independence and Security Act directs DOE to consider regional standards in addition to a national standard for residential furnaces. For furnace analysis purposes, the country has a Northern and a Southern region, with the assumption that the Northern region will have a more stringent standard if regional standards are pursued. The following questions focus on the impacts of multiple regional standards on your business.

13.1 If regional energy conservation standards were introduced, how would your conversion costs compare to those under a single national standard? Would you expect conversion costs under regional standards to scale with the percentage of shipments impacted by the standard?

13.2 If regional standards were introduced, are there any products you would consider no longer producing if they could only be sold in one region? Why or why not?

13.3 Would regional standards affect your current markup structure differently than would a national standard? Is it possible that a single product might see different manufacturer markups depending on region?

13.4 If regional energy conservation standards are introduced, would you expect the percentage split between new construction and replacement to differ from that under a national standard? If so, how would the split be different and why?

13.5 Would the introduction of regional standards affect industry competition, domestic employment, or small businesses differently than a national energy conservation standard?

13.6 Does the introduction of regional standards create additional complexities for manufacturing that have not yet been covered in this guide?

14 Impacts On Small Businesses

14.1 The Small Business Association (SBA) defines a small business in the residential HVAC industry as having less than 750 employees.[a] By this definition, is your company considered a small business?

14.2 Below are lists of small business residential furnace manufacturers compiled by DOE. Are there any small manufacturers that should be added to this list? Are there specific manufacturers on this list that may be more severely impacted by an amended energy conservation standard than others?

- Adams Manufacturing
- Bard Manufacturing
- Boyertown Furnace Company
- ECR International
- EFM
- H.E.P Materials Corp.
- Heat Controller, Inc.
- Kerr Energy Systems
- National Comfort Products
- Newmac Manufacturing Inc.
- Texas Furnace, LLC (Allstyle Coil Company)
- Wolf Steel Ltd.

14.3 Are there any reasons that a small business might be at a disadvantage relative to a larger business under amended energy conservation standards? Please consider such factors as technical expertise, access to capital, bulk purchasing power for materials/components, engineering resources, and any other relevant issues.

14.4 To your knowledge, are there any small business manufacturers for which the adoption of amended energy conservation standards would have a particularly severe impact?

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[a] DOE uses the small business size standards published on August 22, 2008, as amended, by the SBA to determine whether a company is a small business. To be categorized as a small business, an air conditioning and warm air heating equipment manufacturer and its affiliates may employ a maximum of 750 employees. The 750 employee threshold includes all employees in a business's parent company and any other subsidiaries.

15 Shipping Costs

An amended energy conservation standard can change overall shipments by altering product attributes, product size, amount of shipments, and price. Having an accurate estimate of the shipping costs for the industry allows DOE to better examine impacts on profitability and employment due to amended energy conservation standards. DOE has based its shipping costs on the average industry cost per trailer and the number of units that can be shipped per trailer. In the analysis, DOE assumed trailer dimensions of 10′ by 8′ by 53′, an average total shipping cost per trailer of $4,000, and that standard pallets were used for products that require them. Although DOE recognizes that many combinations of products at different capacities and efficiencies may be shipped together in a given trailer load, for simplicity DOE's shipping costs represent an estimate of the per unit shipping cost based on a full load of a particular unit (i.e., at a given capacity and efficiency).

15.1 Table 15-1 provides DOE's estimates of the shipping costs for residential furnaces for each product class being considered. DOE has observed that on average, shipping dimensions and, accordingly, shipping costs do not change with efficiency level for furnaces. Would you please comment on the estimated values?

Table 15-1 **Shipping Cost Data for Residential Furnaces**

Product Class	Shipping Size Estimates					
	Height (in)	**Width (in)**	**Depth (in)**	**Weight (lbs)**	**Units Per Trailer**	**Cost Per Unit (2013$)**
Non-Weatherized Gas Furnaces	40.5	17.6	28.0	150	220	11
Mobile Home Gas Furnaces (with no evaporator coil cabinet)	40.5	17.6	28.0	150	220	11*

*Baseline mobile home furnaces tend to be legacy designs that have a larger cabinet in order to accommodate an evaporator coil. This larger size raises shipping cost. Baseline mobile home furnaces cost approximately $20 to ship.

15.2 Would you expect per unit shipping costs to increase as a result of an amended energy conservation standard?

CHAPTER 13. EMISSIONS IMPACT ANALYSIS

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CHAPTER 13. EMISSIONS IMPACT ANALYSIS

13.1 INTRODUCTION

The emissions analysis consists of two components. The first component estimates the effect of potential energy conservation standards on power sector and site combustion emissions of carbon dioxide (CO_2), nitrogen oxides (NO_X), sulfur dioxide (SO_2) and mercury (Hg). The second component estimates the impacts of a potential standard on emissions of two additional greenhouse gases, methane (CH_4) and nitrous oxide (N_2O), as well as the reductions to emissions of all species due to “upstream” activities in the fuel production chain. These upstream activities comprise extraction, processing, and transporting fuels to the site of combustion. The associated emissions are referred to as upstream emissions. Together, these emissions account for the full-fuel-cycle (FFC), in accordance with DOE’s FFC Statement of Policy. 76 FR 51282 (Aug. 18, 2011).

The on-site operation of residential non-weatherized gas furnaces (NWGFs) and mobile home gas furnaces (MHGFs) requires use of fossil fuels and results in emissions of CO_2, NO_X, and SO_2 at the sites where the equipment is used. The considered standard levels will reduce fuel use at the site, but in some cases DOE estimates that switching to electric heating will occur, leading to an increase in electricity use. The higher electricity use will result in increased power sector emissions. DOE estimated the increase in power sector emissions of CO_2, NO_X, SO_2, and mercury (Hg).[a] In addition, DOE estimated upstream emissions impacts in production activities that provide the energy inputs to power plants.

The analysis of power sector emissions uses marginal emissions intensity factors calculated by DOE. As of 2014, DOE is using a new methodology based on results published for the *Annual Energy Outlook 2014 (AEO 2014)* reference case and a set of side cases that implement a variety of efficiency-related policies.[1] The new methodology is described in chapter 15 and in the report “Utility Sector Impacts of Reduced Electricity Demand” (Coughlin, 2014).[2] Site emissions of CO_2 and NO_X are estimated using emissions intensity factors from a publication of the Environmental Protection Agency (EPA).[3]

Combustion emissions of CH_4 and N_2O are estimated using emissions intensity factors published by the EPA, GHG Emissions Factors Hub.[b] The FFC upstream emissions are estimated based on the methodology developed by Coughlin (2013).[4] The upstream emissions include both emissions from fuel combustion during extraction, processing and transportation of fuel, and “fugitive” emissions (direct leakage to the atmosphere) of CH_4 and CO_2.

The emissions intensity factors are expressed in terms of physical units per MWh or MMBtu of site energy savings. Total emissions reductions are estimated using the energy savings calculated in the national impact analysis (chapter 10).

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[a] Note that the reduction in site emissions of CO_2 and NO_X is larger than the increase in power sector emissions.
[b] http://www.epa.gov/climateleadership/guidance/ghg-emissions.html

For CH_4 and N_2O, DOE also presents results in terms of units of carbon dioxide equivalent (CO_2eq). Gases are converted to CO_2e by multiplying the physical units by the gas global warming potential (GWP) over a 100 year time horizon. Based on the Fifth Assessment Report of the Intergovernmental Panel on Climate Change,[5] DOE used GWP values of 28 for CH_4 and 265 for N_2O.[c]

13.2 AIR QUALITY REGULATIONS AND EMISSIONS IMPACTS

Each annual version of the AEO incorporates the projected impacts of existing air quality regulations on emissions. *AEO 2014* generally represents current Federal and State legislation and final implementation regulations in place as of the end of October 2013.

SO_2 emissions from affected electric generating units (EGUs) are subject to nationwide and regional emissions cap and trading programs. Title IV of the Clean Air Act sets an annual emissions cap on SO_2 for affected EGUs in the 48 contiguous states and the District of Columbia (D.C.). SO_2 emissions from 28 eastern states and D.C. were also limited under the Clean Air Interstate Rule (CAIR), which created an allowance-based trading program that that operates along with the Title IV program in those States and D.C. 70 FR 25162 (May 12, 2005). CAIR was remanded to EPA by the U.S. Court of Appeals for the District of Columbia Circuit (D.C. Circuit) but parts of it remained in effect. On July 6, 2011 EPA issued a replacement for CAIR, the Cross-State Air Pollution Rule (CSAPR). 76 FR 48208 (August 8, 2011). On August 21, 2012, the D.C. Circuit issued a decision to vacate CSAPR. See *EME Homer City Generation, LP v. EPA*, 696 F.3d 7, 38 (D.C. Cir. 2012). The court ordered EPA to continue administering CAIR. The *AEO 2014* emissions factors used for the present analysis assume that CAIR remains a binding regulation through 2040. [d]

The attainment of emissions caps is typically flexible among affected Electric Generating Units (EGUs) and is enforced through the use of emissions allowances and tradable permits. Under existing EPA regulations, any excess SO_2 emissions allowances resulting from the lower electricity demand caused by the imposition of an efficiency standard could be used to permit offsetting increases in SO_2 emissions by any regulated EGU. In past rulemakings, DOE recognized that there was uncertainty about the effects of efficiency standards on SO_2 emissions covered by the existing cap-and-trade system, but it concluded that no reductions in power sector emissions would occur for SO_2 as a result of standards.

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[c] The values are without inclusion of climate-carbon feedbacks in response to emissions of the indicated non-CO_2 gases.

[d] 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. Because DOE is using emissions factors based on AEO 2013, the analysis assumes that CAIR, not CSAPR, is the regulation in force. The difference between CAIR and CSAPR is not relevant for the purpose of DOE's analysis of SO_2 emissions.

Beginning in 2016, however, SO_2 emissions will fall as a result of the Mercury and Air Toxics Standards (MATS) for power plants. 77 FR 9304 (Feb. 16, 2012). In the final MATS rule, EPA established a standard for hydrogen chloride as a surrogate for acid gas hazardous air pollutants (HAP), and also established a standard for SO_2 (a non-HAP acid gas) as an alternative equivalent surrogate standard for acid gas HAP. The same controls are used to reduce HAP and non-HAP acid gas; thus, SO_2 emissions will be reduced as a result of the control technologies installed on coal-fired power plants to comply with the MATS requirements for acid gas. *AEO 2014* assumes that, in order to continue operating, coal plants must have either flue gas desulfurization or dry sorbent injection systems installed by 2016. Both technologies, which are used to reduce acid gas emissions, also reduce SO_2 emissions. Under the MATS, emissions will be far below the cap established by CAIR, so it is unlikely that excess SO_2 emissions allowances resulting from the lower electricity demand would be needed or used to permit offsetting increases in SO_2 emissions by any regulated EGU. Therefore, DOE believes that efficiency standards will reduce SO_2 emissions in 2016 and beyond.

CAIR established a cap on NO_x emissions in 28 eastern States and the District of Columbia. Energy conservation standards are expected to have little effect on NO_x emissions in those States covered by CSAPR because excess NO_x emissions allowances resulting from the lower electricity demand could be used to permit offsetting increases in NO_x emissions. However, standards would be expected to reduce NO_x emissions in the States not affected by CAIR, so DOE estimated NO_X emissions reductions from potential standards for those States.

The MATS limit mercury emissions from power plants, but they do not include emissions caps and, as such, DOE's energy conservation standards would likely reduce Hg emissions. DOE estimated mercury emissions reductions using the NEMS-BT based on *AEO 2014*, which incorporates the MATS.

13.3 POWER SECTOR AND SITE EMISSIONS FACTORS

The analysis of power sector emissions uses marginal emissions intensity factors derived from analysis of the *AEO 2014* reference and a number of side cases incorporating enhanced equipment efficiencies. To model the impact of a standard, DOE calculates factors that relate a unit reduction to annual site electricity demand for a given end use to corresponding reductions to installed capacity by fuel type, fuel use for generation, and power sector emissions. Details on the approach used may be found in Coughlin (2014).

Table 13.3.1 and 13.3.2 present the average power plant emissions factors for selected years. These power plant emissions factors are derived from the emissions factors of the plant types used to supply electricity for space heating to homes and commercial buildings. The average factors for each year take into account the projected shares of each of the sources in total electricity generation.

Table 13.3.3 presents the natural gas site combustion emissions factors for selected years.

Table 13.3.1 Power Plant Emissions Factors (for Residential Space Heating)

	Unit*	2020	2025	2030	2035	2040
CO_2	kg/MWh	742	656	592	540	491
SO_2	g/MWh	756	590	496	417	373
NO_X	g/MWh	597	497	434	382	345
Hg	g/MWh	0.00233	0.00182	0.00153	0.00129	0.00115
N_2O	g/MWh	7.2	7.1	6.9	6.6	6.4
CH_4	g/MWh	50.2	49.4	47.9	46.4	44.8

* Refers to site electricity savings.

Table 13.3.2 Power Plant Emissions Factors (for Commercial Space Heating)

	Unit*	2020	2025	2030	2035	2040
CO_2	kg/MWh	745	658	594	541	493
SO_2	g/MWh	760	593	499	419	375
NO_X	g/MWh	599	499	436	383	346
Hg	g/MWh	0.00235	0.00183	0.00154	0.00129	0.00116
N_2O	g/MWh	7.2	7.1	6.9	6.6	6.4
CH_4	g/MWh	50.2	49.4	47.9	46.4	44.8

* Refers to site electricity savings.

Table 13.3.3 Natural Gas Site Combustion Emissions Factors

	Unit*	2020	2025	2030	2035	2040
CO_2	kg/mcf	54.2	54.2	54.2	54.2	54.2
SO_2	g/ mcf	0.271	0.271	0.271	0.271	0.271
NO_X	g/ mcf	69.9	69.9	69.9	69.9	69.9
N_2O	g/ mcf	0.102	0.102	0.102	0.102	0.102
CH_4	g/ mcf	1.022	1.022	1.022	1.022	1.022

* Refers to site gas savings.

13.4 UPSTREAM FACTORS

The upstream emissions accounting uses the same approach as the upstream energy accounting described in appendix 10B. See also Coughlin (2013) and Coughlin (2014). When demand for a particular fuel is reduced, there is a corresponding reduction in the emissions from combustion of that fuel at either the building site or the power plant. The associated reduction in energy use for upstream activities leads to further reductions in emissions. These upstream emissions are defined to include the combustion emissions from the fuel used upstream, the fugitive emissions associated with the fuel used upstream, and the fugitive emissions associated with the fuel used on site.

Fugitive emissions of CO_2 occur during oil and gas production, but are small relative to combustion emissions. They comprise about 2.5 percent of total CO_2 emissions for natural gas and 1.7 percent for petroleum fuels. Fugitive emissions of methane occur during oil, gas and coal production. Combustion emissions of CH_4 are very small, while fugitive emissions (particularly for gas production) may be relatively large. Hence, fugitive emissions make up over 99 percent of total methane emissions for natural gas, about 95 percent for coal, and 93 percent for petroleum fuels.

Upstream emissions factors account for both fugitive emissions and combustion emissions in extraction, processing, and transport of primary fuels. Fugitive emissions factors for methane from coal mining and natural gas production were estimated based on a review of recent studies compiled by Burnham (2011).[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 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.

For ease of application in its analysis, DOE developed all of the emissions factors using site (point of use) energy savings in the denominator. Table 13.4.1 presents the electricity upstream emissions factors for selected years. The caps that apply to power sector NO_X emissions do not apply to upstream combustion sources.

Table 13.4.1 Electricity Upstream Emissions Factors

	Unit	2020	2025	2030	2035	2040
CO_2	kg/MWh	29.1	29.4	29.7	29.9	29.8
SO_2	g/MWh	5.0	5.1	4.9	4.7	4.6
NO_X	g/MWh	368	375	382	387	387
Hg	g/MWh	0.00001	0.00001	0.00001	0.00001	0.00001
N_2O	g/MWh	0.25	0.25	0.24	0.23	0.23
CH_4	g/MWh	2,149	2,195	2,216	2,248	2,255

Table 13.4.2 illustrates the natural gas upstream emissions factors for selected years. These were used to estimate the emissions associated with the increased gas use at some of the considered efficiency levels.

Table 13.4.2 Natural Gas Upstream Emissions Factors

	Unit	2020	2025	2030	2035	2040
CO_2	kg/ mcf	7.1	7.2	7.3	7.4	7.4
SO_2	g/ mcf	0.030	0.031	0.031	0.032	0.032
NO_X	g/ mcf	101	103	105	105	105
N_2O	g/ mcf	0.011	0.011	0.012	0.012	0.012
CH_4	g/ mcf	659	665	666	670	670

13.5 EMISSIONS IMPACT RESULTS

Table 13.5.1 and Table 13.5.2 present the estimated cumulative emissions reductions for the lifetime of products sold in 2021-2050 for each TSL. Negative values indicate that emissions increase. As mentioned previously, electricity use increases under the considered NWGF TSLs due to switching to electric heating systems (see chapter 8 for discussion of switching).

Table 13.5.1 Cumulative Emissions Reduction for NWGFs and MHGFs for AFUE Standards

	Trial Standard Level				
	1	2	3	4	5
Site and Power Sector Emissions					
CO2 (million metric tons)	51.0	91.3	105.5	163.2	215.5
SO2 (thousand tons)	(76.3)	(72.3)	(200.5)	(242.0)	(339.0)
NOX (thousand tons)	126.7	181.3	292.5	404.2	547.7
Hg (tons)	(0.238)	(0.226)	(0.624)	(0.754)	(1.056)
CH4 (thousand tons)	(5.79)	(4.63)	(15.89)	(18.46)	(26.14)
N2O (thousand tons)	(0.95)	(0.82)	(2.57)	(3.04)	(4.28)
Upstream Emissions					
CO2 (million metric tons)	13.6	18.7	31.9	43.4	59.0
SO2 (thousand tons)	(0.81)	(0.74)	(2.14)	(2.57)	(3.61)
NOX (thousand tons)	222.6	303.0	523.4	708.7	965
Hg (tons)	(0.002)	(0.002)	(0.005)	(0.006)	(0.009)
CH4 (thousand tons)	1,458	1,969	3,440	4,643	6,326
N2O (thousand tons)	(0.011)	(0.001)	(0.037)	(0.036)	(0.054)
Total FFC Emissions					
CO2 (million metric tons)	64.6	110.0	137.3	206.5	274.5
SO2 (thousand tons)	(77.1)	(73.0)	(202.6)	(244.6)	(342.6)
NOX (thousand tons)	349.3	484.3	815.9	1,113	1,513
Hg (tons)	(0.240)	(0.228)	(0.629)	(0.760)	(1.065)
CH4 (thousand tons)	1,452	1,964	3,424	4,624	6,300
CH4 (thousand tons CO2eq)*	40,663	54,995	95,882	129,480	176,393
N2O (thousand tons)	(0.96)	(0.82)	(2.61)	(3.07)	(4.34)
N2O (thousand tons CO2eq)*	(256)	(217)	(692)	(814)	(1,149)

Note: Parentheses indicate negative values.

Table 13.5.2 Cumulative Emissions Reduction for NWGFs and MHGFs for Standby Mode and Off Mode Standards

	Trial Standard Level		
	1	2	3
Site and Power Sector Emissions			
CO2 (million metric tons)	8.2	9.8	14.7
SO2 (thousand tons)	7.1	8.6	12.9
NOX (thousand tons)	6.5	7.8	11.8
Hg (tons)	0.022	0.026	0.040
CH4 (thousand tons)	0.82	0.98	1.48
N2O (thousand tons)	0.12	0.14	0.21
Upstream Emissions			
CO2 (million metric tons)	0.5	0.6	0.9
SO2 (thousand tons)	0.08	0.10	0.15
NOX (thousand tons)	7.0	8.4	12.5
Hg (tons)	0.0002	0.0002	0.0003
CH4 (thousand tons)	40.6	48.8	73.1
N2O (thousand tons)	0.004	0.005	0.007
Total FFC Emissions			
CO2 (million metric tons)	8.6	10.4	15.6
SO2 (thousand tons)	7.2	8.7	13.0
NOX (thousand tons)	13.5	16.2	24.3
Hg (tons)	0.022	0.027	0.040
CH4 (thousand tons)	41.4	49.7	74.6
CH4 (thousand tons CO2eq)*	1,161	1,393	2,088
N2O (thousand tons)	0.121	0.146	0.219
N2O (thousand tons CO2eq)*	32	39	58

Note: Parentheses indicate negative values.

Figure 13.5.1 through Figure 13.5.12 show the annual change in total emissions for each type of emission from each TSL. The impacts reflect the lifetime impacts of products sold in 2021-2050. Note that negative values indicate an increase in emissions. Figure 13.5.1 through Figure 13.5.6 show the impacts for AFUE standards for NWGFs and MHGFs. Figure 13.5.7 through Figure 13.5.12 show the impacts for standby and off mode standards for NWGFs and MHGFs.

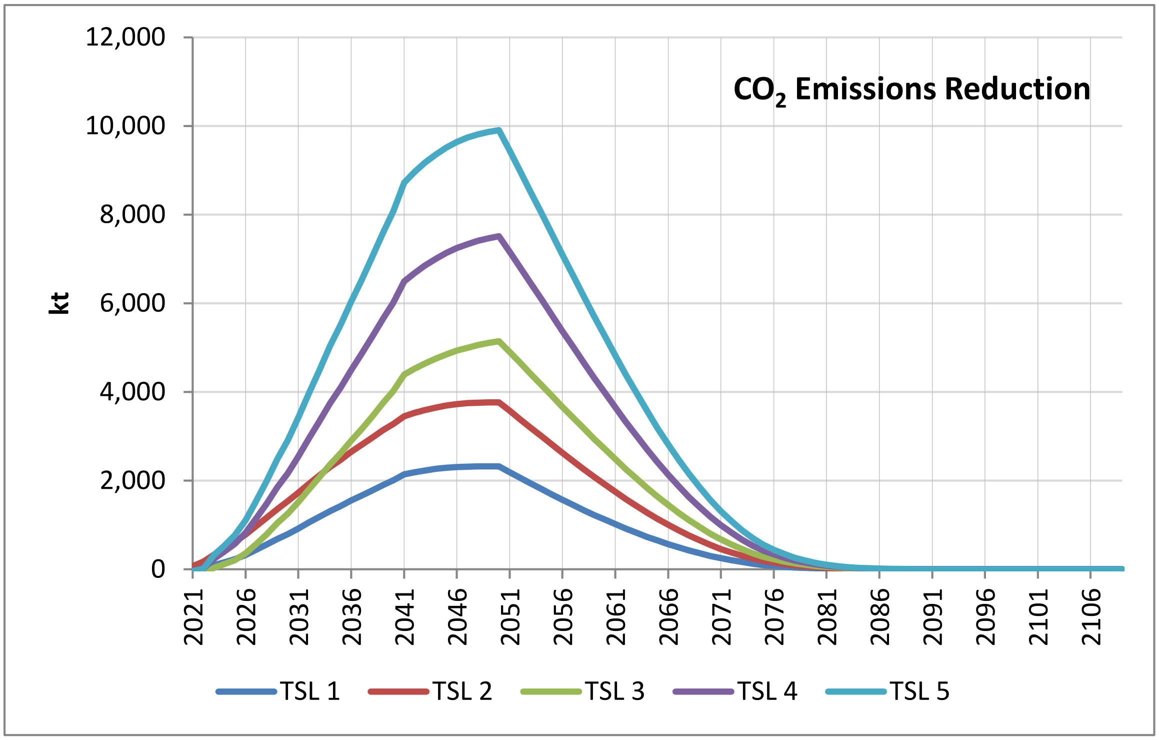

Figure 13.5.1 **CO$_2$ Total Emissions Reduction for NWGFs and MHGFs for AFUE Standards**

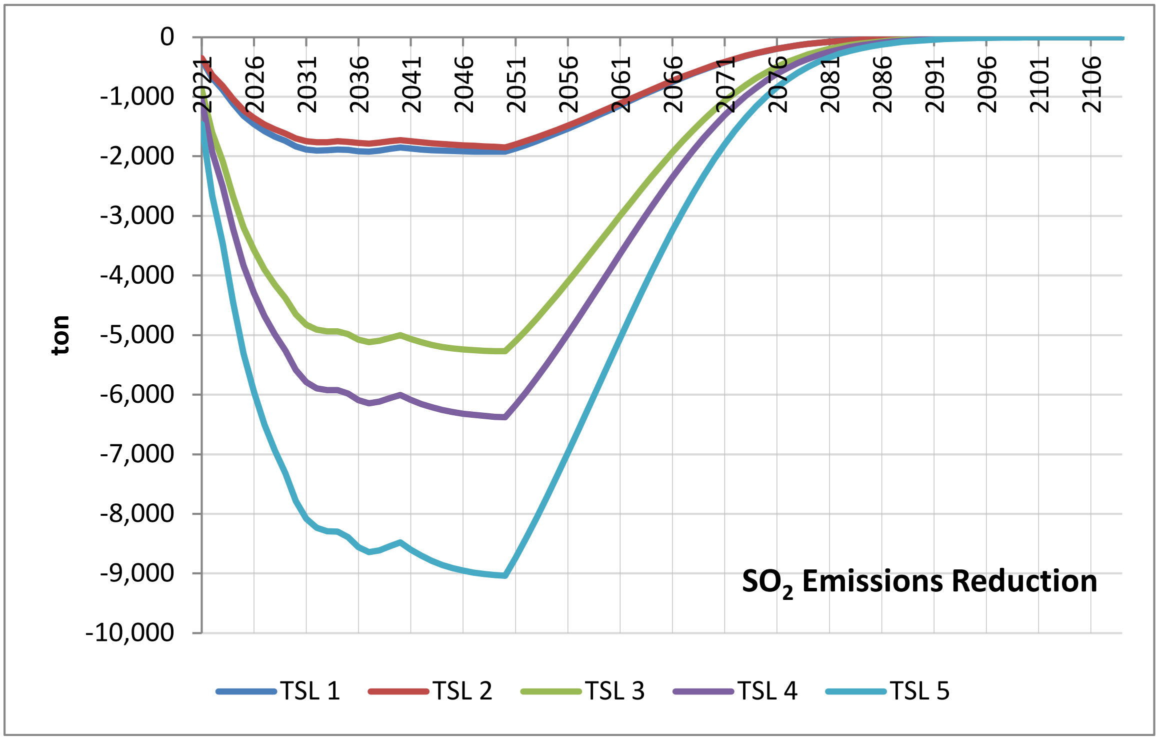

Figure 13.5.2 **SO$_2$ Total Emissions Reduction for NWGFs and MHGFs for AFUE Standards**

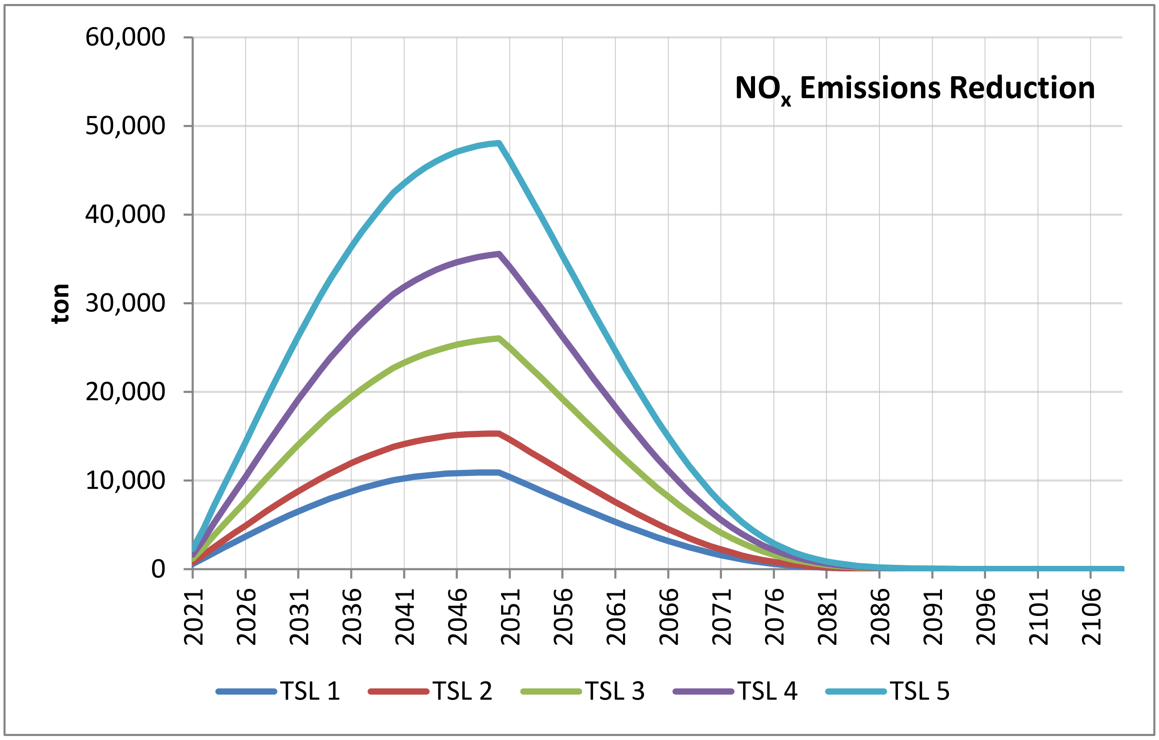

Figure 13.5.3 NO$_x$ Total Emissions Reduction for NWGFs and MHGFs for AFUE Standards

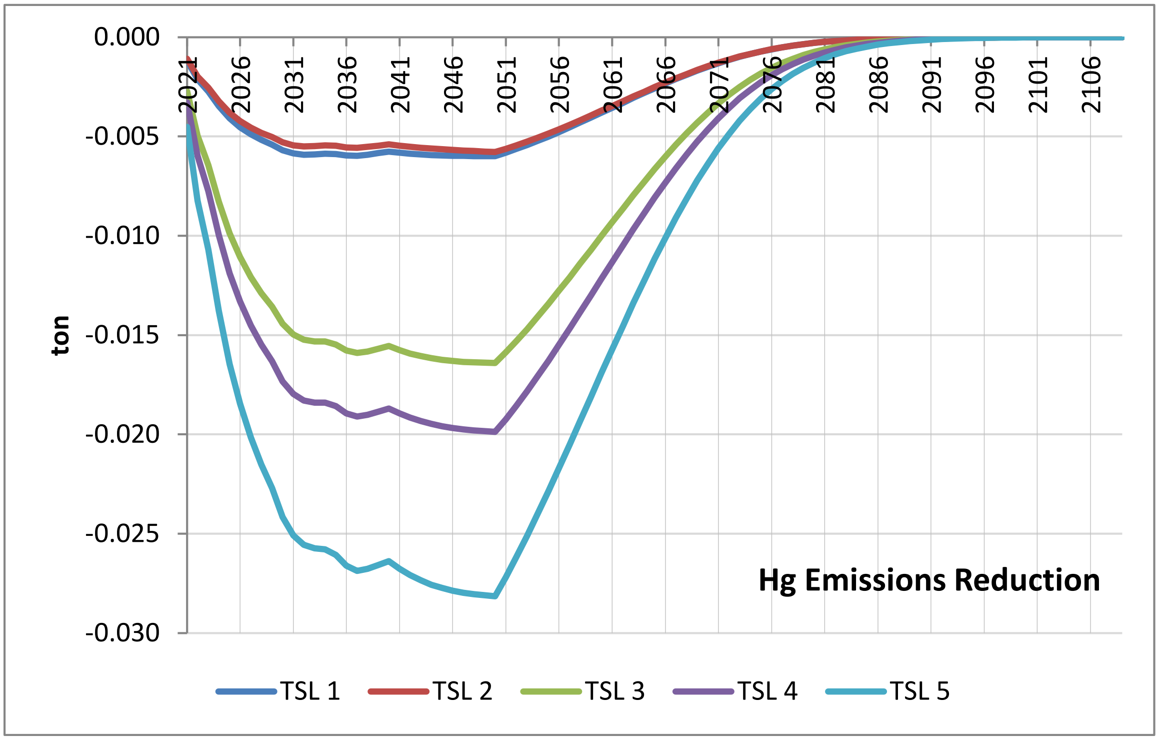

Figure 13.5.4 Hg Total Emissions Reduction for NWGFs and MHGFs for AFUE Standards

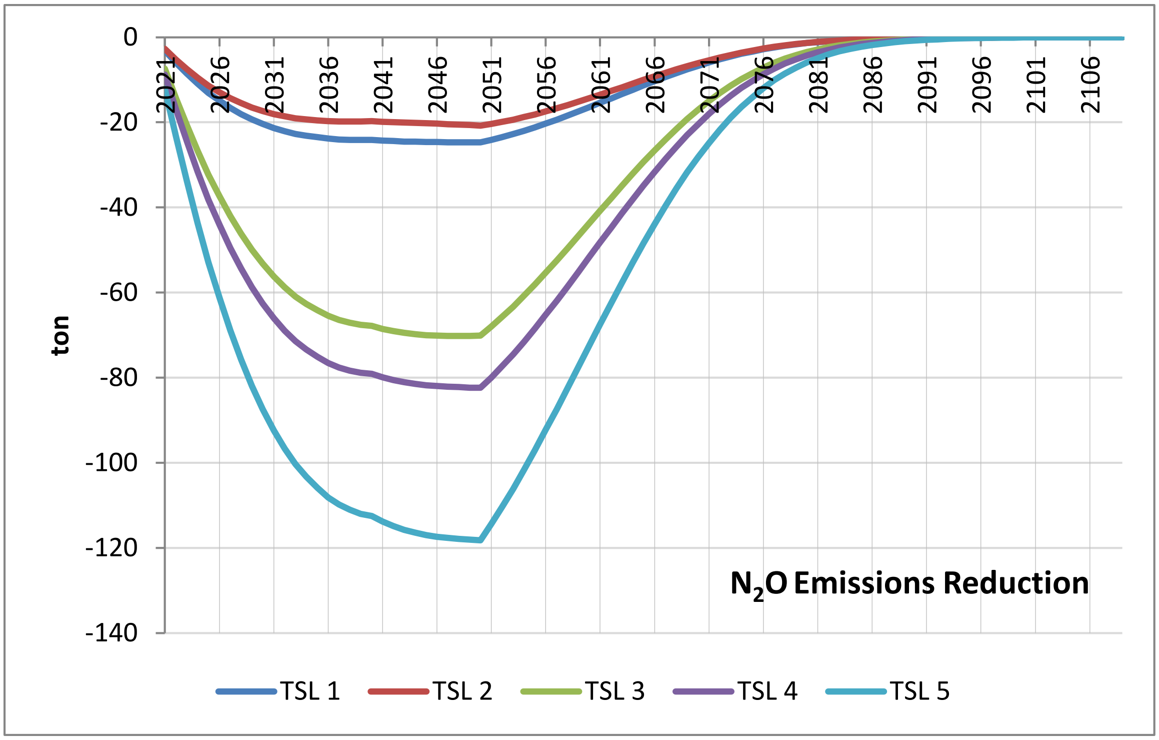

Figure 13.5.5 N$_2$O Total Emissions Reduction for NWGFs and MHGFs for AFUE Standards

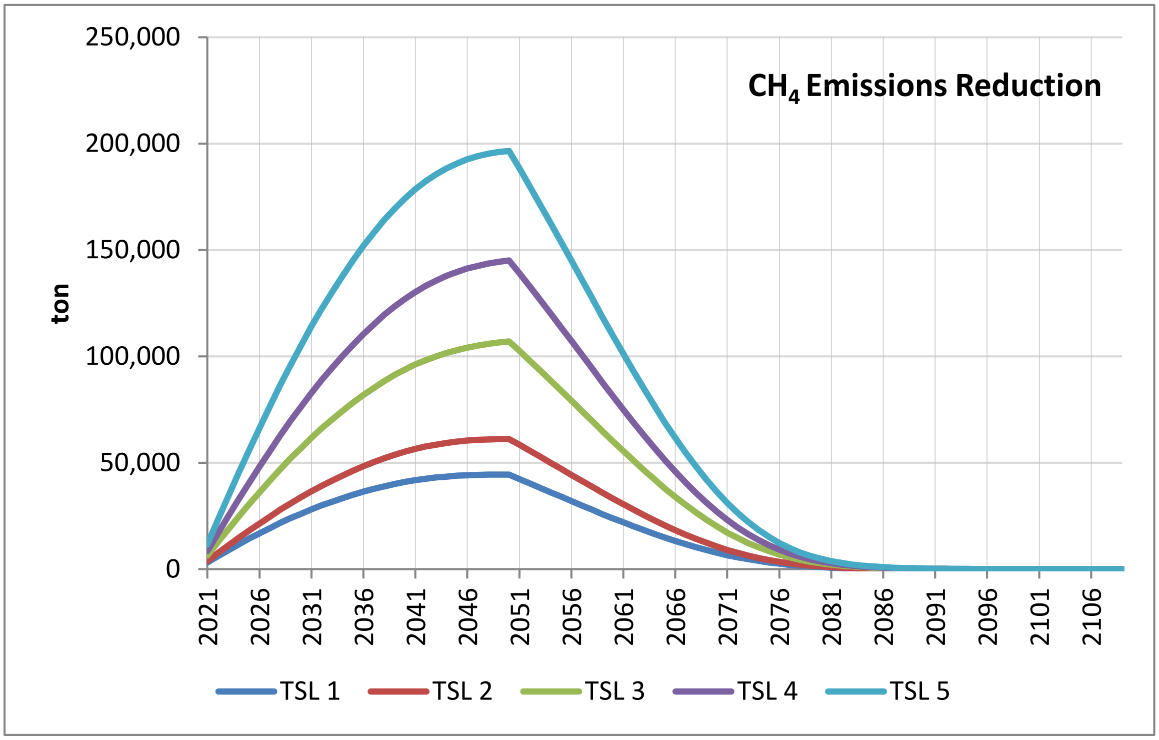

Figure 13.5.6 CH$_4$ Total Emissions Reduction for NWGFs and MHGFs for AFUE Standards

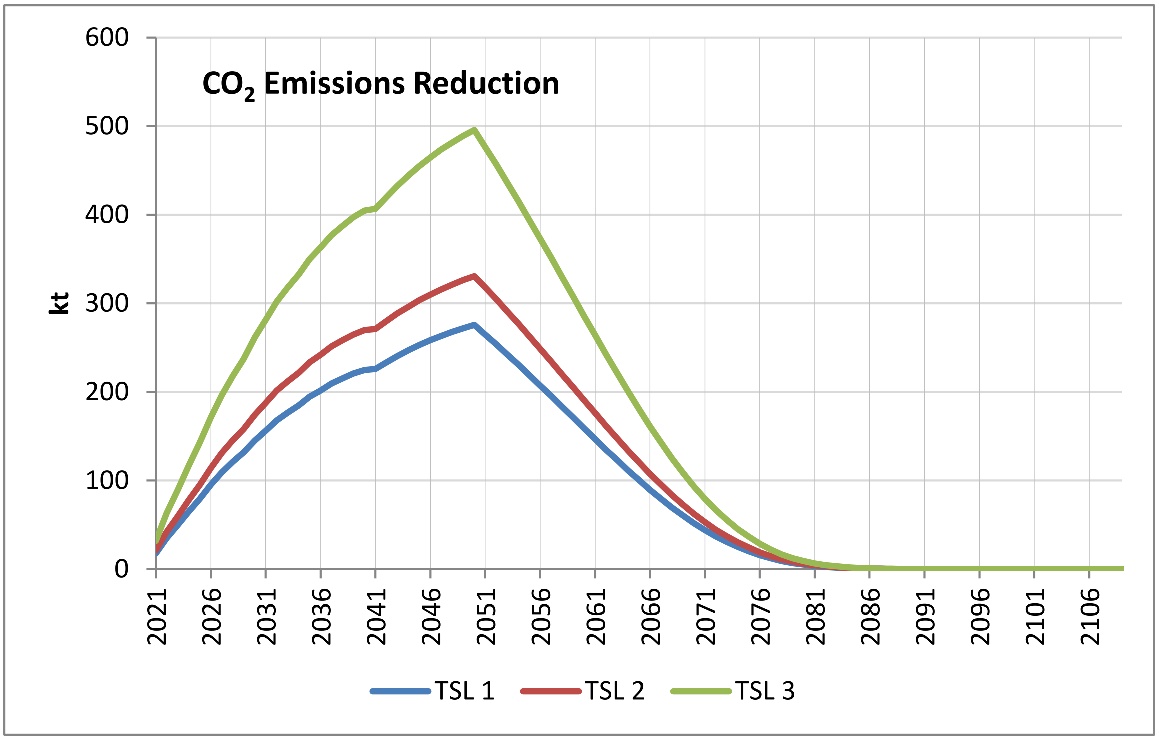

Figure 13.5.7 CO_2 Total Emissions Reduction for NWGFs and MHGFs for Standby Mode and Off Mode Standards

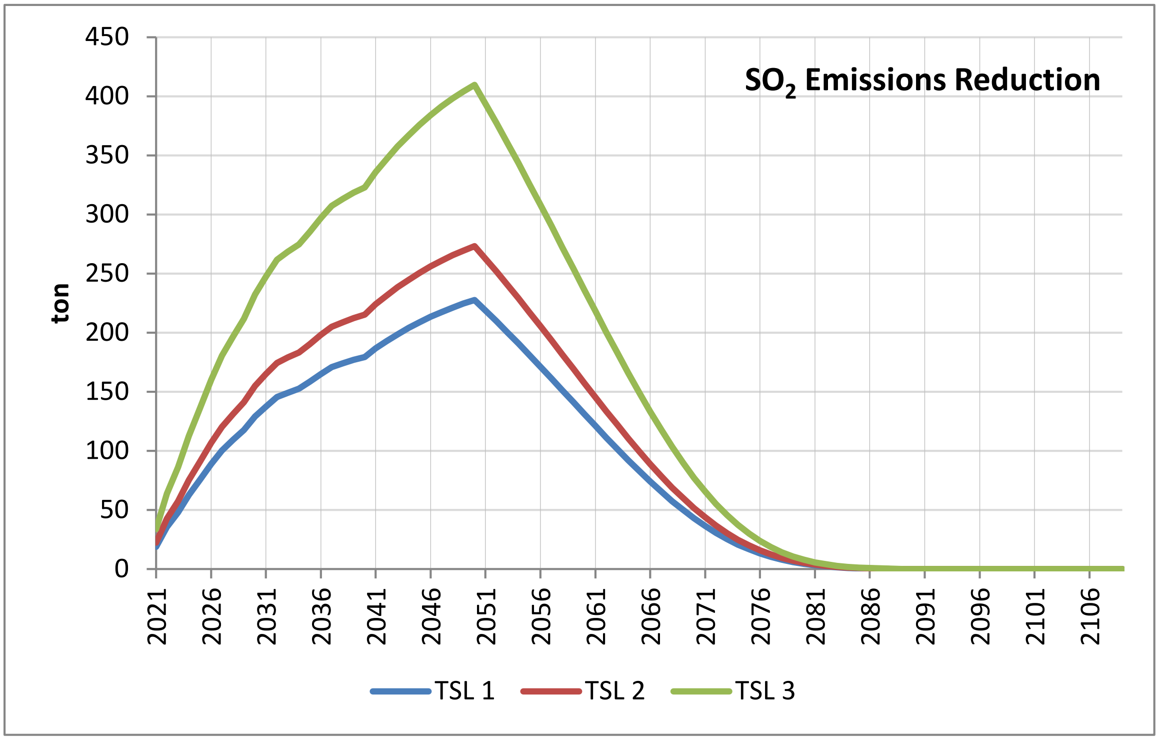

Figure 13.5.8 SO_2 Total Emissions Reduction for NWGFs and MHGFs for Standby Mode and Off Mode Standards

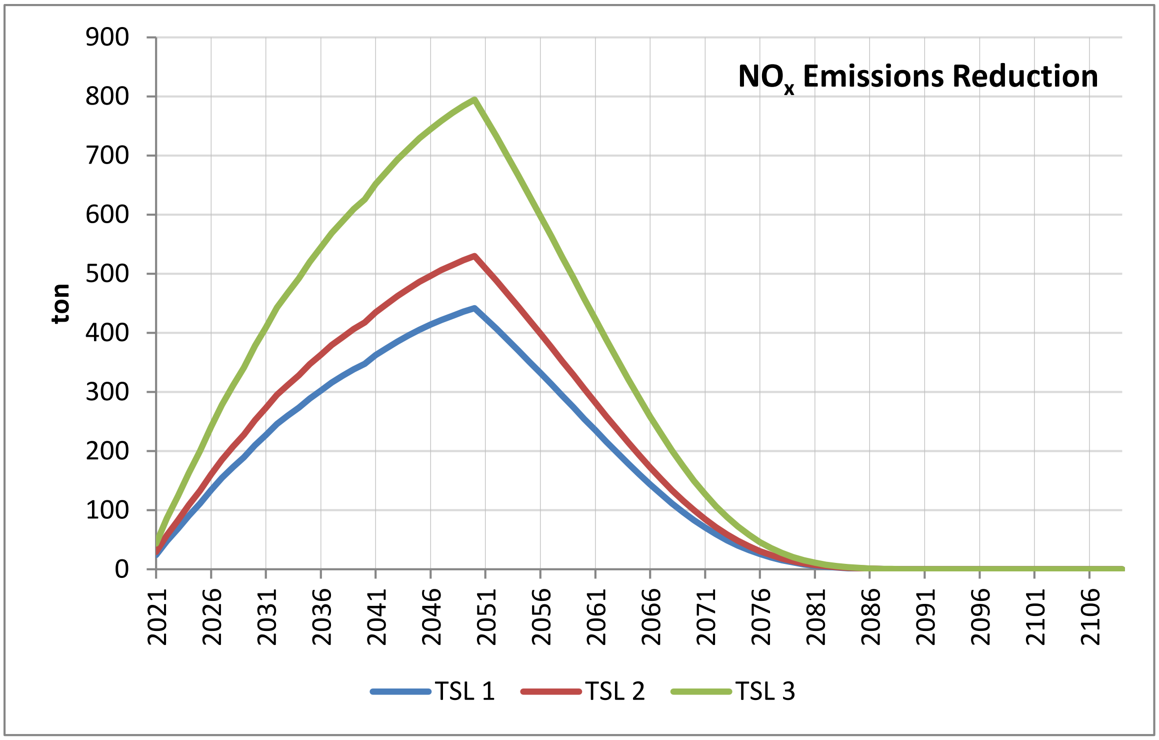

Figure 13.5.9 **NO$_x$ Total Emissions Reduction for NWGFs and MHGFs for Standby Mode and Off Mode Standards**

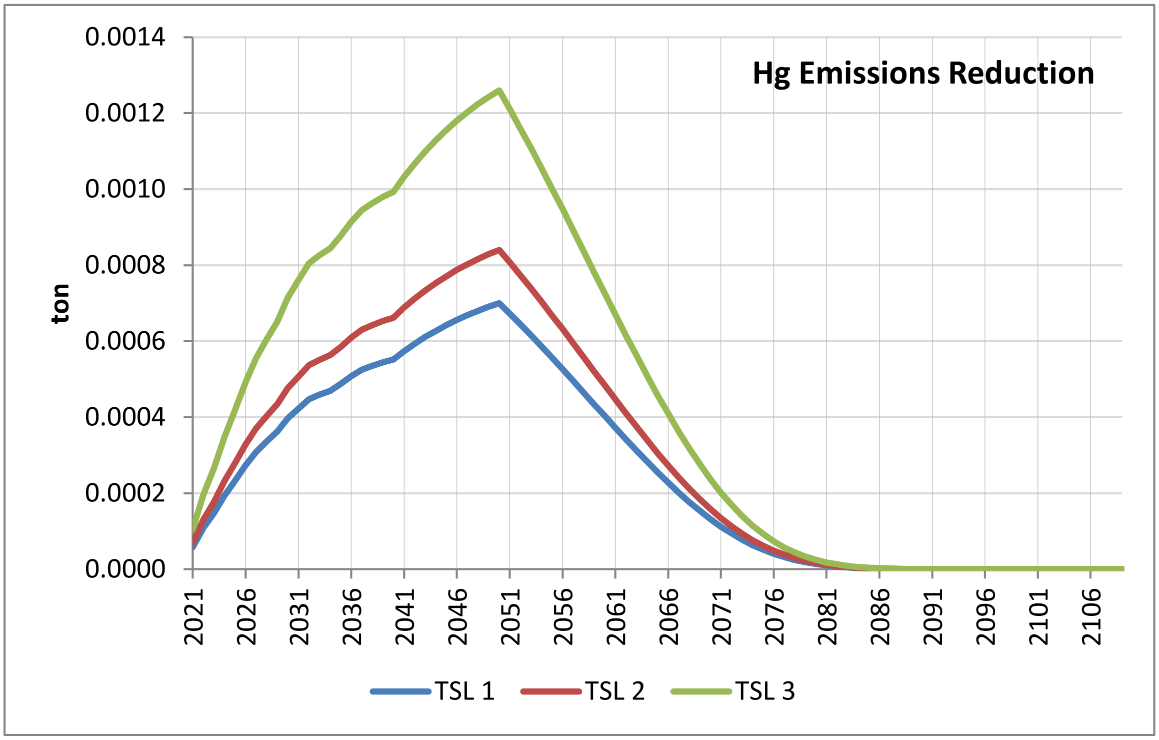

Figure 13.5.10 **Hg Total Emissions Reduction for NWGFs and MHGFs for Standby Mode and Off Mode Standards**

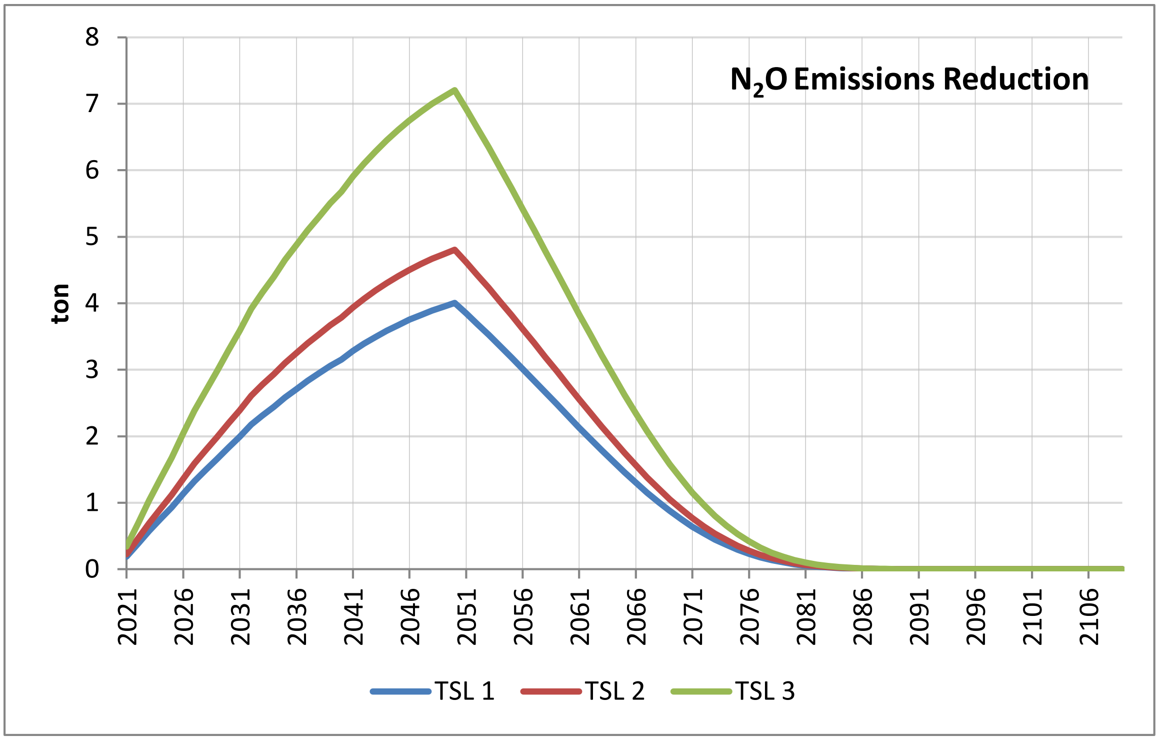

Figure 13.5.11 **N_2O Total Emissions Reduction for NWGFs and MHGFs for Standby Mode and Off Mode Standards**

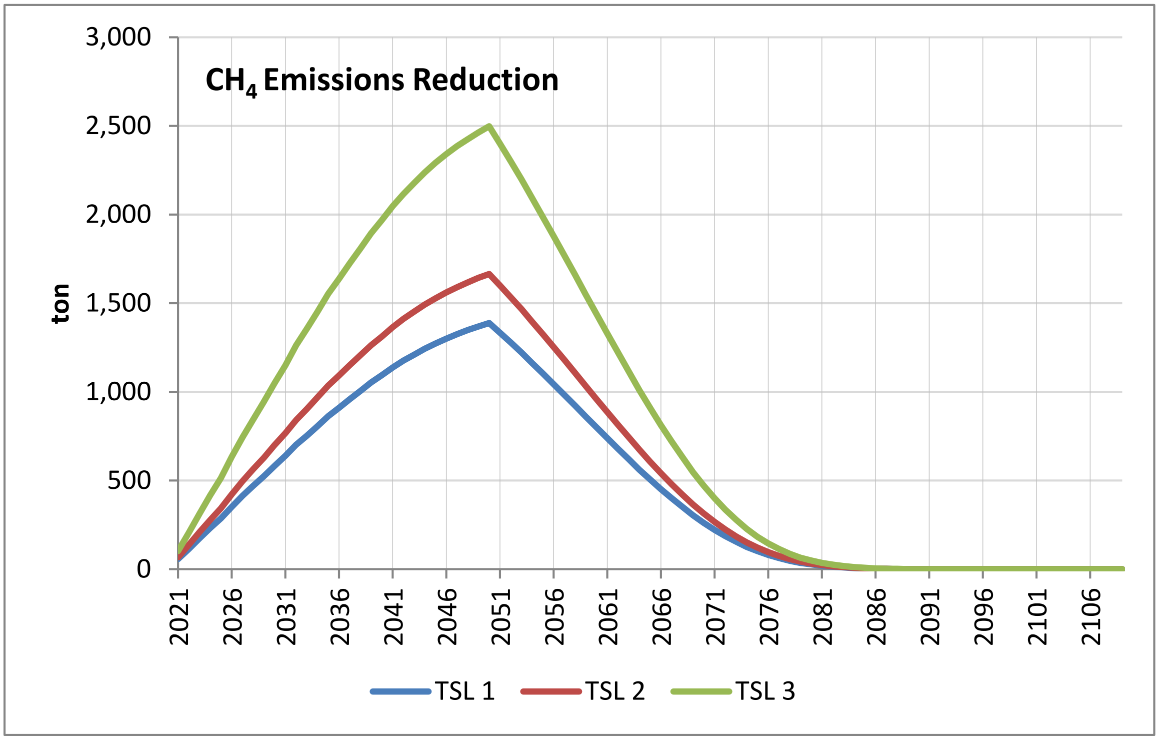

Figure 13.5.12 **CH_4 Total Emissions Reduction for NWGFs and MHGFs for Standby Mode and Off Mode Standards**

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CHAPTER 14. MONETIZATION OF EMISSION REDUCTIONS BENEFITS

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CHAPTER 14. MONETIZATION OF EMISSION REDUCTIONS BENEFITS

14.1 INTRODUCTION

As part of its assessment of energy conservation standards, 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 of the TSLs considered. This chapter summarizes the basis for the monetary values used for each of these emissions and presents the benefits estimates considered.

14.2 MONETIZING CARBON DIOXIDE EMISSIONS

14.2.1 Social Cost of Carbon

The social cost of carbon (SCC) is an estimate of the monetized damages associated with an incremental increase in carbon emissions in a given year. It is intended to include (but is not limited to) changes in net agricultural productivity, human health, property damages from increased flood risk, and the value of ecosystem services. Estimates of the SCC are provided in dollars per metric ton of carbon dioxide. A domestic SCC value is meant to reflect the value of damages in the United States resulting from a unit change in carbon dioxide emissions, while a global SCC value is meant to reflect the value of damages worldwide.

Under section 1(b)(6) of Executive Order 12866,"Regulatory Planning and Review," 58 FR 51735 (Oct. 4, 1993), agencies must, to the extent permitted by law, "assess both the costs and the benefits of the intended regulation and, recognizing that some costs and benefits are difficult to quantify, propose or adopt a regulation only upon a reasoned determination that the benefits of the intended regulation justify its costs." The purpose of the SCC estimates presented here is to allow agencies to incorporate the monetized social benefits of reducing CO_2 emissions into cost-benefit analyses of regulatory actions that have small, or "marginal," impacts on cumulative global emissions. The estimates are presented with an acknowledgement of the many uncertainties involved and with a clear understanding that they should be updated over time to reflect increasing knowledge of the science and economics of climate impacts.

As part of the interagency process that developed these SCC estimates, technical experts from numerous agencies met on a regular basis to explore the technical literature in relevant fields, discuss key model inputs and assumptions, and consider public comments. The main objective of this process was to develop a range of SCC values using a defensible set of input assumptions grounded in the existing scientific and economic literatures. In this way, key uncertainties and model differences transparently and consistently inform the range of SCC estimates used in the rulemaking process.

14.2.2 Monetizing Carbon Dioxide Emissions

When attempting to assess the incremental economic impacts of carbon dioxide emissions, the analyst faces a number of serious challenges. A report from the National Research Council[1] points out that any assessment will suffer from uncertainty, speculation, and lack of information about (1) future emissions of greenhouse gases, (2) the effects of past and future emissions on the climate system, (3) the impact of changes in climate on the physical and biological environment, and (4) the translation of these environmental impacts into economic damages. As a result, any effort to quantify and monetize the harms associated with climate change will raise serious questions of science, economics, and ethics and should be viewed as provisional.

Despite the serious limits of both quantification and monetization, SCC estimates can be useful in estimating the social benefits of reducing carbon dioxide emissions. Most Federal regulatory actions can be expected to have marginal impacts on global emissions. For such policies, the agency can estimate the benefits from reduced (or costs from increased) emissions in any future year by multiplying the change in emissions in that year by the SCC value appropriate for that year. The net present value of the benefits can then be calculated by multiplying each of these future benefits by an appropriate discount factor and summing across all affected years. This approach assumes that the marginal damages from increased emissions are constant for small departures from the baseline emissions path, an approximation that is reasonable for policies that have effects on emissions that are small relative to cumulative global carbon dioxide emissions.

In 2009, an interagency process was initiated to offer a preliminary assessment of how best to quantify the benefits from reducing carbon dioxide emissions. To ensure consistency in how benefits are evaluated across agencies, the Administration sought to develop a transparent and defensible method, specifically designed for the rulemaking process, to quantify avoided climate change damages from reduced CO_2 emissions. The interagency group did not undertake any original analysis. Instead, it combined SCC estimates from the existing literature to use as interim values until a more comprehensive analysis could be conducted. 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 proposed rule. 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

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[a] The models are described in appendix 14A of the TSD.

frequently cited in the peer-reviewed literature and were used in the last assessment of the Intergovernmental Panel on Climate Change. Each model was given equal weight in the SCC values that were developed.

Each model takes a slightly different approach to model how changes in emissions result in changes in economic damages. A key objective of the interagency process was to enable a consistent exploration of the three models while respecting the different approaches to quantifying damages taken by the key modelers in the field. An extensive review of the literature was conducted to select three sets of input parameters for these models: (1) climate sensitivity; (2) socio-economic and emissions trajectories; and (3) discount rates. A probability distribution for climate sensitivity was specified as an input into all three models. In addition, the interagency group used a range of scenarios for the socio-economic parameters and a range of values for the discount rate. All other model features were left unchanged, relying on the model developers' best estimates and judgments.

The interagency group selected four SCC values for use in regulatory analyses. Three values are based on the average SCC from three integrated assessment models, at discount rates of 2.5, 3, and 5 percent. The fourth value, which represents the 95th percentile SCC estimate across all three models at a 3 percent discount rate, is included to represent higher-than-expected impacts from temperature change further out in the tails of the SCC distribution. The values grow in real terms over time. Additionally, the interagency group determined that a range of values from 7 percent to 23 percent should be used to adjust the global SCC to calculate domestic effects, although preference is given to consideration of the global benefits of reducing CO_2 emissions. Table 14.2.1 presents the values in the 2010 interagency group report,[2] which is reproduced in appendix 14A of the TSD.

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 November 2013).[3] Table 14.2.2 shows the updated sets of SCC estimates in five year increments from 2010 to 2050. The full set of annual SCC estimates between 2010 and 2050 is reported in appendix 14B of the TSD. 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. For the years after 2050, DOE applied the average annual growth rate of the SCC estimates in 2040−2050 associated with each of the four sets of values.

Table 14.2.1 Annual SCC Values from 2010 Interagency Report, 2010–2050 (in 2007 dollars per metric ton of CO_2)

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

Table 14.2.2 Annual SCC Values from 2013 Interagency Update, 2010–2050 (in 2007 dollars per metric ton of CO_2)

Year	Discount Rate %			
	5	3	2.5	3
	Average	Average	Average	95th Percentile
2010	11	32	51	89
2015	11	37	57	109
2020	12	43	64	128
2025	14	47	69	143
2030	16	52	75	159
2035	19	56	80	175
2040	21	61	86	191
2045	24	66	92	206
2050	26	71	97	220

It is important to recognize that a number of key uncertainties remain, and that current SCC estimates should be treated as provisional and revisable since they will evolve with improved scientific and economic understanding. The interagency group also recognizes that the existing models are imperfect and incomplete. The National Research Council report mentioned above points out that there is tension between the goal of producing quantified estimates of the economic damages from an incremental ton of carbon and the limits of existing efforts to model these effects. There are a number of concerns and problems that should be addressed by the research community, including research programs housed in many of the agencies participating in the interagency process to estimate the SCC. The interagency group intends to periodically review and reconsider estimates of the SCC used for cost-benefit analyses to reflect increasing knowledge of the science and economics of climate impacts, as well as improvements in modeling.

In summary, in considering the potential global benefits resulting from reduced CO_2 emissions, DOE used the values from the 2013 interagency report, escalated to 2013$ using the GDP price deflator. For each of the four cases specified, the values used for emissions in 2015 were $12.0, $40.5, $62.4, and $119 per metric ton avoided.

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, the interagency report notes that damages from future emissions should be discounted at the same rate as that used to calculate the SCC estimates themselves to ensure internal consistency. Thus, 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

DOE considered the potential monetary benefit of reduced NO_X emissions from the TSLs it considered. As noted in chapter 13, new or amended energy conservation standards would reduce NO_X emissions in those States that are not affected by caps. DOE estimated the monetized value of NO_X emissions reductions resulting from each of the TSLs considered based on environmental damage estimates found in the relevant scientific literature. Estimates of monetary value for reducing NO_X from stationary sources range from $476 to $4,893 per ton in 2013$.[4] DOE calculated monetary benefits using a medium value for NO_X emissions of $2,684 per short ton (in 2013$), and real discount rates of 3 percent and 7 percent.

DOE is still evaluating appropriate values to use to monetize avoided SO_2 and Hg emissions. It did not monetize these emissions for this analysis.

14.4 RESULTS

Table 14.4.1 presents the global values of CO_2 emissions reductions for each considered AFUE 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.

Table 14.4.3 presents the present value of cumulative NO_X emissions reductions for each AFUE TSL, calculated at seven and three percent discount rates using the average dollar-per-ton value.

Table 14.4.4 through Table 14.4.6 present the same results for standby mode and off mode TSLs.

Table 14.4.1 Estimates of Global Present Value of CO_2 Emissions Reduction for Non-Weatherized Gas Furnaces and Mobile Home Gas Furnaces AFUE Trial Standard Levels

TSL	SCC Case*			
	5% discount rate, average	3% discount rate, average	2.5% discount rate, average	3% discount rate, 95th percentile
	million 2013$			
Site and Power Sector Emissions				
1	279.9	1,428	2,312	4,432
2	508.4	2,574	4,162	7,981
3	552.3	2,880	4,680	8,935
4	870.0	4,496	7,295	13,945
5	1,151	5,944	9,643	18,436
Upstream Emissions				
1	78.2	389.9	628.7	1,207.6
2	106.9	534.7	862.7	1,656
3	180.0	904.2	1,460	2,800
4	244.7	1,229	1,985	3,808
5	333.6	1,674	2,703	5,185
Total FFC Emissions				
1	358.1	1,818	2,941	5,640
2	615.4	3,109	5,024	9,637
3	732.3	3,784	6,140	11,735
4	1,115	5,726	9,280	17,752
5	1,484	7,618	12,346	23,621

* For each of the four cases, the corresponding global SCC value for emissions in 2015 is $12.0, $40.5, $62.4, and $119 per metric ton (2013$).

Table 14.4.2 Estimates of Domestic Present Value of CO$_2$ Emissions Reduction for Non-Weatherized Gas Furnaces and Mobile Home Gas Furnaces AFUE Trial Standard Levels

TSL	SCC Case*			
	5% discount rate, average	3% discount rate, average	2.5% discount rate, average	3% discount rate, 95th percentile
	Million 2013$			
Site and Power Sector Energy Emissions				
1	19.6 to 64.4	100.0 to 328.5	161.9 to 531.8	310.2 to 1019.4
2	35.6 to 116.9	180.2 to 592.1	291.3 to 957.2	558.7 to 1835.6
3	38.7 to 127.0	201.6 to 662.4	327.6 to 1076.3	625.4 to 2055.0
4	60.9 to 200.1	314.7 to 1034.1	510.6 to 1677.8	976.1 to 3207.3
5	80.6 to 264.7	416.1 to 1367.1	675.0 to 2217.8	1290.5 to 4240.3
Upstream Emissions				
1	5.5 to 18.0	27.3 to 89.7	44.0 to 144.6	84.5 to 277.8
2	7.5 to 24.6	37.4 to 123.0	60.4 to 198.4	115.9 to 380.9
3	12.6 to 41.4	63.3 to 208.0	102.2 to 335.8	196.0 to 644.1
4	17.1 to 56.3	86.1 to 282.8	139.0 to 456.6	266.5 to 875.7
5	23.4 to 76.7	117.2 to 385.1	189.2 to 621.7	363.0 to 1192.6
Total Emissions				
1	25.1 to 82.4	127.3 to 418.2	205.9 to 676.4	394.8 to 1297.1
2	43.1 to 141.5	217.6 to 715.0	351.7 to 1155.6	674.6 to 2216.6
3	51.3 to 168.4	264.9 to 870.3	429.8 to 1412.1	821.5 to 2699.1
4	78.0 to 256.4	400.8 to 1316.9	649.6 to 2134.4	1242.7 to 4083.1
5	103.9 to 341.4	533.3 to 1752.2	864.2 to 2839.5	1653.5 to 5432.9

* For each of the four cases, the corresponding global SCC value for emissions in 2015 is $12.0, $40.5, $62.4, and $119 per metric ton (2013$).

Table 14.4.3 Estimates of Present Value of NO_X Emissions Reduction for Non-Weatherized Gas Furnaces and Mobile Home Gas Furnaces AFUE Trial Standard Levels

TSL	3% Discount Rate	7% Discount Rate
	million 2013$	
Site and Power Sector Emissions		
1	137.6	49.9
2	196.6	71.4
3	310.0	109.4
4	429.6	152.1
5	583.6	207.3
Upstream Emissions		
1	246.4	92.6
2	332.8	123.6
3	568.5	209.0
4	769.2	282.2
5	1050	386.4
Total FFC Emissions*		
1	384.0	142.5
2	529.5	195.0
3	878.6	318.4
4	1,199	434.4
5	1,634	593.7

* Components may not sum to total due to rounding.

Table 14.4.4 Estimates of Global Present Value of CO_2 Emissions Reduction for Non-Weatherized Gas Furnaces and Mobile Home Gas Furnaces Standby Mode and Off Mode Trial Standard Levels

TSL	SCC Case*			
	5% discount rate, average	3% discount rate, average	2.5% discount rate, average	3% discount rate, 95th percentile
	million 2013$			
Site and Power Sector Emissions				
1	46.1	231.4	373.6	716.5
2	55.3	277.7	448.4	859.8
3	82.9	416.4	672.3	1,289
Upstream Emissions				
1	2.7	13.7	22.1	42.4
2	3.2	16.4	26.6	50.9
3	4.8	24.6	39.8	76.2
Total FFC Emissions				
1	48.8	245.1	395.8	758.9
2	58.5	294.1	474.9	910.6
3	87.8	441.0	712.1	1,365

* For each of the four cases, the corresponding global SCC value for emissions in 2015 is $12.0, $40.5, $62.4, and $119 per metric ton (2013$).

Table 14.4.5 Estimates of Domestic Present Value of CO_2 Emissions Reduction for Non-Weatherized Gas Furnaces and Mobile Home Gas Furnaces Standby Mode and Off Mode Trial Standard Levels

TSL	SCC Case*			
	5% discount rate, average	3% discount rate, average	2.5% discount rate, average	3% discount rate, 95th percentile
	million 2013$			
Site and Power Sector Energy Emissions				
1	3.2 to 10.6	16.2 to 53.2	26.2 to 85.9	50.2 to 164.8
2	3.9 to 12.7	19.4 to 63.9	31.4 to 103.1	60.2 to 197.7
3	5.8 to 19.1	29.1 to 95.8	47.1 to 154.6	90.2 to 296.5
Upstream Emissions				
1	0.2 to 0.6	1.0 to 3.1	1.5 to 5.1	3.0 to 9.7
2	0.2 to 0.7	1.1 to 3.8	1.9 to 6.1	3.6 to 11.7
3	0.3 to 1.1	1.7 to 5.7	2.8 to 9.2	5.3 to 17.5
Total Emissions				
1	3.4 to 11.2	17.2 to 56.4	27.7 to 91.0	53.1 to 174.5
2	4.1 to 13.5	20.6 to 67.6	33.2 to 109.2	63.7 to 209.4
3	6.1 to 20.2	30.9 to 101.4	49.8 to 163.8	95.6 to 314.0

* For each of the four cases, the corresponding global SCC value for emissions in 2015 is $12.0, $40.5, $62.4, and $119 per metric ton (2013$).

Table 14.4.6 Estimates of Present Value of NO_X Emissions Reduction for Non-Weatherized Gas Furnaces and Mobile Home Gas Furnaces Standby Mode and Off Mode Trial Standard Levels

TSL	3% Discount Rate	7% Discount Rate
	million 2013$	
Site and Power Sector Emissions		
1	7.1	2.6
2	8.5	3.2
3	12.8	4.7
Upstream Emissions		
1	7.4	2.6
2	8.8	3.1
3	13.2	4.7
Total FFC Emissions*		
1	14.5	5.2
2	17.4	6.3
3	26.0	9.4

* Components may not sum to total due to rounding.

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APPENDIX 14A. SOCIAL COST OF CARBON FOR REGULATORY IMPACT ANALYSIS UNDER EXECUTIVE ORDER 12866

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APPENDIX 14A. SOCIAL COST OF CARBON FOR REGULATORY IMPACT ANALYSIS UNDER EXECUTIVE ORDER 12866[a]

14A.1 EXECUTIVE SUMMARY

Under Executive Order 12866, agencies are required, to the extent permitted by law, "to assess both the costs and the benefits of the intended regulation and, recognizing that some costs and benefits are difficult to quantify, propose or adopt a regulation only upon a reasoned determination that the benefits of the intended regulation justify its costs." The purpose of the "social cost of carbon" (SCC) estimates presented here is to allow agencies to incorporate the social benefits of reducing carbon dioxide (CO_2) emissions into cost-benefit analyses of regulatory actions that have small, or "marginal," impacts on cumulative global emissions. The estimates are presented with an acknowledgement of the many uncertainties involved and with a clear understanding that they should be updated over time to reflect increasing knowledge of the science and economics of climate impacts.

The SCC is an estimate of the monetized damages associated with an incremental increase in carbon emissions in a given year. It is intended to include (but is not limited to) changes in net agricultural productivity, human health, property damages from increased flood risk, and the value of ecosystem services due to climate change.

This document presents a summary of the interagency process that developed these SCC estimates. Technical experts from numerous agencies met on a regular basis to consider public comments, explore the technical literature in relevant fields, and discuss key model inputs and assumptions. The main objective of this process was to develop a range of SCC values using a defensible set of input assumptions grounded in the existing scientific and economic literatures. In this way, key uncertainties and model differences transparently and consistently inform the range of SCC estimates used in the rulemaking process.

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[a] Prepared by Interagency Working Group on Social Cost of Carbon, United States Government.
With participation by:
Council of Economic Advisers
Council on Environmental Quality
Department of Agriculture
Department of Commerce
Department of Energy
Department of Transportation
Environmental Protection Agency
National Economic Council
Office of Energy and Climate Change
Office of Management and Budget
Office of Science and Technology Policy
Department of the Treasury

The interagency group selected four SCC values for use in regulatory analyses. Three values are based on the average SCC from three integrated assessment models, at discount rates of 2.5, 3, and 5 percent. The fourth value, which represents the 95th percentile SCC estimate across all three models at a 3 percent discount rate, is included to represent higher-than-expected impacts from temperature change further out in the tails of the SCC distribution.

Table 14A.1.1 Social Cost of CO_2, 2010 – 2050 (in 2007 dollars)

	Discount Rate			
	5%	3%	2.5%	3%
Year	Avg	Avg	Avg	95th
2010	4.7	21.4	35.1	64.9
2015	5.7	23.8	38.4	72.8
2020	6.8	26.3	41.7	80.7
2025	8.2	29.6	45.9	90.4
2030	9.7	32.8	50.0	100.0
2035	11.2	36.0	54.2	109.7
2040	12.7	39.2	58.4	119.3
2045	14.2	42.1	61.7	127.8
2050	15.7	44.9	65.0	136.2

14A.2 MONETIZING CARBON DIOXIDE EMISSIONS

The SCC is an estimate of the monetized damages associated with an incremental increase in carbon emissions in a given year. We report estimates of the SCC in dollars per metric ton of carbon dioxide throughout this document.[b]

When attempting to assess the incremental economic impacts of carbon dioxide emissions, the analyst faces a number of serious challenges. A recent report from the National Academies of Science (NRC 2009) points out that any assessment will suffer from uncertainty, speculation, and lack of information about (1) future emissions of greenhouse gases, (2) the effects of past and future emissions on the climate system, (3) the impact of changes in climate on the physical and biological environment, and (4) the translation of these environmental impacts into economic damages. As a result, any effort to quantify and monetize the harms associated with climate change will raise serious questions of science, economics, and ethics and should be viewed as provisional.

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[b] In this document, we present all values of the SCC as the cost per metric ton of CO_2 emissions. Alternatively, one could report the SCC as the cost per metric ton of carbon emissions. The multiplier for translating between mass of CO_2 and the mass of carbon is 3.67 (the molecular weight of CO_2 divided by the molecular weight of carbon = 44/12 = 3.67).

Despite the serious limits of both quantification and monetization, SCC estimates can be useful in estimating the social benefits of reducing carbon dioxide emissions. Under Executive Order 12866, agencies are required, to the extent permitted by law, "to assess both the costs and the benefits of the intended regulation and, recognizing that some costs and benefits are difficult to quantify, propose or adopt a regulation only upon a reasoned determination that the benefits of the intended regulation justify its costs." The purpose of the SCC estimates presented here is to make it possible for agencies to incorporate the social benefits from reducing carbon dioxide emissions into cost-benefit analyses of regulatory actions that have small, or "marginal," impacts on cumulative global emissions. Most federal regulatory actions can be expected to have marginal impacts on global emissions.

For such policies, the benefits from reduced (or costs from increased) emissions in any future year can be estimated by multiplying the change in emissions in that year by the SCC value appropriate for that year. The net present value of the benefits can then be calculated by multiplying each of these future benefits by an appropriate discount factor and summing across all affected years. This approach assumes that the marginal damages from increased emissions are constant for small departures from the baseline emissions path, an approximation that is reasonable for policies that have effects on emissions that are small relative to cumulative global carbon dioxide emissions. For policies that have a large (non-marginal) impact on global cumulative emissions, there is a separate question of whether the SCC is an appropriate tool for calculating the benefits of reduced emissions; we do not attempt to answer that question here.

An interagency group convened on a regular basis to consider public comments, explore the technical literature in relevant fields, and discuss key inputs and assumptions in order to generate SCC estimates. Agencies that actively participated in the interagency process include the Environmental Protection Agency, and the Departments of Agriculture, Commerce, Energy, Transportation, and Treasury. This process was convened by the Council of Economic Advisers and the Office of Management and Budget, with active participation and regular input from the Council on Environmental Quality, National Economic Council, Office of Energy and Climate Change, and Office of Science and Technology Policy. The main objective of this process was to develop a range of SCC values using a defensible set of input assumptions that are grounded in the existing literature. In this way, key uncertainties and model differences can more transparently and consistently inform the range of SCC estimates used in the rulemaking process.

The interagency group selected four SCC estimates for use in regulatory analyses. For 2010, these estimates are \$5, \$21, \$35, and \$65 (in 2007 dollars). The first three estimates are based on the average SCC across models and socioeconomic and emissions scenarios at the 5, 3, and 2.5 percent discount rates, respectively. The fourth value is included to represent the higher-than-expected impacts from temperature change further out in the tails of the SCC distribution. For this purpose, we use the SCC value for the 95th percentile at a 3 percent discount rate. The central value is the average SCC across models at the 3 percent discount rate. For purposes of capturing the uncertainties involved in regulatory impact analysis, we emphasize the importance and value of considering the full range. These SCC estimates also grow over time. For instance, the central value increases to \$24 per ton of CO_2 in 2015 and \$26 per ton of CO_2 in 2020. See section 16-A.5 for the full range of annual SCC estimates from 2010 to 2050.

It is important to emphasize that the interagency process is committed to updating these estimates as the science and economic understanding of climate change and its impacts on society improves over time. Specifically, we have set a preliminary goal of revisiting the SCC values within two years or at such time as substantially updated models become available, and to continue to support research in this area. In the meantime, we will continue to explore the issues raised in this document and consider public comments as part of the ongoing interagency process.

14A.3 SOCIAL COST OF CARBON VALUES USED IN PAST REGULATORY ANALYSES

To date, economic analyses for Federal regulations have used a wide range of values to estimate the benefits associated with reducing carbon dioxide emissions. In the final model year 2011 CAFE rule, the Department of Transportation (DOT) used both a “domestic” SCC value of \$2 per ton of CO_2 and a “global” SCC value of \$33 per ton of CO_2 for 2007 emission reductions (in 2007 dollars), increasing both values at 2.4 percent per year. It also included a sensitivity analysis at \$80 per ton of CO_2. A domestic SCC value is meant to reflect the value of damages in the United States resulting from a unit change in carbon dioxide emissions, while a global SCC value is meant to reflect the value of damages worldwide.

A 2008 regulation proposed by DOT assumed a domestic SCC value of \$7 per ton CO_2 (in 2006 dollars) for 2011 emission reductions (with a range of \$0-\$14 for sensitivity analysis), also increasing at 2.4 percent per year. A regulation finalized by DOE in October of 2008 used a domestic SCC range of \$0 to \$20 per ton CO_2 for 2007 emission reductions (in 2007 dollars). In addition, EPA’s 2008 Advance Notice of Proposed Rulemaking for Greenhouse Gases identified what it described as “very preliminary” SCC estimates subject to revision. EPA’s global mean values were \$68 and \$40 per ton CO_2 for discount rates of approximately 2 percent and 3 percent, respectively (in 2006 dollars for 2007 emissions).

In 2009, an interagency process was initiated to offer a preliminary assessment of how best to quantify the benefits from reducing carbon dioxide emissions. To ensure consistency in how benefits are evaluated across agencies, the Administration sought to develop a transparent and defensible method, specifically designed for the rulemaking process, to quantify avoided climate change damages from reduced CO_2 emissions. The interagency group did not undertake any original analysis. Instead, it combined SCC estimates from the existing literature to use as interim values until a more comprehensive analysis could be conducted.

The outcome of the preliminary assessment by the interagency group was a set of five interim values: global SCC estimates for 2007 (in 2006 dollars) of \$55, \$33, \$19, \$10, and \$5 per ton of $CO_{2.}$ The \$33 and \$5 values represented model-weighted means of the published estimates produced from the most recently available versions of three integrated assessment models—

DICE, PAGE, and FUND—at approximately 3 and 5 percent discount rates. The $55 and $10 values were derived by adjusting the published estimates for uncertainty in the discount rate (using factors developed by Newell and Pizer (2003)) at 3 and 5 percent discount rates, respectively. The $19 value was chosen as a central value between the $5 and $33 per ton estimates. All of these values were assumed to increase at 3 percent annually to represent growth in incremental damages over time as the magnitude of climate change increases.

These interim values represent the first sustained interagency effort within the U.S. government to develop an SCC for use in regulatory analysis. The results of this preliminary effort were presented in several proposed and final rules and were offered for public comment in connection with proposed rules, including the joint EPA-DOT fuel economy and CO_2 tailpipe emission proposed rules.

14A.4 APPROACH AND KEY ASSUMPTIONS

Since the release of the interim values, the interagency group has reconvened on a regular basis to generate improved SCC estimates. Specifically, the group has considered public comments and further explored the technical literature in relevant fields. This section details the several choices and assumptions that underlie the resulting estimates of the SCC.

It is important to recognize that a number of key uncertainties remain, and that current SCC estimates should be treated as provisional and revisable, since they will evolve with improved scientific and economic understanding. The interagency group also recognizes that the existing models are imperfect and incomplete. The National Academy of Science (2009) points out that there is tension between the goal of producing quantified estimates of the economic damages from an incremental ton of carbon and the limits of existing efforts to model these effects. Throughout this document, we highlight a number of concerns and problems that should be addressed by the research community, including research programs housed in many of the agencies participating in the interagency process to estimate the SCC.

The U.S. Government will periodically review and reconsider estimates of the SCC used for cost-benefit analyses to reflect increasing knowledge of the science and economics of climate impacts, as well as improvements in modeling. In this context, statements recognizing the limitations of the analysis and calling for further research take on exceptional significance. The interagency group offers the new SCC values with all due humility about the uncertainties embedded in them and with a sincere promise to continue work to improve them.

14A.4.1 Integrated Assessment Models

We rely on three integrated assessment models (IAMs) commonly used to estimate the SCC: the FUND, DICE, and PAGE models.[c] These models are frequently cited in the peer-reviewed literature and used in the IPCC assessment. Each model is given equal weight in the SCC values developed through this process, bearing in mind their different limitations (discussed below).

These models are useful because they combine climate processes, economic growth, and feedbacks between the climate and the global economy into a single modeling framework. At the same time, they gain this advantage at the expense of a more detailed representation of the underlying climatic and economic systems. DICE, PAGE, and FUND all take stylized, reduced-form approaches (see NRC 2009 for a more detailed discussion; see Nordhaus 2008 on the possible advantages of this approach). Other IAMs may better reflect the complexity of the science in their modeling frameworks but do not link physical impacts to economic damages. There is currently a limited amount of research linking climate impacts to economic damages, which makes this exercise even more difficult. Underlying the three IAMs selected for this exercise are a number of simplifying assumptions and judgments reflecting the various modelers' best attempts to synthesize the available scientific and economic research characterizing these relationships.

The three IAMs translate emissions into changes in atmospheric greenhouse concentrations, atmospheric concentrations into changes in temperature, and changes in temperature into economic damages. The emissions projections used in the models are based on specified socioeconomic (GDP and population) pathways. These emissions are translated into concentrations using the carbon cycle built into each model, and concentrations are translated into warming based on each model's simplified representation of the climate and a key parameter, climate sensitivity. Each model uses a different approach to translate warming into damages. Finally, transforming the stream of economic damages over time into a single value requires judgments about how to discount them.

Each model takes a slightly different approach to model how changes in emissions result in changes in economic damages. In PAGE, for example, the consumption-equivalent damages in each period are calculated as a fraction of GDP, depending on the temperature in that period relative to the pre-industrial average temperature in each region. In FUND, damages in each period also depend on the rate of temperature change from the prior period. In DICE, temperature affects both consumption and investment. We describe each model in greater detail here. In a later section, we discuss key gaps in how the models account for various scientific and

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[c] The DICE (Dynamic Integrated Climate and Economy) model by William Nordhaus evolved from a series of energy models and was first presented in 1990 (Nordhaus and Boyer 2000, Nordhaus 2008). The PAGE (Policy Analysis of the Greenhouse Effect) model was developed by Chris Hope in 1991 for use by European decision-makers in assessing the marginal impact of carbon emissions (Hope 2006, Hope 2008). The FUND (Climate Framework for Uncertainty, Negotiation, and Distribution) model, developed by Richard Tol in the early 1990s, originally to study international capital transfers in climate policy. is now widely used to study climate impacts (*e.g.*, Tol 2002a, Tol 2002b, Anthoff et al. 2009, Tol 2009).

economic processes (*e.g.* the probability of catastrophe, and the ability to adapt to climate change and the physical changes it causes).

The parameters and assumptions embedded in the three models vary widely. A key objective of the interagency process was to enable a consistent exploration of the three models while respecting the different approaches to quantifying damages taken by the key modelers in the field. An extensive review of the literature was conducted to select three sets of input parameters for these models: climate sensitivity, socioeconomic and emissions trajectories, and discount rates. A probability distribution for climate sensitivity was specified as an input into all three models. In addition, the interagency group used a range of scenarios for the socioeconomic parameters and a range of values for the discount rate. All other model features were left unchanged, relying on the model developers' best estimates and judgments. In DICE, these parameters are handled deterministically and represented by fixed constants; in PAGE, most parameters are represented by probability distributions. FUND was also run in a mode in which parameters were treated probabilistically.

The sensitivity of the results to other aspects of the models (*e.g.* the carbon cycle or damage function) is also important to explore in the context of future revisions to the SCC but has not been incorporated into these estimates. Areas for future research are highlighted at the end of this document.

The DICE Model

The DICE model is an optimal growth model based on a global production function with an extra stock variable (atmospheric carbon dioxide concentrations). Emission reductions are treated as analogous to investment in "natural capital." By investing in natural capital today through reductions in emissions—implying reduced consumption—harmful effects of climate change can be avoided and future consumption thereby increased.

For purposes of estimating the SCC, carbon dioxide emissions are a function of global GDP and the carbon intensity of economic output, with the latter declining over time due to technological progress. The DICE damage function links global average temperature to the overall impact on the world economy. It varies quadratically with temperature change to capture the more rapid increase in damages expected to occur under more extreme climate change, and is calibrated to include the effects of warming on the production of market and nonmarket goods and services. It incorporates impacts on agriculture, coastal areas (due to sea level rise), "other vulnerable market sectors" (based primarily on changes in energy use), human health (based on climate-related diseases, such as malaria and dengue fever, and pollution), non-market amenities (based on outdoor recreation), and human settlements and ecosystems. The DICE damage function also includes the expected value of damages associated with low probability, high impact "catastrophic" climate change. This last component is calibrated based on a survey of experts (Nordhaus 1994). The expected value of these impacts is then added to the other market and non-market impacts mentioned above.

No structural components of the DICE model represent adaptation explicitly, though it is included implicitly through the choice of studies used to calibrate the aggregate damage function. For example, its agricultural impact estimates assume that farmers can adjust land use decisions in response to changing climate conditions, and its health impact estimates assume improvements in healthcare over time. In addition, the small impacts on forestry, water systems, construction, fisheries, and outdoor recreation imply optimistic and costless adaptation in these sectors (Nordhaus and Boyer, 2000; Warren et al., 2006). Costs of resettlement due to sea level rise are incorporated into damage estimates, but their magnitude is not clearly reported. Mastrandrea's (2009) review concludes that "in general, DICE assumes very effective adaptation, and largely ignores adaptation costs."

Note that the damage function in DICE has a somewhat different meaning from the damage functions in FUND and PAGE. Because GDP is endogenous in DICE and because damages in a given year reduce investment in that year, damages propagate forward in time and reduce GDP in future years. In contrast, GDP is exogenous in FUND and PAGE, so damages in any given year do not propagate forward.[d]

The PAGE Model

PAGE2002 (version 1.4epm) treats GDP growth as exogenous. It divides impacts into economic, non-economic, and catastrophic categories and calculates these impacts separately for eight geographic regions. Damages in each region are expressed as a fraction of output, where the fraction lost depends on the temperature change in each region. Damages are expressed as power functions of temperature change. The exponents of the damage function are the same in all regions but are treated as uncertain, with values ranging from 1 to 3 (instead of being fixed at 2 as in DICE).

PAGE2002 includes the consequences of catastrophic events in a separate damage sub-function. Unlike DICE, PAGE2002 models these events probabilistically. The probability of a "discontinuity" (*i.e.*, a catastrophic event) is assumed to increase with temperature above a specified threshold. The threshold temperature, the rate at which the probability of experiencing a discontinuity increases above the threshold, and the magnitude of the resulting catastrophe are all modeled probabilistically.

Adaptation is explicitly included in PAGE. Impacts are assumed to occur for temperature increases above some tolerable level (2°C for developed countries and 0°C for developing countries for economic impacts, and 0°C for all regions for non-economic impacts), but

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[d] Using the default assumptions in DICE 2007, this effect generates an approximately 25 percent increase in the SCC relative to damages calculated by fixing GDP. In DICE2007, the time path of GDP is endogenous. Specifically, the path of GDP depends on the rate of saving and level of abatement in each period chosen by the optimizing representative agent in the model. We made two modifications to DICE to make it consistent with EMF GDP trajectories (see next section): we assumed a fixed rate of savings of 20 percent, and we re-calibrated the exogenous path of total factor productivity so that DICE would produce GDP projections in the absence of warming that exactly matched the EMF scenarios.

adaptation is assumed to reduce these impacts. Default values in PAGE2002 assume that the developed countries can ultimately eliminate up to 90 percent of all economic impacts beyond the tolerable 2°C increase and that developing countries can eventually eliminate 50 percent of their economic impacts. All regions are assumed to be able to mitigate 25 percent of the non-economic impacts through adaptation (Hope 2006).

The FUND Model

Like PAGE, the FUND model treats GDP growth as exogenous. It includes separately calibrated damage functions for eight market and nonmarket sectors: agriculture, forestry, water, energy (based on heating and cooling demand), sea level rise (based on the value of land lost and the cost of protection), ecosystems, human health (diarrhea, vector-borne diseases, and cardiovascular and respiratory mortality), and extreme weather. Each impact sector has a different functional form, and is calculated separately for sixteen geographic regions. In some impact sectors, the fraction of output lost or gained due to climate change depends not only on the absolute temperature change but also on the rate of temperature change and level of regional income.[e] In the forestry and agricultural sectors, economic damages also depend on CO_2 concentrations.

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.

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[e] In the deterministic version of FUND, the majority of damages are attributable to increased air conditioning demand, while reduced cold stress in Europe, North America, and Central and East Asia results in health benefits in those regions at low to moderate levels of warming (Warren et al., 2006).

Damage Functions

To generate revised SCC values, we rely on the IAM modelers' current best judgments of how to represent the effects of climate change (represented by the increase in global-average surface temperature) on the consumption-equivalent value of both market and non-market goods (represented as a fraction of global GDP). We recognize that these representations are incomplete and highly uncertain. But given the paucity of data linking the physical impacts to economic damages, we were not able to identify a better way to translate changes in climate into net economic damages, short of launching our own research program.

The damage functions for the three IAMs are presented in Figure 14A.4.1 and Figure 14A.4.2, using the modeler's default scenarios and mean input assumptions. There are significant differences between the three models both at lower (Figure 14A.4.2) and higher (Figure 14A.4.1) increases in global-average temperature.

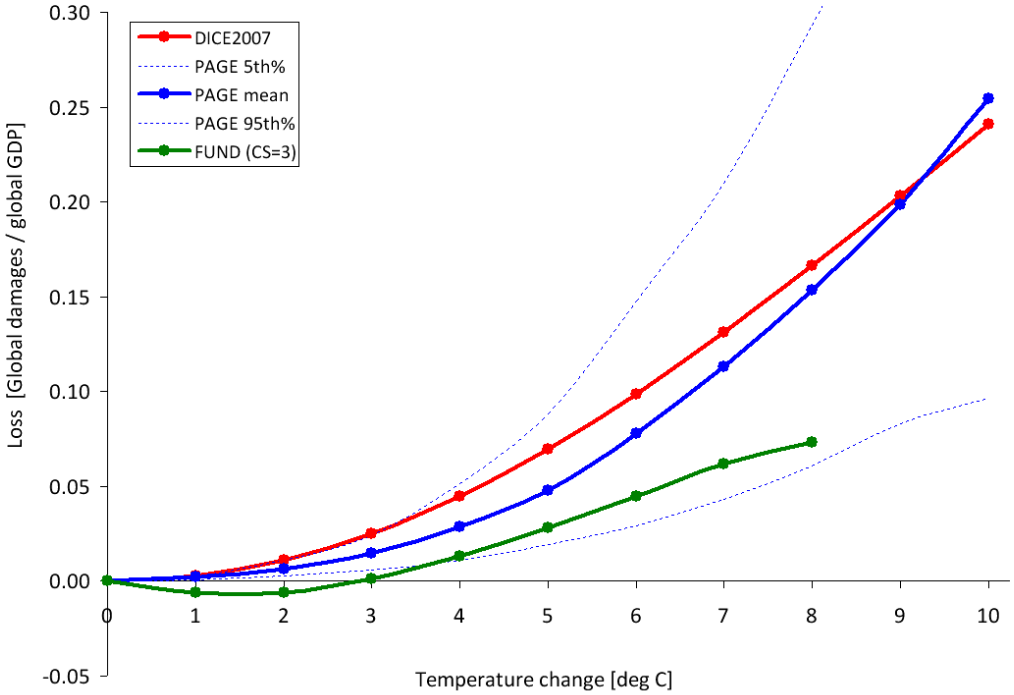

Figure 14A.4.1 Annual Consumption Loss as a Fraction of Global GDP in 2100 Due to an Increase in Annual Global Temperature in the DICE, FUND, and PAGE models[f]

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[f] The x-axis represents increases in annual, rather than equilibrium, temperature, while the y-axis represents the annual stream of benefits as a share of global GDP. Each specific combination of climate sensitivity, socioeconomic, and emissions parameters will produce a different realization of damages for each IAM. The damage functions represented in Figures 1A and 1B are the outcome of default assumptions. For instance, under alternate assumptions, the damages from FUND may cross from negative to positive at less than or greater than 3 °C.

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.

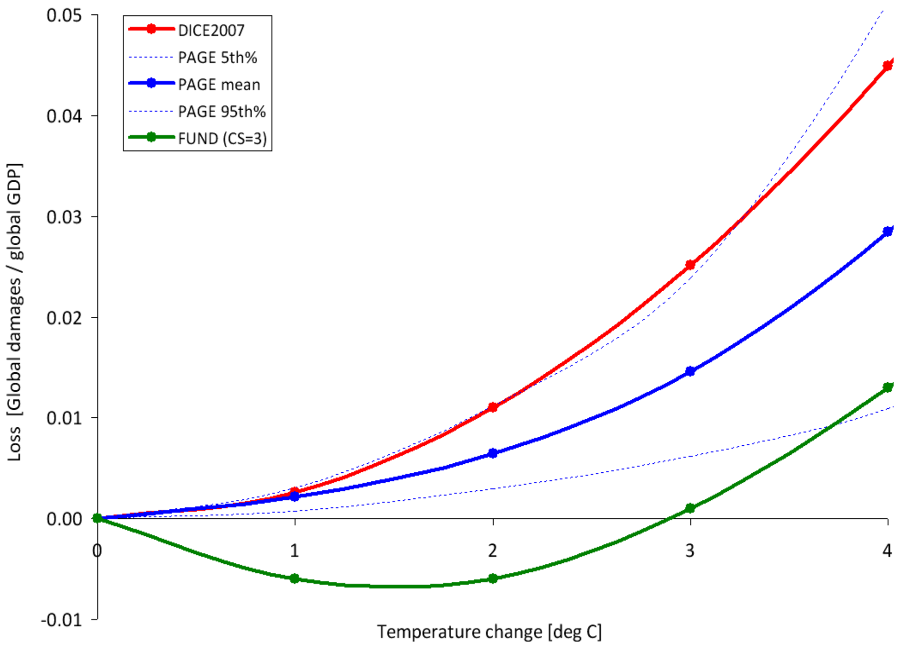

Figure 14A.4.2 Annual Consumption Loss for Lower Temperature Changes in DICE, FUND, and PAGE

14A.4.2 Global versus Domestic Measures of SCC

Because of the distinctive nature of the climate change problem, we center our current attention on a global measure of SCC. This approach is the same as that taken for the interim values, but it otherwise represents a departure from past practices, which tended to put greater emphasis on a domestic measure of SCC (limited to impacts of climate change experienced within U.S. borders). As a matter of law, consideration of both global and domestic values is generally permissible; the relevant statutory provisions are usually ambiguous and allow selection of either measure.[g]

Global SCC

Under current OMB guidance contained in Circular A-4, analysis of economically significant proposed and final regulations from the domestic perspective is required, while analysis from the international perspective is optional. However, the climate change problem is highly unusual in at least two respects. First, it involves a global externality: emissions of most greenhouse gases contribute to damages around the world even when they are emitted in the United States. Consequently, to address the global nature of the problem, the SCC must incorporate the full (global) damages caused by GHG emissions. Second, climate change presents a problem that the United States alone cannot solve. Even if the United States were to reduce its greenhouse gas emissions to zero, that step would be far from enough to avoid substantial climate change. Other countries would also need to take action to reduce emissions if significant changes in the global climate are to be avoided. Emphasizing the need for a global solution to a global problem, the United States has been actively involved in seeking international agreements to reduce emissions and in encouraging other nations, including emerging major economies, to take significant steps to reduce emissions. When these considerations are taken as a whole, the interagency group concluded that a global measure of the benefits from reducing U.S. emissions is preferable.

When quantifying the damages associated with a change in emissions, a number of analysts (*e.g.*, Anthoff, et al. 2009a) employ "equity weighting" to aggregate changes in consumption across regions. This weighting takes into account the relative reductions in wealth in different regions of the world. A per-capita loss of $500 in GDP, for instance, is weighted more heavily in a country with a per-capita GDP of $2,000 than in one with a per-capita GDP of $40,000. The main argument for this approach is that a loss of $500 in a poor country causes a greater reduction in utility or welfare than does the same loss in a wealthy nation. Notwithstanding the theoretical claims on behalf of equity weighting, the interagency group concluded that this approach would not be appropriate for estimating a SCC value used in domestic regulatory analysis.[h] For this reason, the group concluded that using the global (rather than domestic) value, without equity weighting, is the appropriate approach.

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[g] It is true that federal statutes are presumed not to have extraterritorial effect, in part to ensure that the laws of the United States respect the interests of foreign sovereigns. But use of a global measure for the SCC does not give extraterritorial effect to federal law and hence does not intrude on such interests.

[h] It is plausible that a loss of $X inflicts more serious harm on a poor nation than on a wealthy one, but development of the appropriate "equity weight" is challenging. Emissions reductions also impose costs, and hence a full account would have to consider that a given cost of emissions reductions imposes a greater utility or welfare loss on a poor nation than on a wealthy one. Even if equity weighting—for both the costs and benefits of emissions reductions—is appropriate when considering the utility or welfare effects of international action, the interagency group concluded that it should not be used in developing an SCC for use in regulatory policy at this time.

Domestic SCC

As an empirical matter, the development of a domestic SCC is greatly complicated by the relatively few region- or country-specific estimates of the SCC in the literature. One potential source of estimates comes from the FUND model. The resulting estimates suggest that the ratio of domestic to global benefits of emission reductions varies with key parameter assumptions. For example, with a 2.5 or 3 percent discount rate, the U.S. benefit is about 7-10 percent of the global benefit, on average, across the scenarios analyzed. Alternatively, if the fraction of GDP lost due to climate change is assumed to be similar across countries, the domestic benefit would be proportional to the U.S. share of global GDP, which is currently about 23 percent.[i]

On the basis of this evidence, the interagency workgroup determined that a range of values from 7 to 23 percent should be used to adjust the global SCC to calculate domestic effects. Reported domestic values should use this range. It is recognized that these values are approximate, provisional, and highly speculative. There is no a priori reason why domestic benefits should be a constant fraction of net global damages over time. Further, FUND does not account for how damages in other regions could affect the United States (*e.g.*, global migration, economic and political destabilization). If more accurate methods for calculating the domestic SCC become available, the Federal government will examine these to determine whether to update its approach.

14A.4.3 Valuing Non-CO_2 Emissions

While CO_2 is the most prevalent greenhouse gas emitted into the atmosphere, the U.S. included five other greenhouse gases in its recent endangerment finding: methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride. The climate impact of these gases is commonly discussed in terms of their 100-year global warming potential (GWP). GWP measures the ability of different gases to trap heat in the atmosphere (*i.e.*, radiative forcing per unit of mass) over a particular timeframe relative to CO_2. However, because these gases differ in both radiative forcing and atmospheric lifetimes, their relative damages are not constant over time. For example, because methane has a short lifetime, its impacts occur primarily in the near term and thus are not discounted as heavily as those caused by longer-lived gases. Impacts other than temperature change also vary across gases in ways that are not captured by GWP. For instance, CO_2 emissions, unlike methane and other greenhouse gases, contribute to ocean acidification. Likewise, damages from methane emissions are not offset by the positive effect of CO_2 fertilization. Thus, transforming gases into CO_2-equivalents using GWP, and then multiplying the carbon-equivalents by the SCC, would not result in accurate estimates of the social costs of non-CO_2 gases.

In light of these limitations, and the significant contributions of non-CO_2 emissions to climate change, further research is required to link non-CO_2 emissions to economic impacts. Such work would feed into efforts to develop a monetized value of reductions in non-CO_2 greenhouse gas emissions. As part of ongoing work to further improve the SCC estimates, the

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[i] Based on 2008 GDP (in current US dollars) from the *World Bank Development Indicators Report*.

interagency group hopes to develop methods to value these other greenhouse gases. The goal is to develop these estimates by the time we issue revised SCC estimates for carbon dioxide emissions.

14A.4.4 Equilibrium Climate Sensitivity

Equilibrium climate sensitivity (ECS) is a key input parameter for the DICE, PAGE, and FUND models.[j] It is defined as the long-term increase in the annual global-average surface temperature from a doubling of atmospheric CO_2 concentration relative to pre-industrial levels (or stabilization at a concentration of approximately 550 parts per million (ppm)). Uncertainties in this important parameter have received substantial attention in the peer-reviewed literature.

The most authoritative statement about equilibrium climate sensitivity appears in the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC):

> *Basing our assessment on a combination of several independent lines of evidence…including observed climate change and the strength of known feedbacks simulated in [global climate models], we conclude that the global mean equilibrium warming for doubling CO_2, or 'equilibrium climate sensitivity', is likely to lie in the range 2 °C to 4.5 °C, with a most likely value of about 3 °C. Equilibrium climate sensitivity is very likely larger than 1.5 °C.* [k]
>
> *For fundamental physical reasons as well as data limitations, values substantially higher than 4.5 °C still cannot be excluded, but agreement with observations and proxy data is generally worse for those high values than for values in the 2 °C to 4.5 °C range.* (Meehl et al., 2007, p 799)

After consulting with several lead authors of this chapter of the IPCC report, the interagency workgroup selected four candidate probability distributions and calibrated them to be consistent with the above statement: Roe and Baker (2007), log-normal, gamma, and Weibull. Table 14A.4.1 included below gives summary statistics for the four calibrated distributions.

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[j] The equilibrium climate sensitivity includes the response of the climate system to increased greenhouse gas concentrations over the short to medium term (up to 100-200 years), but it does not include long-term feedback effects due to possible large-scale changes in ice sheets or the biosphere, which occur on a time scale of many hundreds to thousands of years (*e.g.* Hansen et al. 2007).

[k] This is in accord with the judgment that it "is likely to lie in the range 2 °C to 4.5 °C" and the IPCC definition of "likely" as greater than 66 percent probability (Le Treut et al.2007). "Very likely" indicates a greater than 90 percent probability.

Table 14A.4.1 Summary Statistics for Four Calibrated Climate Sensitivity Distributions

	Roe & Baker	Log-normal	Gamma	Weibull
Pr(ECS < 1.5°C)	0.013	0.050	0.070	0.102
Pr(2°C < ECS < 4.5°C)	0.667	0.667	0.667	0.667
5th percentile	1.72	1.49	1.37	1.13
10th percentile	1.91	1.74	1.65	1.48
Mode	2.34	2.52	2.65	2.90
Median (50th percentile)	3.00	3.00	3.00	3.00
Mean	3.50	3.28	3.19	3.07
90th percentile	5.86	5.14	4.93	4.69
95th percentile	7.14	5.97	5.59	5.17

Each distribution was calibrated by applying three constraints from the IPCC:

(1) a median equal to 3°C, to reflect the judgment of "a most likely value of about 3 °C";[1]
(2) two-thirds probability that the equilibrium climate sensitivity lies between 2 and 4.5 °C; and
(3) zero probability that it is less than 0°C or greater than 10°C (see Hegerl et al. 2006, p. 721).

We selected the calibrated Roe and Baker distribution from the four candidates for two reasons. First, the Roe and Baker distribution is the only one of the four that is based on a theoretical understanding of the response of the climate system to increased greenhouse gas concentrations (Roe and Baker 2007, Roe 2008). In contrast, the other three distributions are mathematical functions that are arbitrarily chosen based on simplicity, convenience, and general shape. The Roe and Baker distribution results from three assumptions about climate response: (1) absent feedback effects, the equilibrium climate sensitivity is equal to 1.2 °C; (2) feedback factors are proportional to the change in surface temperature; and (3) uncertainties in feedback factors are normally distributed. There is widespread agreement on the first point and the second and third points are common assumptions.

Second, the calibrated Roe and Baker distribution better reflects the IPCC judgment that "values substantially higher than 4.5°C still cannot be excluded." Although the IPCC made no quantitative judgment, the 95th percentile of the calibrated Roe & Baker distribution (7.1 °C) is much closer to the mean and the median (7.2 °C) of the 95th percentiles of 21 previous studies summarized by Newbold and Daigneault (2009). It is also closer to the mean (7.5 °C) and

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[1] 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.

median (7.9 °C) of the nine truncated distributions examined by the IPCC (Hegerl, et al., 2006) than are the 95th percentiles of the three other calibrated distributions (5.2-6.0 °C).

Finally, we note the IPCC judgment that the equilibrium climate sensitivity "is very likely larger than 1.5°C." Although the calibrated Roe & Baker distribution, for which the probability of equilibrium climate sensitivity being greater than 1.5 °C is almost 99 percent, is not inconsistent with the IPCC definition of "very likely" as "greater than 90 percent probability," it reflects a greater degree of certainty about very low values of ECS than was expressed by the IPCC.

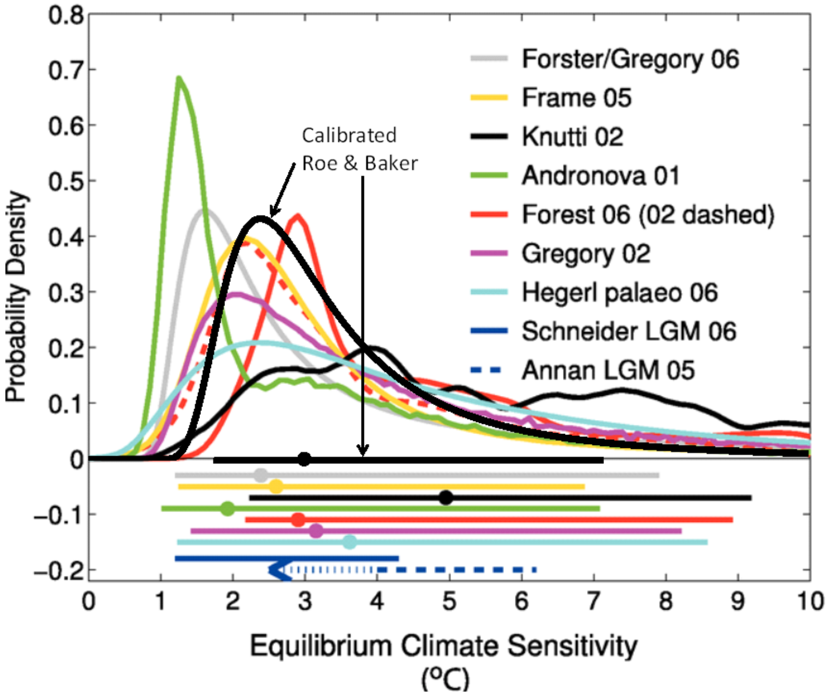

Figure 14A.4.3 Estimates of the Probability Density Function for Equilibrium Climate Sensitivity (°C)

To show how the calibrated Roe and Baker distribution compares to different estimates of the probability distribution function of equilibrium climate sensitivity in the empirical literature, Figure 14A.4.3 (above) overlays it on Figure 9.20 from the IPCC Fourth Assessment Report. These functions are scaled to integrate to unity between 0 °C and 10 °C. The horizontal bars show the respective 5 percent to 95 percent ranges; dots indicate the median estimate.[m]

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[m] The estimates based on instrumental data are from Andronova and Schlesinger (2001), Forest et al. (2002; dashed line, anthropogenic forcings only), Forest et al. (2006; solid line, anthropogenic and natural forcings), Gregory et al. (2002a), Knutti et al. (2002), Frame et al. (2005), and Forster and Gregory (2006). Hegerl et al. (2006) are based on multiple palaeoclimatic reconstructions of north hemisphere mean temperatures over the last 700 years. Also shown are the 5-95 percent approximate ranges for two estimates from the last glacial maximum (dashed, Annan et al. 2005; solid, Schneider von Deimling et al. 2006), which are based on models with different structural properties.

14A.4.5 Socioeconomic and Emissions Trajectories

Another key issue considered by the interagency group is how to select the set of socioeconomic and emissions parameters for use in PAGE, DICE, and FUND. Socioeconomic pathways are closely tied to climate damages because, all else equal, more and wealthier people tend to emit more greenhouse gases and also have a higher (absolute) willingness to pay to avoid climate disruptions. For this reason, we consider how to model several input parameters in tandem: GDP, population, CO_2 emissions, and non-CO_2 radiative forcing. A wide variety of scenarios have been developed and used for climate change policy simulations (*e.g.*, SRES 2000, CCSP 2007, EMF 2009). In determining which scenarios are appropriate for inclusion, we aimed to select scenarios that span most of the plausible ranges of outcomes for these variables.

To accomplish this task in a transparent way, we decided to rely on the recent Stanford Energy Modeling Forum exercise, EMF-22. EMF-22 uses ten well-recognized models to evaluate substantial, coordinated global action to meet specific stabilization targets. A key advantage of relying on these data is that GDP, population, and emission trajectories are internally consistent for each model and scenario evaluated. The EMF-22 modeling effort also is preferable to the IPCC SRES due to their age (SRES were developed in 1997) and the fact that 3 of 4 of the SRES scenarios are now extreme outliers in one or more variables. Although the EMF-22 scenarios have not undergone the same level of scrutiny as the SRES scenarios, they are recent, peer-reviewed, published, and publicly available.

To estimate the SCC for use in evaluating domestic policies that will have a small effect on global cumulative emissions, we use socioeconomic and emission trajectories that span a range of plausible scenarios. Five trajectories were selected from EMF-22 (see Table 14A.4.2 below). Four of these represent potential business-as-usual (BAU) growth in population, wealth, and emissions and are associated with CO_2 (only) concentrations ranging from 612 to 889 ppm in 2100. One represents an emissions pathway that achieves stabilization at 550 ppm CO_2e (i*i.e.*, CO_2-only concentrations of 425 – 484 ppm or a radiative forcing of 3.7 W/m^2) in 2100, a lower-than-BAU trajectory.[n] Out of the 10 models included in the EMF-22 exercise, we selected the trajectories used by MiniCAM, MESSAGE, IMAGE, and the optimistic scenario from MERGE. For the BAU pathways, we used the GDP, population, and emission trajectories from each of these four models. For the 550 ppm CO_2e scenario, we averaged the GDP, population, and emission trajectories implied by these same four models.

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[n] Such an emissions path would be consistent with widespread action by countries to mitigate GHG emissions, though it could also result from technological advances. It was chosen because it represents the most stringent case analyzed by the EMF-22 where all the models converge: a 550 ppm, not to exceed, full participation scenario.

Table 14A.4.2 Socioeconomic and Emissions Projections from Select EMF-22 Reference Scenarios

Reference Fossil and Industrial CO_2 Emissions ($GtCO_2$/yr)

EMF – 22 Based Scenarios	2000	2010	2020	2030	2050	2100
IMAGE	26.6	31.9	36.9	40.0	45.3	60.1
MERGE Optimistic	24.6	31.5	37.6	45.1	66.5	117.9
MESSAGE	26.8	29.2	37.6	42.1	43.5	42.7
MiniCAM	26.5	31.8	38.0	45.1	57.8	80.5
550 ppm average	26.2	31.1	33.2	32.4	20.0	12.8

Reference GDP (using market exchange rates in trillion 2005$)[o]

EMF – 22 Based Scenarios	2000	2010	2020	2030	2050	2100
IMAGE	38.6	53.0	73.5	97.2	156.3	396.6
MERGE Optimistic	36.3	45.9	59.7	76.8	122.7	268.0
MESSAGE	38.1	52.3	69.4	91.4	153.7	334.9
MiniCAM	36.1	47.4	60.8	78.9	125.7	369.5
550 ppm average	37.1	49.6	65.6	85.5	137.4	337.9

Global Population (billions)

EMF – 22 Based Scenarios	2000	2010	2020	2030	2050	2100
IMAGE	6.1	6.9	7.6	8.2	9.0	9.1
MERGE Optimistic	6.0	6.8	7.5	8.2	9.0	9.7
MESSAGE	6.1	6.9	7.7	8.4	9.4	10.4
MiniCAM	6.0	6.8	7.5	8.1	8.8	8.7
550 ppm average	6.1	6.8	7.6	8.2	8.7	9.1

We explore how sensitive the SCC is to various assumptions about how the future will evolve without prejudging what is likely to occur. The interagency group considered formally assigning probability weights to different states of the world, but this proved challenging to do in an analytically rigorous way given the dearth of information on the likelihood of a full range of future socioeconomic pathways.

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[o] While the EMF-22 models used market exchange rates (MER) to calculate global GDP, it is also possible to use purchasing power parity (PPP). PPP takes into account the different price levels across countries, so it more accurately describes relative standards of living across countries. MERs tend to make low-income countries appear poorer than they actually are. Because many models assume convergence in per capita income over time, use of MER-adjusted GDP gives rise to projections of higher economic growth in low income countries. There is an ongoing debate about how much this will affect estimated climate impacts. Critics of the use of MER argue that it leads to overstated economic growth and hence a significant upward bias in projections of greenhouse gas emissions, and unrealistically high future temperatures (*e.g.*, Castles and Henderson 2003). Others argue that convergence of the emissions-intensity gap across countries at least partially offset the overstated income gap so that differences in exchange rates have less of an effect on emissions (Holtsmark and Alfsen, 2005; Tol, 2006). Nordhaus (2007b) argues that the ideal approach is to use superlative PPP accounts (*i.e.*, using cross-sectional PPP measures for relative incomes and outputs and national accounts price and quantity indexes for time-series extrapolations). However, he notes that it important to keep this debate in perspective; it is by no means clear that exchange-rate-conversion issues are as important as uncertainties about population, technological change, or the many geophysical uncertainties.

There are a number of caveats. First, EMF BAU scenarios represent the modelers' judgment of the most likely pathway absent mitigation policies to reduce greenhouse gas emissions, rather than the wider range of possible outcomes. Nevertheless, these views of the most likely outcome span a wide range, from the more optimistic (*e.g.*, abundant low-cost, low-carbon energy) to more pessimistic (*e.g.*, constraints on the availability of nuclear and renewables).[p] Second, the socioeconomic trajectories associated with a 550 ppm CO_2e concentration scenario are not derived from an assessment of what policy is optimal from a benefit-cost standpoint. Rather, it is indicative of one possible future outcome. The emission trajectories underlying some BAU scenarios (*e.g.*, MESSAGE's 612 ppm) also are consistent with some modest policy action to address climate change.[q] We chose not to include socioeconomic trajectories that achieve even lower GHG concentrations at this time, given the difficulty many models had in converging to meet these targets.

For comparison purposes, the Energy Information Agency in its 2009 Annual Energy Outlook projected that global carbon dioxide emissions will grow to 30.8, 35.6, and 40.4 gigatons in 2010, 2020, and 2030, respectively, while world GDP is projected to be $51.8, $71.0 and $93.9 trillion (in 2005 dollars using market exchange rates) in 2010, 2020, and 2030, respectively. These projections are consistent with one or more EMF-22 scenarios. Likewise, the United Nations' 2008 Population Prospect projects population will grow from 6.1 billion people in 2000 to 9.1 billion people in 2050, which is close to the population trajectories for the IMAGE, MiniCAM, and MERGE models.

In addition to fossil and industrial CO_2 emissions, each EMF scenario provides projections of methane, nitrous oxide, fluorinated greenhouse gases, and net land use CO_2 emissions out to 2100. These assumptions also are used in the three models while retaining the default radiative forcings due to other factors (*e.g.*, aerosols and other gases). See the Annex for greater detail.

14A.4.6 Discount Rate

The choice of a discount rate, especially over long periods of time, raises highly contested and exceedingly difficult questions of science, economics, philosophy, and law. Although it is well understood that the discount rate has a large influence on the current value of future damages, there is no consensus about what rates to use in this context. Because carbon dioxide emissions are long-lived, subsequent damages occur over many years. In calculating the SCC, we first estimate the future damages to agriculture, human health, and other market and non-market sectors from an additional unit of carbon dioxide emitted in a particular year in terms

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[p] For instance, in the MESSAGE model's reference case total primary energy production from nuclear, biomass, and non-biomass renewables is projected to increase from about 15 percent of total primary energy in 2000 to 54 percent in 2100. In comparison, the MiniCAM reference case shows 10 percent in 2000 and 21 percent in 2100.

[q] For example, MiniCAM projects if all non-US OECD countries reduce CO_2 emissions to 83 percent below 2005 levels by 2050 (per the G-8 agreement) but all other countries continue along a BAU path CO_2 concentrations in 2100 would drop from 794 ppmv in its reference case to 762 ppmv.

of reduced consumption (or consumption equivalents) due to the impacts of elevated temperatures, as represented in each of the three IAMs. Then we discount the stream of future damages to its present value in the year when the additional unit of emissions was released using the selected discount rate, which is intended to reflect society's marginal rate of substitution between consumption in different time periods.

For rules with both intra- and intergenerational effects, agencies traditionally employ constant discount rates of both 3 percent and 7 percent in accordance with OMB Circular A-4. As Circular A-4 acknowledges, however, the choice of discount rate for intergenerational problems raises distinctive problems and presents considerable challenges. After reviewing those challenges, Circular A-4 states, “If your rule will have important intergenerational benefits or costs you might consider a further sensitivity analysis using a lower but positive discount rate in addition to calculating net benefits using discount rates of 3 and 7 percent.” For the specific purpose of developing the SCC, we adapt and revise that approach here.

Arrow et al. (1996) outlined two main approaches to determine the discount rate for climate change analysis, which they labeled “descriptive” and “prescriptive.” The descriptive approach reflects a positive (non-normative) perspective based on observations of people’s actual choices—*e.g.*, savings versus consumption decisions over time, and allocations of savings among more and less risky investments. Advocates of this approach generally call for inferring the discount rate from market rates of return “because of a lack of justification for choosing a social welfare function that is any different than what decision makers [individuals] actually use” (Arrow et al. 1996).

One theoretical foundation for the cost-benefit analyses in which the social cost of carbon will be used—the Kaldor-Hicks potential-compensation test—also suggests that market rates should be used to discount future benefits and costs, because it is the market interest rate that would govern the returns potentially set aside today to compensate future individuals for climate damages that they bear (*e.g.*, Just et al. 2004). As some have noted, the word “potentially” is an important qualification; there is no assurance that such returns will actually be set aside to provide compensation, and the very idea of compensation is difficult to define in the intergenerational context. On the other hand, societies provide compensation to future generations through investments in human capital and the resulting increase in knowledge, as well as infrastructure and other physical capital.

The prescriptive approach specifies a social welfare function that formalizes the normative judgments that the decision-maker wants explicitly to incorporate into the policy evaluation—*e.g.*, how inter-personal comparisons of utility should be made, and how the welfare of future generations should be weighed against that of the present generation. Ramsey (1928), for example, has argued that it is “ethically indefensible” to apply a positive pure rate of time preference to discount values across generations, and many agree with this view.

Other concerns also motivate making adjustments to descriptive discount rates. In particular, it has been noted that the preferences of future generations with regard to consumption versus environmental amenities may not be the same as those today, making the current market rate on consumption an inappropriate metric by which to discount future climate-related damages. Others argue that the discount rate should be below market rates to correct for market distortions and uncertainties or inefficiencies in intergenerational transfers of wealth, which in the Kaldor-Hicks logic are presumed to compensate future generations for damage (a potentially controversial assumption, as noted above) (Arrow et al. 1996, Weitzman 1999).

Further, a legitimate concern about both descriptive and prescriptive approaches is that they tend to obscure important heterogeneity in the population. The utility function that underlies the prescriptive approach assumes a representative agent with perfect foresight and no credit constraints. This is an artificial rendering of the real world that misses many of the frictions that characterize individuals' lives and indeed the available descriptive evidence supports this. For instance, many individuals smooth consumption by borrowing with credit cards that have relatively high rates. Some are unable to access traditional credit markets and rely on payday lending operations or other high-cost forms of smoothing consumption. Whether one puts greater weight on the prescriptive or descriptive approach, the high interest rates that credit-constrained individuals accept suggest that some account should be given to the discount rates revealed by their behavior.

We draw on both approaches but rely primarily on the descriptive approach to inform the choice of discount rate. With recognition of its limitations, we find this approach to be the most defensible and transparent given its consistency with the standard contemporary theoretical foundations of benefit-cost analysis and with the approach required by OMB's existing guidance. The logic of this framework also suggests that market rates should be used for discounting future consumption-equivalent damages. Regardless of the theoretical approach used to derive the appropriate discount rate(s), we note the inherent conceptual and practical difficulties of adequately capturing consumption trade-offs over many decades or even centuries. While relying primarily on the descriptive approach in selecting specific discount rates, the interagency group has been keenly aware of the deeply normative dimensions of both the debate over discounting in the intergenerational context and the consequences of selecting one discount rate over another.

Historically Observed Interest Rates

In a market with no distortions, the return to savings would equal the private return on investment, and the market rate of interest would be the appropriate choice for the social discount rate. In the real world risk, taxes, and other market imperfections drive a wedge between the risk-free rate of return on capital and the consumption rate of interest. Thus, the literature recognizes two conceptual discount concepts—the consumption rate of interest and the opportunity cost of capital.

According to OMB's Circular A-4, it is appropriate to use the rate of return on capital when a regulation is expected to displace or alter the use of capital in the private sector. In this case, OMB recommends Agencies use a discount rate of 7 percent. When regulation is expected to primarily affect private consumption—for instance, via higher prices for goods and services—

a lower discount rate of 3 percent is appropriate to reflect how private individuals trade-off current and future consumption.

The interagency group examined the economics literature and concluded that the consumption rate of interest is the correct concept to use in evaluating the benefits and costs of a marginal change in carbon emissions (see Lind 1990, Arrow et al 1996, and Arrow 2000). The consumption rate of interest also is appropriate when the impacts of a regulation are measured in consumption (-equivalent) units, as is done in the three integrated assessment models used for estimating the SCC.

Individuals use a variety of savings instruments that vary with risk level, time horizon, and tax characteristics. The standard analytic framework used to develop intuition about the discount rate typically assumes a representative agent with perfect foresight and no credit constraints. The risk-free rate is appropriate for discounting certain future benefits or costs, but the benefits calculated by IAMs are uncertain. To use the risk-free rate to discount uncertain benefits, these benefits first must be transformed into "certainty equivalents," that is the maximum certain amount that we would exchange for the uncertain amount. However, the calculation of the certainty-equivalent requires first estimating the correlation between the benefits of the policy and baseline consumption.

If the IAM projections of future impacts represent expected values (not certainty-equivalent values), then the appropriate discount rate generally does not equal the risk-free rate. If the benefits of the policy tend to be high in those states of the world in which consumption is low, then the certainty-equivalent benefits will be higher than the expected benefits (and vice versa). Since many (though not necessarily all) of the important impacts of climate change will flow through market sectors such as agriculture and energy, and since willingness to pay for environmental protections typically increases with income, we might expect a positive (though not necessarily perfect) correlation between the net benefits from climate policies and market returns. This line of reasoning suggests that the proper discount rate would exceed the riskless rate. Alternatively, a negative correlation between the returns to climate policies and market returns would imply that a discount rate below the riskless rate is appropriate.

This discussion suggests that both the post-tax riskless and risky rates can be used to capture individuals' consumption-equivalent interest rate. As a measure of the post-tax riskless rate, we calculate the average real return from Treasury notes over the longest time period available (those from Newell and Pizer 2003) and adjust for Federal taxes (the average marginal rate from tax years 2003 through 2006 is around 27 percent).[r] This calculation produces a real interest rate of about 2.7 percent, which is roughly consistent with Circular A-4's

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[r] The literature argues for a risk-free rate on government bonds as an appropriate measure of the consumption rate of interest. Arrow (2000) suggests that it is roughly 3-4 percent. OMB cites evidence of a 3.1 percent pre-tax rate for 10-year Treasury notes in the A-4 guidance. Newell and Pizer (2003) find real interest rates between 3.5 and 4 percent for 30-year Treasury securities.

recommendation to use 3 percent to represent the consumption rate of interest.[s] A measure of the post-tax risky rate for investments whose returns are positively correlated with overall equity market returns can be obtained by adjusting pre-tax rates of household returns to risky investments (approximately 7 percent) for taxes, which yields a real rate of roughly 5 percent.[t]

The Ramsey Equation

Ramsey discounting also provides a useful framework to inform the choice of a discount rate. Under this approach, the analyst applies either positive or normative judgments in selecting values for the key parameters of the Ramsey equation: η (coefficient of relative risk aversion or elasticity of the marginal utility of consumption) and ρ (pure rate of time preference).[u] These are then combined with g (growth rate of per-capita consumption) to equal the interest rate at which future monetized damages are discounted: $\rho + \eta \cdot g$.[v] In the simplest version of the Ramsey model, with an optimizing representative agent with perfect foresight, what we are calling the "Ramsey discount rate," $\rho + \eta \cdot g$, will be equal to the rate of return to capital, *i.e.*, the market interest rate.

A review of the literature provides some guidance on reasonable parameter values for the Ramsey discounting equation, based on both prescriptive and descriptive approaches.

- η. Most papers in the climate change literature adopt values for η in the range of 0.5 to 3 (Weitzman cites plausible values as those ranging from 1 to 4), although not all authors

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[s] The positive approach reflects how individuals make allocation choices across time, but it is important to keep in mind that we wish to reflect preferences for society as a whole, which generally has a longer planning horizon.

[t] Cambell et al (2001) estimates that the annual real return from stocks for 1900-1995 was about 7 percent. The annual real rate of return for the S&P 500 from 1950 – 2008 was about 6.8 percent. In the absence of a better way to population-weight the tax rates, we use the middle of the 20 – 40 percent range to derive a post-tax interest rate (Kotlikoff and Rapson 2006).

[u] The parameter ρ measures the *pure rate of time preference*: people's behavior reveals a preference for an increase in utility today versus the future. Consequently, it is standard to place a lower weight on utility in the future. The parameter η captures *diminishing marginal utility*: consumption in the future is likely to be higher than consumption today, so diminishing marginal utility of consumption implies that the same monetary damage will cause a smaller reduction of utility for wealthier individuals, either in the future or in current generations. If $\eta = 0$, then a one dollar increase in income is equally valuable regardless of level of income; if $\eta = 1$, then a one percent increase in income is equally valuable no matter the level of income; and if $\eta > 1$, then a one percent increase in income is less valuable to wealthier individuals.

[v] In this case, g could be taken from the selected EMF socioeconomic scenarios or alternative assumptions about the rate of consumption growth.

articulate whether their choice is based on prescriptive or descriptive reasoning.[w] Dasgupta (2008) argues that η should be greater than 1 and may be as high as 3, because η equal to 1 suggests savings rates that do not conform to observed behavior.

- ρ. With respect to the pure rate of time preference, most papers in the climate change literature adopt values for ρ in the range of 0 to 3 percent per year. The very low rates tend to follow from moral judgments involving intergenerational neutrality. Some have argued that to use any value other than $\rho = 0$ would unjustly discriminate against future generations (*e.g.*, Arrow et al. 1996, Stern et al. 2006). However, even in an inter-generational setting, it may make sense to use a small positive pure rate of time preference because of the small probability of unforeseen cataclysmic events (Stern et al. 2006).

- g. A commonly accepted approximation is around 2 percent per year. For the socioeconomic scenarios used for this exercise, the EMF models assume that g is about 1.5-2 percent to 2100.

Some economists and non-economists have argued for constant discount rates below 2 percent based on the prescriptive approach. When grounded in the Ramsey framework, proponents of this approach have argued that a ρ of zero avoids giving preferential treatment to one generation over another. The choice of η has also been posed as an ethical choice linked to the value of an additional dollar in poorer countries compared to wealthier ones. Stern et al. (2006) applies this perspective through his choice of $\rho = 0.1$ percent per year, $\eta = 1$ and $g = 1.3$ percent per year, which yields an annual discount rate of 1.4 percent. In the context of permanent income savings behavior, however, Stern's assumptions suggest that individuals would save 93 percent of their income.[x]

Recently, Stern (2008) revisited the values used in Stern et al. (2006), stating that there is a case to be made for raising η due to the amount of weight lower values place on damages far in the future (over 90 percent of expected damages occur after 2200 with $\eta = 1$). Using Stern's assumption that $\rho = 0.1$ percent, combined with a η of 1.5 to 2 and his original growth rate, yields a discount rate of greater than 2 percent.

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[w] Empirical estimates of η span a wide range of values. A benchmark value of 2 is near the middle of the range of values estimated or used by Szpiro (1986), Hall and Jones (2007), Arrow (2007), Dasgupta (2006, 2008), Weitzman (2007, 2009), and Nordhaus (2008). However, Chetty (2006) developed a method of estimating η using data on labor supply behavior. He shows that existing evidence of the effects of wage changes on labor supply imposes a tight upper bound on the curvature of utility over wealth (CRRA < 2) with the mean implied value of 0.71 and concludes that the standard expected utility model cannot generate high levels of risk aversion without contradicting established facts about labor supply. Recent work has jointly estimated the components of the Ramsey equation. Evans and Sezer (2005) estimate $\eta = 1.49$ for 22 OECD countries. They also estimate $\rho = 1.08$ percent per year using data on mortality rates. Anthoff, et al. (2009b) estimate $\eta = 1.18$, and $\rho = 1.4$ percent. When they multiply the bivariate probability distributions from their work and Evans and Sezer (2005) together, they find $\eta = 1.47$, and $\rho = 1.07$.

[x] Stern (2008) argues that building in a positive rate of exogenous technical change over time reduces the implied savings rate and that η at or above 2 are inconsistent with observed behavior with regard to equity. (At the same time, adding exogenous technical change—all else equal—would increase g as well.)

We conclude that arguments made under the prescriptive approach can be used to justify discount rates between roughly 1.4 and 3.1 percent. In light of concerns about the most appropriate value for η, we find it difficult to justify rates at the lower end of this range under the Ramsey framework.

Accounting for Uncertainty in the Discount Rate

While the consumption rate of interest is an important driver of the benefits estimate, it is uncertain over time. Ideally, we would formally model this uncertainty, just as we do for climate sensitivity. Weitzman (1998, 2001) showed theoretically and Newell and Pizer (2003) and Groom et al. (2006) confirm empirically that discount rate uncertainty can have a large effect on net present values. A main result from these studies is that if there is a persistent element to the uncertainty in the discount rate (*e.g.*, the rate follows a random walk), then it will result in an effective (or certainty-equivalent) discount rate that declines over time. Consequently, lower discount rates tend to dominate over the very long term (see Weitzman 1998, 1999, 2001; Newell and Pizer 2003; Groom et al. 2006; Gollier 2008; Summers and Zeckhauser 2008; and Gollier and Weitzman 2009).

The proper way to model discount rate uncertainty remains an active area of research. Newell and Pizer (2003) employ a model of how long-term interest rates change over time to forecast future discount rates. Their model incorporates some of the basic features of how interest rates move over time, and its parameters are estimated based on historical observations of long-term rates. Subsequent work on this topic, most notably Groom et al. (2006), uses more general models of interest rate dynamics to allow for better forecasts. Specifically, the volatility of interest rates depends on whether rates are currently low or high and the variation in the level of persistence over time.

While Newell and Pizer (2003) and Groom et al (2006) attempt formally to model uncertainty in the discount rate, others argue for a declining scale of discount rates applied over time (*e.g.*, Weitzman 2001, and the UK's "Green Book" for regulatory analysis). This approach uses a higher discount rate initially, but applies a graduated scale of lower discount rates further out in time.[y] A key question that has emerged with regard to both of these approaches is the trade-off between potential time inconsistency and giving greater weight to far future outcomes (see the EPA Science Advisory Board's recent comments on this topic as part of its review of their *Guidelines for Economic Analysis*).[z]

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[y] For instance, the UK applies a discount rate of 3.5 percent to the first 30 years; 3 percent for years 31 - 75; 2.5 percent for years 76 - 125; 2 percent for years 126 - 200; 1.5 percent for years 201 - 300; and 1 percent after 300 years. As a sensitivity, it recommends a discount rate of 3 percent for the first 30 years, also decreasing over time.

[z] Uncertainty in future damages is distinct from uncertainty in the discount rate. Weitzman (2008) argues that Stern's choice of a low discount rate was "right for the wrong reasons." He demonstrates how the damages from a low probability, catastrophic event far in the future dominate the effect of the discount rate in a present value calculation and result in an infinite willingness-to-pay for mitigation today. Newbold and Daigneault, (2009) and Nordhaus (2009) find that Weitzman's result is sensitive to the functional forms chosen for climate sensitivity,

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.[aa] Without giving preference to a particular model, the average of the two rates is 2.5 percent. Further, a rate below the riskless rate would be justified if climate investments are negatively correlated with the overall market rate of return. Use of this lower value also responds to certain judgments using the prescriptive or normative approach and to ethical objections that have been raised about rates of 3 percent or higher.

14A.5 REVISED SCC ESTIMATES

Our general approach to estimating SCC values is to run the three integrated assessment models (FUND, DICE, and PAGE) using the following inputs agreed upon by the interagency group:

- A Roe and Baker distribution for the climate sensitivity parameter bounded between 0 and 10 with a median of 3 °C and a cumulative probability between 2 and 4.5 °C of two-thirds.
- Five sets of GDP, population, and carbon emissions trajectories based on EMF-22.
- Constant annual discount rates of 2.5, 3, and 5 percent.

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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.

[aa] Calculations done by Pizer et al. using the original simulation program from Newell and Pizer (2003).

Because the climate sensitivity parameter is modeled probabilistically, and because PAGE and FUND incorporate uncertainty in other model parameters, the final output from each model run is a distribution over the SCC in year *t*.

For each of the IAMs, the basic computational steps for calculating the SCC in a particular year *t* are:

1. Input the path of emissions, GDP, and population from the selected EMF-22 scenarios, and the extrapolations based on these scenarios for post-2100 years.

2. Calculate the temperature effects and (consumption-equivalent) damages in each year resulting from the baseline path of emissions.

    a. In PAGE, the consumption-equivalent damages in each period are calculated as a fraction of the EMF GDP forecast, depending on the temperature in that period relative to the pre-industrial average temperature in each region.
    b. In FUND, damages in each period depend on both the level and the rate of temperature change in that period.
    c. In DICE, temperature affects both consumption and investment, so we first adjust the EMF GDP paths as follows: Using the Cobb-Douglas production function with the DICE2007 parameters, we extract the path of exogenous technical change implied by the EMF GDP and population paths, then we recalculate the baseline GDP path taking into account climate damages resulting from the baseline emissions path.

3. Add an additional unit of carbon emissions in year *t.* (The exact unit varies by model.)

4. Recalculate the temperature effects and damages expected in all years beyond *t* resulting from this adjusted path of emissions, as in step 2.

5. Subtract the damages computed in step 2 from those in step 4 in each year. (DICE is run in 10-year time steps, FUND in annual time steps, while the time steps in PAGE vary.)

6. Discount the resulting path of marginal damages back to the year of emissions using the agreed upon fixed discount rates.

7. Calculate the SCC as the net present value of the discounted path of damages computed in step 6, divided by the unit of carbon emissions used to shock the models in step 3.

8. Multiply by 12/44 to convert from dollars per ton of carbon to dollars per ton of CO_2 (2007 dollars) in DICE and FUND. (All calculations are done in tons of CO_2 in PAGE).

The steps above were repeated in each model for multiple future years to cover the time horizons anticipated for upcoming rulemaking analysis. To maintain consistency across the three IAMs, climate damages are calculated as lost consumption in each future year.

It is important to note that each of the three models has a different default end year. The default time horizon is 2200 for PAGE, 2595 for DICE, and 3000 for the latest version of FUND. This is an issue for the multi-model approach because differences in SCC estimates may arise simply due to the model time horizon. Many consider 2200 too short a time horizon because it could miss a significant fraction of damages under certain assumptions about the growth of marginal damages and discounting, so each model is run here through 2300. This step required a small adjustment in the PAGE model only. This step also required assumptions about GDP, population, and greenhouse gas emission trajectories after 2100, the last year for which these data are available from the EMF-22 models. (A more detailed discussion of these assumptions is included in the Annex.)

This exercise produces 45 separate distributions of the SCC for a given year, the product of 3 models, 3 discount rates, and 5 socioeconomic scenarios. This is clearly too many separate distributions for consideration in a regulatory impact analysis.

To produce a range of plausible estimates that still reflects the uncertainty in the estimation exercise, the distributions from each of the models and scenarios are equally weighed and combined to produce three separate probability distributions for SCC in a given year, one for each assumed discount rate. These distributions are then used to define a range of point estimates for the global SCC. In this way, no IAM or socioeconomic scenario is given greater weight than another. Because the literature shows that the SCC is quite sensitive to assumptions about the discount rate, and because no consensus exists on the appropriate rate to use in an intergenerational context, we present SCCs based on the average values across models and socioeconomic scenarios for each discount rate.

The interagency group selected four SCC values for use in regulatory analyses. Three values are based on the average SCC across models and socioeconomic and emissions scenarios at the 2.5, 3, and 5 percent discount rates. The fourth value is included to represent the higher-than-expected economic impacts from climate change further out in the tails of the SCC distribution. For this purpose, we use the SCC value for the 95th percentile at a 3 percent discount rate. (The full set of distributions by model and scenario combination is included in the Annex.) As noted above, the 3 percent discount rate is the central value, and so the central value that emerges is the average SCC across models at the 3 percent discount rate. For purposes of capturing the uncertainties involved in regulatory impact analysis, we emphasize the importance and value of considering the full range.

As previously discussed, low probability, high impact events are incorporated into the SCC values through explicit consideration of their effects in two of the three models as well as the use of a probability density function for equilibrium climate sensitivity. Treating climate sensitivity probabilistically results in more high-temperature outcomes, which in turn lead to higher projections of damages. Although FUND does not include catastrophic damages (in contrast to the other two models), its probabilistic treatment of the equilibrium climate sensitivity parameter will directly affect the non-catastrophic damages that are a function of the rate of temperature change.

In Table 14A.5.1, we begin by presenting SCC estimates for 2010 by model, scenario, and discount rate to illustrate the variability in the SCC across each of these input parameters. As expected, higher discount rates consistently result in lower SCC values, while lower discount rates result in higher SCC values for each socioeconomic trajectory. It is also evident that there are differences in the SCC estimated across the three main models. For these estimates, FUND produces the lowest estimates, while PAGE generally produces the highest estimates.

Table 14A.5.1 Disaggregated Social Cost of CO_2 Values by Model, Socioeconomic Trajectory, and Discount Rate for 2010 (in 2007 dollars)

	Discount rate:	**5%**	**3%**	**2.5%**	**3%**
Model	*Scenario*	Avg	Avg	Avg	95th
DICE	IMAGE	10.8	35.8	54.2	70.8
	MERGE	7.5	22.0	31.6	42.1
	Message	9.8	29.8	43.5	58.6
	MiniCAM	8.6	28.8	44.4	57.9
	550 Average	8.2	24.9	37.4	50.8
PAGE	IMAGE	8.3	39.5	65.5	142.4
	MERGE	5.2	22.3	34.6	82.4
	Message	7.2	30.3	49.2	115.6
	MiniCAM	6.4	31.8	54.7	115.4
	550 Average	5.5	25.4	42.9	104.7
FUND	IMAGE	-1.3	8.2	19.3	39.7
	MERGE	-0.3	8.0	14.8	41.3
	Message	-1.9	3.6	8.8	32.1
	MiniCAM	-0.6	10.2	22.2	42.6
	550 Average	-2.7	-0.2	3.0	19.4

These results are not surprising when compared to the estimates in the literature for the latest versions of each model. For example, adjusting the values from the literature that were used to develop interim SCC values to 2007 dollars for the year 2010 (assuming, as we did for the interim process, that SCC grows at 3 percent per year), FUND yields SCC estimates at or near zero for a 5 percent discount rate and around \$9 per ton for a 3 percent discount rate. There are far fewer estimates using the latest versions of DICE and PAGE in the literature: Using similar adjustments to generate 2010 estimates, we calculate a SCC from DICE (based on Nordhaus 2008) of around \$9 per ton for a 5 percent discount rate, and a SCC from PAGE (based on Hope 2006, 2008) close to \$8 per ton for a 4 percent discount rate. Note that these comparisons are only approximate since the literature generally relies on Ramsey discounting, while we have assumed constant discount rates.[bb]

[bb] Nordhaus (2008) runs DICE2007 with $\rho = 1.5$ and $\eta = 2$. The default approach in PAGE2002 (version 1.4epm) treats 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

The SCC estimates from FUND are sensitive to differences in emissions paths but relatively insensitive to differences in GDP paths across scenarios, while the reverse is true for DICE and PAGE. This likely occurs because of several structural differences among the models. Specifically in DICE and PAGE, the fraction of economic output lost due to climate damages increases with the level of temperature alone, whereas in FUND the fractional loss also increases with the rate of temperature change. Furthermore, in FUND increases in income over time decrease vulnerability to climate change (a form of adaptation), whereas this does not occur in DICE and PAGE. These structural differences among the models make FUND more sensitive to the path of emissions and less sensitive to GDP compared to DICE and PAGE.

Figure 14A.5.1 shows that IMAGE has the highest GDP in 2100 while MERGE Optimistic has the lowest. The ordering of global GDP levels in 2100 directly corresponds to the rank ordering of SCC for PAGE and DICE. For FUND, the correspondence is less clear, a result that is to be expected given its less direct relationship between its damage function and GDP.

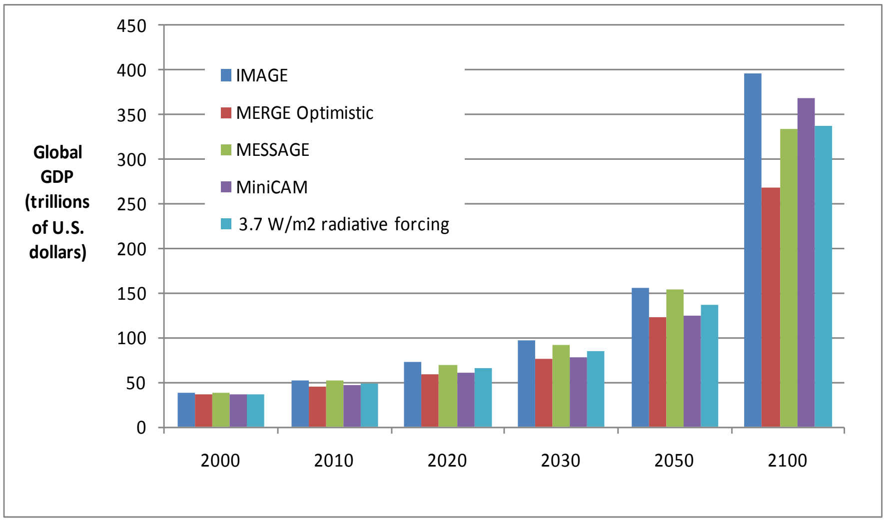

Figure 14A.5.1 Level of Global GDP across EMF Scenarios

Table 14A.5.2 shows the four selected SCC values in five-year increments from 2010 to 2050. Values for 2010, 2020, 2040, and 2050 are calculated by first combining all outputs (10,000 estimates per model run) from all scenarios and models for a given discount rate. Values for the years in between are calculated using a simple linear interpolation.

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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 (in 2007 dollars)

Discount	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 Annex.

Table 14A.5.3 Changes in the Average Annual Growth Rates of SCC Estimates between 2010 and 2050

Average Annual Growth Rate (%)	**5%** Avg	**3%** Avg	**2.5%** Avg	**3.0%** 95th
2010-2020	3.6%	2.1%	1.7%	2.2%
2020-2030	3.7%	2.2%	1.8%	2.2%
2030-2040	2.7%	1.8%	1.6%	1.8%
2040-2050	2.1%	1.4%	1.1%	1.3%

While the SCC estimate grows over time, the future monetized value of emissions reductions in each year (the SCC in year *t* multiplied by the change in emissions in year *t*) must be discounted to the present to determine its total net present value for use in regulatory analysis. Damages from future emissions should be discounted at the same rate as that used to calculate the SCC estimates themselves to ensure internal consistency—*i.e.*, future damages from climate change, whether they result from emissions today or emissions in a later year, should be discounted using the same rate. For example, climate damages in the year 2020 that are calculated using a SCC based on a 5 percent discount rate also should be discounted back to the analysis year using a 5 percent discount rate.[cc]

14A.6 LIMITATIONS OF THE ANALYSIS

As noted, any estimate of the SCC must be taken as provisional and subject to further refinement (and possibly significant change) in accordance with evolving scientific, economic, and ethical understandings. During the course of our modeling, it became apparent that there are several areas in particular need of additional exploration and research. These caveats, and additional observations in the following section, are necessary to consider when interpreting and applying the SCC estimates.

Incomplete treatment of non-catastrophic damages. The impacts of climate change are expected to be widespread, diverse, and heterogeneous. In addition, the exact magnitude of these impacts is uncertain because of the inherent complexity of climate processes, the economic behavior of current and future populations, and our inability to accurately forecast technological change and adaptation. Current IAMs do not assign value to all of the important physical, ecological, and economic impacts of climate change recognized in the climate change literature (some of which are discussed above) because of lack of precise information on the nature of damages and because the science incorporated into these models understandably lags behind the most recent research. Our ability to quantify and monetize impacts will undoubtedly improve with time. But it is also likely that even in future applications, a number of potentially significant damage categories will remain non-monetized. (Ocean acidification is one example of a potentially large damage from CO_2 emissions not quantified by any of the three models. Species and wildlife loss is another example that is exceedingly difficult to monetize.)

Incomplete treatment of potential catastrophic damages. There has been considerable recent discussion of the risk of catastrophic impacts and how best to account for extreme scenarios, such as the collapse of the Atlantic Meridional Overturning Circulation or the West Antarctic Ice Sheet, or large releases of methane from melting permafrost and warming oceans. Weitzman (2009) suggests that catastrophic damages are extremely large—so large, in fact, that the damages from a low probability, catastrophic event far in the future dominate the effect of the discount rate in a present value calculation and result in an infinite willingness-to-pay for mitigation today. However, Nordhaus (2009) concluded that the conditions under which Weitzman's results hold “are limited and do not apply to a wide range of potential uncertain scenarios."

Using a simplified IAM, Newbold and Daigneault (2009) confirmed the potential for large catastrophe risk premiums but also showed that the aggregate benefit estimates can be highly sensitive to the shapes of both the climate sensitivity distribution and the damage function at high temperature changes. Pindyck (2009) also used a simplified IAM to examine high-

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[cc] However, it is possible that other benefits or costs of proposed regulations unrelated to CO_2 emissions will be discounted at rates that differ from those used to develop the SCC estimates.

impact, low-probability risks, using a right-skewed gamma distribution for climate sensitivity as well as an uncertain damage coefficient, but in most cases found only a modest risk premium. Given this difference in opinion, further research in this area is needed before its practical significance can be fully understood and a reasonable approach developed to account for such risks in regulatory analysis. (The next section discusses the scientific evidence on catastrophic impacts in greater detail.)

Uncertainty in extrapolation of damages to high temperatures: The damage functions in these IAMs are typically calibrated by estimating damages at moderate temperature increases (*e.g.*, DICE was calibrated at 2.5 °C) and extrapolated to far higher temperatures by assuming that damages increase as some power of the temperature change. Hence, estimated damages are far more uncertain under more extreme climate change scenarios.

Incomplete treatment of adaptation and technological change: Each of the three integrated assessment models used here assumes a certain degree of low- or no-cost adaptation. For instance, Tol assumes a great deal of adaptation in FUND, including widespread reliance on air conditioning; so much so, that the largest single benefit category in FUND is the reduced electricity costs from not having to run air conditioning as intensively (NRC 2009).

Climate change also will increase returns on investment to develop technologies that allow individuals to cope with adverse climate conditions, and IAMs to do not adequately account for this directed technological change.[dd] For example, scientists may develop crops that are better able to withstand higher and more variable temperatures. Although DICE and FUND have both calibrated their agricultural sectors under the assumption that farmers will change land use practices in response to climate change (Mastrandrea, 2009), they do not take into account technological changes that lower the cost of this adaptation over time. On the other hand, the calibrations do not account for increases in climate variability, pests, or diseases, which could make adaptation more difficult than assumed by the IAMs for a given temperature change. Hence, models do not adequately account for potential adaptation or technical change that might alter the emissions pathway and resulting damages. In this respect, it is difficult to determine whether the incomplete treatment of adaptation and technological change in these IAMs understate or overstate the likely damages.

Risk aversion: A key question unanswered during this interagency process is what to assume about relative risk aversion with regard to high-impact outcomes. These calculations do not take into account the possibility that individuals may have a higher willingness to pay to reduce the likelihood of low-probability, high-impact damages than they do to reduce the likelihood of higher-probability, but lower-impact, damages with the same expected cost. (The inclusion of the 95th percentile estimate in the final set of SCC values was largely motivated by this concern.) If individuals do show such a higher willingness to pay, a further question is whether that fact should be taken into account for regulatory policy. Even if individuals are not

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[dd] However these research dollars will be diverted from whatever their next best use would have been in the absence of climate change (so productivity/GDP would have been still higher).

risk-averse for such scenarios, it is possible that regulatory policy should include a degree of risk-aversion.

Assuming a risk-neutral representative agent is consistent with OMB's Circular A-4, which advises that the estimates of benefits and costs used in regulatory analysis are usually based on the average or the expected value and that "emphasis on these expected values is appropriate as long as society is 'risk neutral' with respect to the regulatory alternatives. While this may not always be the case, [analysts] should in general assume 'risk neutrality' in [their] analysis."

Nordhaus (2008) points to the need to explore the relationship between risk and income in the context of climate change across models and to explore the role of uncertainty regarding various parameters in the results. Using FUND, Anthoff et al (2009) explored the sensitivity of the SCC to Ramsey equation parameter assumptions based on observed behavior. They conclude that "the assumed rate of risk aversion is at least as important as the assumed rate of time preference in determining the social cost of carbon." Since Circular A-4 allows for a different assumption on risk preference in regulatory analysis if it is adequately justified, we plan to continue investigating this issue.

14A.7 A FURTHER DISCUSSION OF CATASTROPHIC IMPACTS AND DAMAGE FUNCTIONS

As noted above, the damage functions underlying the three IAMs used to estimate the SCC may not capture the economic effects of all possible adverse consequences of climate change and may therefore lead to underestimates of the SCC (Mastrandrea 2009). In particular, the models' functional forms may not adequately capture: (1) potentially discontinuous "tipping point" behavior in Earth systems, (2) inter-sectoral and inter-regional interactions, including global security impacts of high-end warming, and (3) limited near-term substitutability between damage to natural systems and increased consumption.

It is the hope of the interagency group that over time researchers and modelers will work to fill these gaps and that the SCC estimates used for regulatory analysis by the Federal government will continue to evolve with improvements in modeling. In the meantime, we discuss some of the available evidence.

Extrapolation of climate damages to high levels of warming

The damage functions in the models are calibrated at moderate levels of warming and should therefore be viewed cautiously when extrapolated to the high temperatures found in the upper end of the distribution. Recent science suggests that there are a number of potential climatic "tipping points" at which the Earth system may exhibit discontinuous behavior with potentially severe social and economic consequences (*e.g.*, Lenton et al, 2008, Kriegler et al., 2009). These tipping points include the disruption of the Indian Summer Monsoon, dieback of the Amazon Rainforest and boreal forests, collapse of the Greenland Ice Sheet and the West Antarctic Ice Sheet, reorganization of the Atlantic Meridional Overturning Circulation, strengthening of El Niño-Southern Oscillation, and the release of methane from melting permafrost. Many of these tipping points are estimated to have thresholds between about 3 °C and 5 °C (Lenton et al., 2008). Probabilities of several of these tipping points were assessed through expert elicitation in 2005–2006 by Kriegler et al. (2009); results from this study are highlighted in Table 14A.7.1. Ranges of probability are averaged across core experts on each topic.

As previously mentioned, FUND does not include potentially catastrophic effects. DICE assumes a small probability of catastrophic damages that increases with increased warming, but the damages from these risks are incorporated as expected values (*i.e.*, ignoring potential risk aversion). PAGE models catastrophic impacts in a probabilistic framework (see Figure 14A.4.1), so the high-end output from PAGE potentially offers the best insight into the SCC if the world were to experience catastrophic climate change. For instance, at the 95th percentile and a 3 percent discount rate, the SCC estimated by PAGE across the five socioeconomic and emission trajectories of $113 per ton of CO_2 is almost double the value estimated by DICE, $58 per ton in 2010. We cannot evaluate how well the three models account for catastrophic or non-catastrophic impacts, but this estimate highlights the sensitivity of SCC values in the tails of the distribution to the assumptions made about catastrophic impacts.

Table 14A.7.1 Probabilities of Various Tipping Points from Expert Elicitation

Possible Tipping Points	**Duration before effect is fully realized (in years)**	**Additional Warming by 2100**		
		0.5-1.5 C	**1.5-3.0 C**	**3-5 C**
Reorganization of Atlantic Meridional Overturning Circulation	about 100	0-18%	6-39%	18-67%
Greenland Ice Sheet collapse	at least 300	8-39%	33-73%	67-96%
West Antarctic Ice Sheet collapse	at least 300	5-41%	10-63%	33-88%
Dieback of Amazon rainforest	about 50	2-46%	14-84%	41-94%
Strengthening of El Niño-Southern Oscillation	about 100	1-13%	6-32%	19-49%
Dieback of boreal forests	about 50	13-43%	20-81%	34-91%
Shift in Indian Summer Monsoon	about 1	Not formally assessed		
Release of methane from melting permafrost	Less than 100	Not formally assessed.		

PAGE treats the possibility of a catastrophic event probabilistically, while DICE treats it deterministically (that is, by adding the expected value of the damage from a catastrophe to the aggregate damage function). In part, this results in different probabilities being assigned to a catastrophic event across the two models. For instance, PAGE places a probability near zero on a catastrophe at 2.5 °C warming, while DICE assumes a 4 percent probability of a catastrophe at 2.5 °C. By comparison, Kriegler et al. (2009) estimate a probability of at least 16-36 percent of crossing at least one of their primary climatic tipping points in a scenario with temperatures about 2-4 °C warmer than pre-Industrial levels in 2100.

It is important to note that crossing a climatic tipping point will not necessarily lead to an economic catastrophe in the sense used in the IAMs. A tipping point is a critical threshold across which some aspect of the Earth system starts to shifts into a qualitatively different state (for instance, one with dramatically reduced ice sheet volumes and higher sea levels). In the IAMs, a catastrophe is a low-probability environmental change with high economic impact.

Failure to incorporate inter-sectoral and inter-regional interactions

The damage functions do not fully incorporate either inter-sectoral or inter-regional interactions. For instance, while damages to the agricultural sector are incorporated, the effects of changes in food supply on human health are not fully captured and depend on the modeler's choice of studies used to calibrate the IAM. Likewise, the effects of climate damages in one region of the world on another region are not included in some of the models (FUND includes the effects of migration from sea level rise). These inter-regional interactions, though difficult to quantify, are the basis for climate-induced national and economic security concerns (*e.g.*, Campbell et al., 2007; U.S. Department of Defense 2010) and are particularly worrisome at higher levels of warming. High-end warming scenarios, for instance, project water scarcity affecting 4.3-6.9 billion people by 2050, food scarcity affecting about 120 million additional people by 2080, and the creation of millions of climate refugees (Easterling et al., 2007; Campbell et al., 2007).

Imperfect substitutability of environmental amenities

Data from the geological record of past climate changes suggests that 6 °C of warming may have severe consequences for natural systems. For instance, during the Paleocene-Eocene Thermal Maximum about 55.5 million years ago, when the Earth experienced a geologically rapid release of carbon associated with an approximately 5 °C increase in global mean temperatures, the effects included shifts of about 400-900 miles in the range of plants (Wing et al., 2005), and dwarfing of both land mammals (Gingerich, 2006) and soil fauna (Smith et al., 2009).

The three IAMs used here assume that it is possible to compensate for the economic consequences of damages to natural systems through increased consumption of non-climate goods, a common assumption in many economic models. In the context of climate change, however, it is possible that the damages to natural systems could become so great that no increase in consumption of non-climate goods would provide complete compensation (Levy et al., 2005). For instance, as water supplies become scarcer or ecosystems become more fragile and less bio-diverse, the services they provide may become increasingly more costly to replace.

Uncalibrated attempts to incorporate the imperfect substitutability of such amenities into IAMs (Sterner and Persson, 2008) indicate that the optimal degree of emissions abatement can be considerably greater than is commonly recognized.

14A.8 CONCLUSION

The interagency group selected four SCC estimates for use in regulatory analyses. For 2010, these estimates are \$5, \$21, \$35, and \$65 (in 2007 dollars). The first three estimates are based on the average SCC across models and socioeconomic and emissions scenarios at the 5, 3, and 2.5 percent discount rates, respectively. The fourth value is included to represent the higher-than-expected impacts from temperature change further out in the tails of the SCC distribution. For this purpose, we use the SCC value for the 95th percentile at a 3 percent discount rate. The central value is the average SCC across models at the 3 percent discount rate. For purposes of capturing the uncertainties involved in regulatory impact analysis, we emphasize the importance and value of considering the full range. These SCC estimates also grow over time. For instance, the central value increases to \$24 per ton of CO_2 in 2015 and \$26 per ton of CO_2 in 2020.

We noted a number of limitations to this analysis, including the incomplete way in which the integrated assessment models capture catastrophic and non-catastrophic impacts, their incomplete treatment of adaptation and technological change, uncertainty in the extrapolation of damages to high temperatures, and assumptions regarding risk aversion. The limited amount of research linking climate impacts to economic damages makes this modeling exercise even more difficult. It is the hope of the interagency group that over time researchers and modelers will work to fill these gaps and that the SCC estimates used for regulatory analysis by the Federal government will continue to evolve with improvements in modeling.

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14A.9 ANNEX

Table 14A.9.1 Annual SCC Values: 2010–2050 (in 2007 dollars)

Discount Rate Year	5% Avg	3% Avg	2.5% Avg	3% 95th
2010	4.7	21.4	35.1	64.9
2011	4.9	21.9	35.7	66.5
2012	5.1	22.4	36.4	68.1
2013	5.3	22.8	37.0	69.6
2014	5.5	23.3	37.7	71.2
2015	5.7	23.8	38.4	72.8
2016	5.9	24.3	39.0	74.4
2017	6.1	24.8	39.7	76.0
2018	6.3	25.3	40.4	77.5
2019	6.5	25.8	41.0	79.1
2020	6.8	26.3	41.7	80.7
2021	7.1	27.0	42.5	82.6
2022	7.4	27.6	43.4	84.6
2023	7.7	28.3	44.2	86.5
2024	7.9	28.9	45.0	88.4
2025	8.2	29.6	45.9	90.4
2026	8.5	30.2	46.7	92.3
2027	8.8	30.9	47.5	94.2
2028	9.1	31.5	48.4	96.2
2029	9.4	32.1	49.2	98.1
2030	9.7	32.8	50.0	100.0
2031	10.0	33.4	50.9	102.0
2032	10.3	34.1	51.7	103.9
2033	10.6	34.7	52.5	105.8
2034	10.9	35.4	53.4	107.8
2035	11.2	36.0	54.2	109.7
2036	11.5	36.7	55.0	111.6
2037	11.8	37.3	55.9	113.6
2038	12.1	37.9	56.7	115.5
2039	12.4	38.6	57.5	117.4
2040	12.7	39.2	58.4	119.3
2041	13.0	39.8	59.0	121.0
2042	13.3	40.4	59.7	122.7
2043	13.6	40.9	60.4	124.4
2044	13.9	41.5	61.0	126.1
2045	14.2	42.1	61.7	127.8
2046	14.5	42.6	62.4	129.4
2047	14.8	43.2	63.0	131.1
2048	15.1	43.8	63.7	132.8
2049	15.4	44.4	64.4	134.5
2050	15.7	44.9	65.0	136.2

This Annex provides additional technical information about the non-CO_2 emission projections used in the modeling and the method for extrapolating emissions forecasts through 2300 and shows the full distribution of 2010 SCC estimates by model and scenario combination.

14A.9.1 Other (non-CO_2) gases

In addition to fossil and industrial CO_2 emissions, each EMF scenario provides projections of methane (CH_4), nitrous oxide (N_2O), fluorinated gases, and net land use CO_2 emissions to 2100. These assumptions are used in all three IAMs while retaining each model's default radiative forcings (RF) due to other factors (*e.g.*, aerosols and other gases). Specifically, to obtain the RF associated with the non-CO_2 EMF emissions only, we calculated the RF associated with the EMF atmospheric CO_2 concentrations and subtracted them from the EMF total RF.[ee] This approach respects the EMF scenarios as much as possible and at the same time takes account of those components not included in the EMF projections. Since each model treats non-CO_2 gases differently (*e.g.*, DICE lumps all other gases into one composite exogenous input), this approach was applied slightly differently in each of the models.

FUND: Rather than relying on RF for these gases, the actual emissions from each scenario were used in FUND. The model default trajectories for CH_4, N_20, SF_6, and the CO_2 emissions from land were replaced with the EMF values.

PAGE: PAGE models CO_2, CH_4, sulfur hexafluoride (SF_6), and aerosols and contains an "excess forcing" vector that includes the RF for everything else. To include the EMF values, we removed the default CH_4 and SF_6 factors[ff], decomposed the excess forcing vector, and constructed a new excess forcing vector that includes the EMF RF for CH_4, N_20, and fluorinated gases, as well as the model default values for aerosols and other factors. Net land use CO_2 emissions were added to the fossil and industrial CO_2 emissions pathway.

DICE: DICE presents the greatest challenge because all forcing due to factors other than industrial CO_2 emissions is embedded in an exogenous non-CO_2 RF vector. To decompose this exogenous forcing path into EMF non-CO_2 gases and other gases, we relied on the references in DICE2007 to the Intergovernmental Panel on Climate Change's (IPCC) Fourth Assessment Report (AR4) and the discussion of aerosol forecasts in the IPCC's Third Assessment Report (TAR) and in AR4, as explained below. In DICE2007, Nordhaus assumes that exogenous forcing from all non-CO_2 sources is -0.06 W/m^2 in 2005, as reported in AR4, and increases linearly to 0.3 W/m^2 in 2105, based on GISS projections, and then stays constant after that time.

According to AR4, the RF in 2005 from CH_4, N_20, and halocarbons (approximately similar to the F-gases in the EMF-22 scenarios) was 0.48 + 0.16 + 0.34 = 0.98 W/m^2 and RF from total aerosols was -1.2 W/m^2. Thus, the -.06 W/m^2 non-CO_2 forcing in DICE can be

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[ee] Note EMF did not provide CO_2 concentrations for the IMAGE reference scenario. Thus, for this scenario, we fed the fossil, industrial, and land CO_2 emissions into MAGICC (considered a "neutral arbiter" model, which is tuned to emulate the major global climate models) and the resulting CO_2 concentrations were used. Note also that MERGE assumes a neutral biosphere so net land CO_2 emissions are set to zero for all years for the MERGE Optimistic reference scenario, and for the MERGE component of the average 550 scenario (*i.e.*, we add up the land use emissions from the other three models and divide by 4).

[ff] Both the model default CH_4 emissions and the initial atmospheric CH_4 is set to zero to avoid double counting the effect of past CH_4 emissions.

decomposed into: 0.98 W/m^2 due to the EMF non-CO_2 gases, -1.2 W/m^2 due to aerosols, and the remainder, 0.16 W/m^2, due to other residual forcing.

For subsequent years, we calculated the DICE default RF from aerosols and other non-CO_2 gases based on the following two assumptions:

> (1) RF from aerosols declines linearly from 2005 to 2100 at the rate projected by the TAR and then stays constant thereafter; and
> (2) With respect to RF from non-CO_2 gases not included in the EMF-22 scenarios, the share of non-aerosol RF matches the share implicit in the AR4 summary statistics cited above and remains constant over time.

Assumption (1) means that the RF from aerosols in 2100 equals 66 percent of that in 2000, which is the fraction of the TAR projection of total RF from aerosols (including sulfates, black carbon, and organic carbon) in 2100 vs. 2000 under the A1B SRES emissions scenario. Since the SRES marker scenarios were not updated for the AR4, the TAR provides the most recent IPCC projection of aerosol forcing. We rely on the A1B projection from the TAR because it provides one of the lower aerosol forecasts among the SRES marker scenarios and is more consistent with the AR4 discussion of the post-SRES literature on aerosols:

> *Aerosols have a net cooling effect and the representation of aerosol and aerosol precursor emissions, including sulfur dioxide, black carbon and organic carbon, has improved in the post-SRES scenarios. Generally, these emissions are projected to be lower than reported in SRES.*[gg]

Assuming a simple linear decline in aerosols from 2000 to 2100 also is more consistent with the recent literature on these emissions. For example, the figure below shows that the sulfur dioxide emissions peak over the short term of some SRES scenarios above the upper bound estimates of the more recent scenarios.[hh] Recent scenarios project sulfur emissions to peak earlier and at lower levels compared to the SRES in part because of new information about present and planned sulfur legislation in some developing countries, such as India and China.[ii] The lower-bound projections of the recent literature have also shifted downward slightly compared to the SRES scenario (IPCC 2007).

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.

[gg] AR4 Synthesis Report, p. 44, www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr.pdf

[hh] See Smith, S.J., R. Andres, E. Conception, and J. Lurz, 2004: Historical sulfur dioxide emissions, 1850-2000: methods and results. Joint Global Research Institute, College Park, 14 pp.

[ii] See Carmichael, G., D. Streets, G. Calori, M. Amann, M. Jacobson, J. Hansen, and H. Ueda, 2002: Changing trends in sulphur emissions in Asia: implications for acid deposition, air pollution, and climate. Environmental Science and Technology, 36(22):4707- 4713; Streets, D., K. Jiang, X. Hu, J. Sinton, X.-Q. Zhang, D. Xu, M. Jacobson, and J. Hansen, 2001: Recent reductions in China's greenhouse gas emissions. Science, 294(5548): 1835-1837.

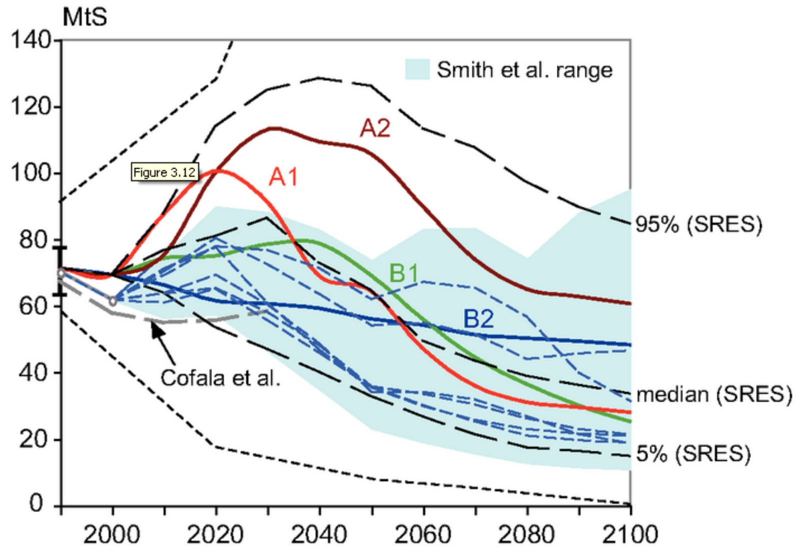

Figure 14A.9.2 Sulfur Dioxide Emission Scenarios

Notes: Thick colored lines depict the four SRES marker scenarios and black dashed lines show the median, 5th, and 95th percentile of the frequency distribution for the full ensemble of 40 SRES scenarios. The blue area (and the thin dashed lines in blue) illustrates individual scenarios and the range of Smith et al. (2004). Dotted lines indicate the minimum and maximum of SO_2 emissions scenarios developed pre-SRES.
Source: IPCC (2007), AR4 WGIII 3.2, www.ipcc.ch/publications_and_data/ar4/wg3/en/ch3-ens3-2-2-4.html.

Although other approaches to decomposing the DICE exogenous forcing vector are possible, initial sensitivity analysis suggests that the differences among reasonable alternative approaches are likely to be minor. For example, adjusting the TAR aerosol projection above to assume that aerosols will be maintained at 2000 levels through 2100 reduces average SCC values (for 2010) by approximately 3 percent (or less than $2); assuming all aerosols are phased out by 2100 increases average 2010 SCC values by 6-7 percent (or $0.50-$3)–depending on the discount rate. These differences increase slightly for SCC values in later years but are still well within 10 percent of each other as far out as 2050.

Finally, as in PAGE, the EMF net land use CO_2 emissions are added to the fossil and industrial CO_2 emissions pathway.

14A.9.2 Extrapolating Emissions Projections to 2300

To run each model through 2300 requires assumptions about GDP, population, greenhouse gas emissions, and radiative forcing trajectories after 2100, the last year for which these projections are available from the EMF-22 models. These inputs were extrapolated from 2100 to 2300 as follows:

1. Population growth rate declines linearly, reaching zero in the year 2200.
2. GDP/per capita growth rate declines linearly, reaching zero in the year 2300.
3. The decline in the fossil and industrial carbon intensity (CO_2/GDP) growth rate over 2090-2100 is maintained from 2100 through 2300.
4. Net land use CO_2 emissions decline linearly, reaching zero in the year 2200.
5. Non-CO_2 radiative forcing remains constant after 2100.

Long run stabilization of GDP per capita was viewed as a more realistic simplifying assumption than a linear or exponential extrapolation of the pre-2100 economic growth rate of each EMF scenario. This is based on the idea that increasing scarcity of natural resources and the degradation of environmental sinks available for assimilating pollution from economic production activities may eventually overtake the rate of technological progress. Thus, the overall rate of economic growth may slow over the very long run. The interagency group also considered allowing an exponential decline in the growth rate of GDP per capita. However, since this would require an additional assumption about how close to zero the growth rate would get by 2300, the group opted for the simpler and more transparent linear extrapolation to zero by 2300.

The population growth rate is also assumed to decline linearly, reaching zero by 2200. This assumption is reasonably consistent with the United Nations long run population forecast, which estimates global population to be fairly stable after 2150 in the medium scenario (UN 2004).[jj] The resulting range of EMF population trajectories (figure below) also encompass the UN medium scenario forecasts through 2300—global population of 8.5 billion by 2200, and 9 billion by 2300.

Maintaining the decline in the 2090-2100 carbon intensity growth rate (*i.e.*, CO_2 per dollar of GDP) through 2300 assumes that technological improvements and innovations in the areas of energy efficiency and other carbon reducing technologies (possibly including currently unavailable methods) will continue to proceed at roughly the same pace that is projected to occur towards the end of the forecast period for each EMF scenario. This assumption implies that total cumulative emissions in 2300 will be between 5,000 and 12,000 GtC, which is within the range of the total potential global carbon stock estimated in the literature.

Net land use CO_2 emissions are expected to stabilize in the long run, so in the absence of any post 2100 projections, the group assumed a linear decline to zero by 2200. Given no a priori reasons for assuming a long run increase or decline in non-CO_2 radiative forcing, it is assumed to remain at the 2100 levels for each EMF scenario through 2300.

Figures below show the paths of global population, GDP, fossil and industrial CO_2 emissions, net land CO_2 emissions, non-CO_2 radiative forcing, and CO_2 intensity (fossil and industrial CO_2 emissions/GDP) resulting from these assumptions.

[jj] United Nations. 2004. *World Population to 2300*. www.un.org/esa/population/publications/longrange2/WorldPop2300final.pdf

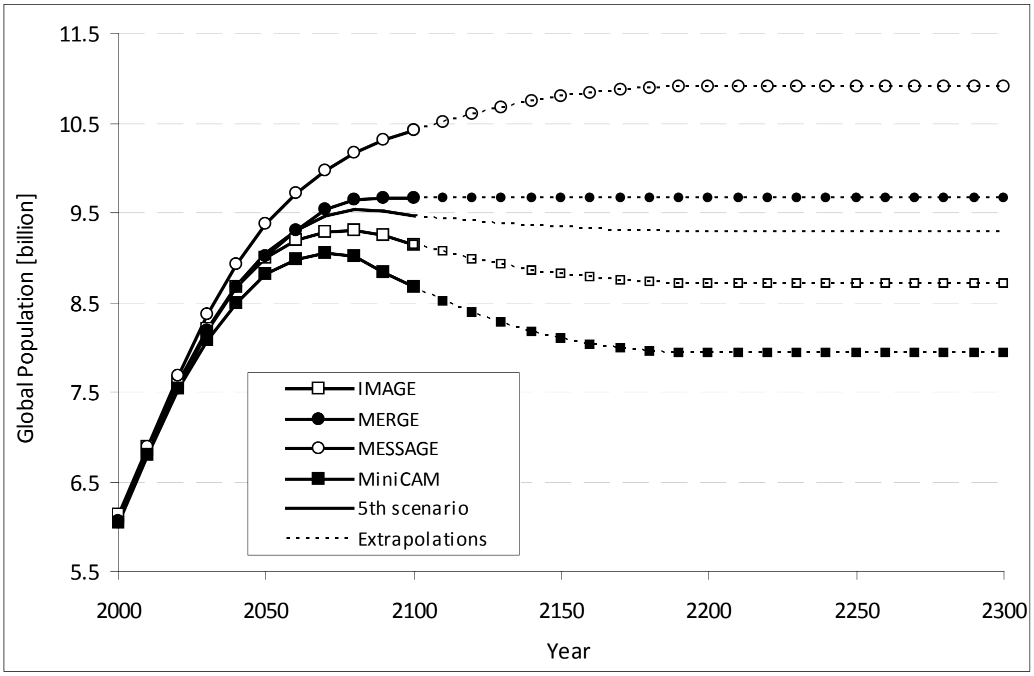

Figure 14A.9.3 Global Population, 2000-2300 (Post-2100 extrapolations assume the population growth rate changes linearly to reach a zero growth rate by 2200.)

Note: In the fifth scenario, 2000-2100 population is equal to the average of the population under the 550 ppm CO_2e, full-participation, not-to-exceed scenarios considered by each of the four models.

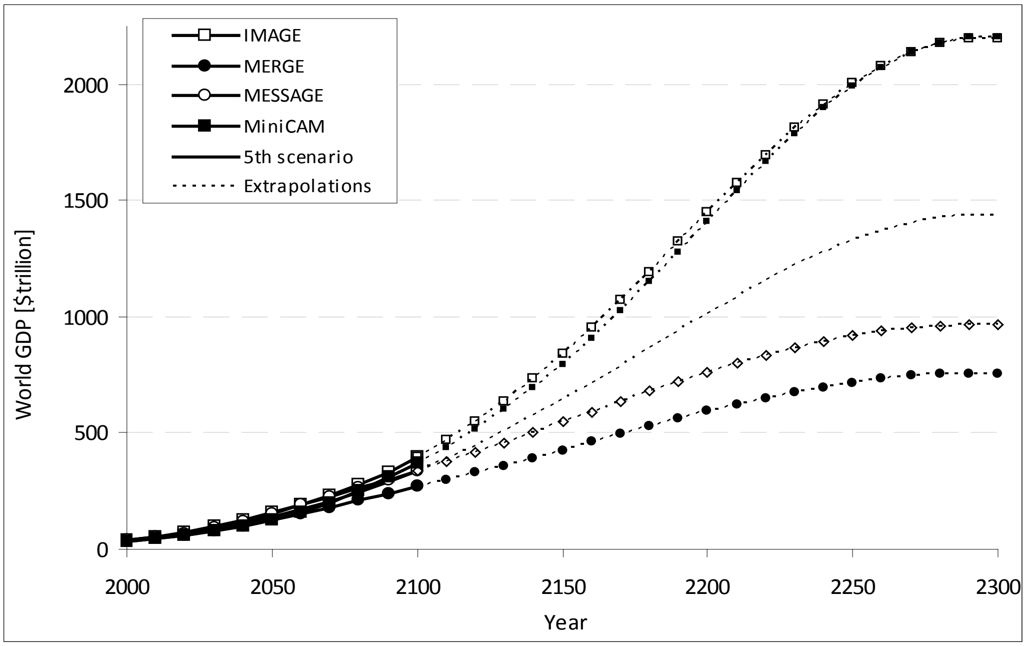

Figure 14A.9.4 World GDP, 2000-2300 (Post-2100 extrapolations assume GDP per capita growth declines linearly, reaching zero in the year 2300)

Note: In the fifth scenario, 2000-2100 GDP is equal to the average of the GDP under the 550 ppm CO_2e, full-participation, not-to-exceed scenarios considered by each of the four models.

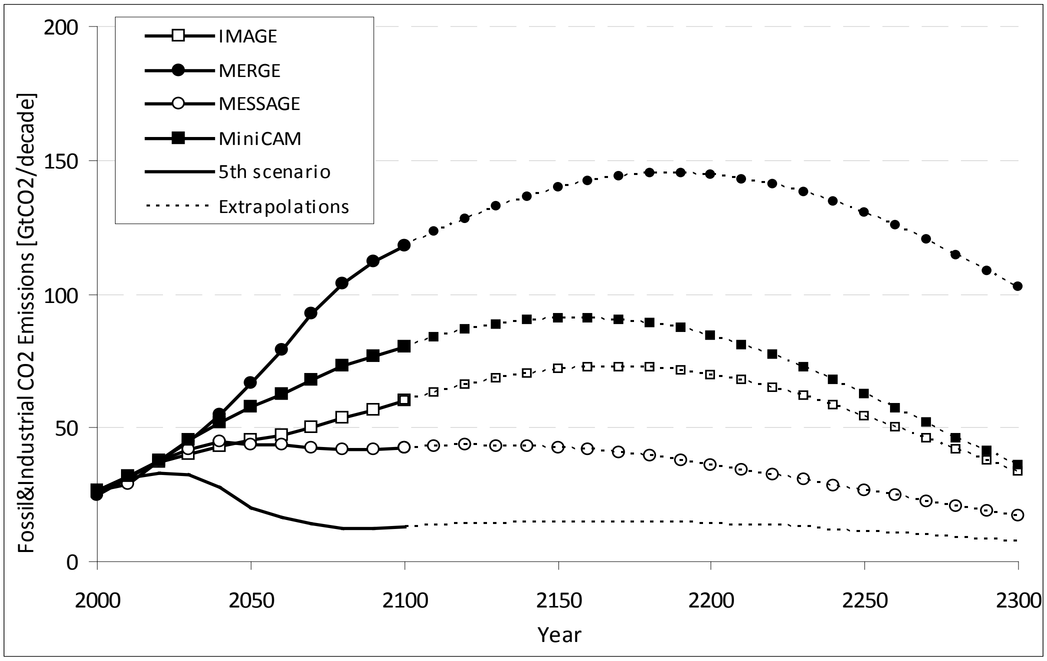

Figure 14A.9.5 Global Fossil and Industrial CO_2 Emissions, 2000-2300 (Post-2100 extrapolations assume growth rate of CO_2 intensity (CO_2/GDP) over 2090-2100 is maintained through 2300)

Note: In the fifth scenario, 2000-2100 emissions are equal to the average of the emissions under the 550 ppm CO_2e, full-participation, not-to-exceed scenarios considered by each of the four models.

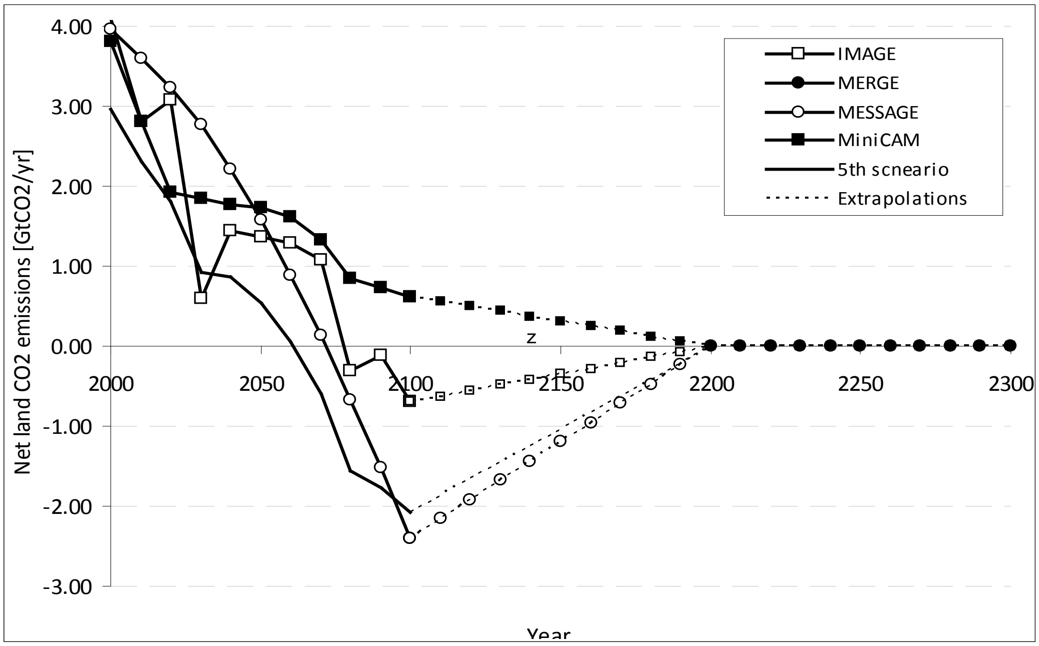

Figure 14A.9.6 Global Net Land Use CO_2 Emissions, 2000-2300 (Post-2100 extrapolations assume emissions decline linearly, reaching zero in the year 2200)[kk]

Note: In the fifth scenario, 2000-2100 emissions are equal to the average of the emissions under the 550 ppm CO_2e, full-participation, not-to-exceed scenarios considered by each of the four models.

[kk] MERGE assumes a neutral biosphere so net land CO_2 emissions are set to zero for all years for the MERGE Optimistic reference scenario, and for the MERGE component of the average 550 scenario (*i.e.*, we add up the land use emissions from the other three models and divide by 4).

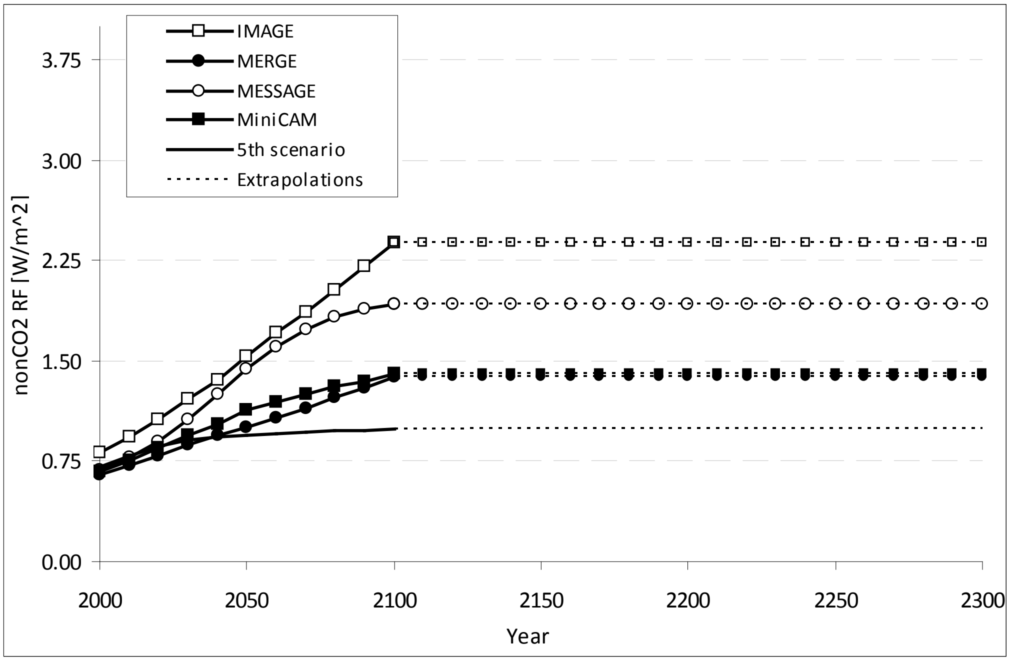

Figure 14A.9.7 Global Non-CO_2 Radiative Forcing, 2000-2300 (Post-2100 extrapolations assume constant non-CO_2 radiative forcing after 2100)

Note: In the fifth scenario, 2000-2100 emissions are equal to the average of the emissions under the 550 ppm CO_2e, full-participation, not-to-exceed scenarios considered by each of the four models.

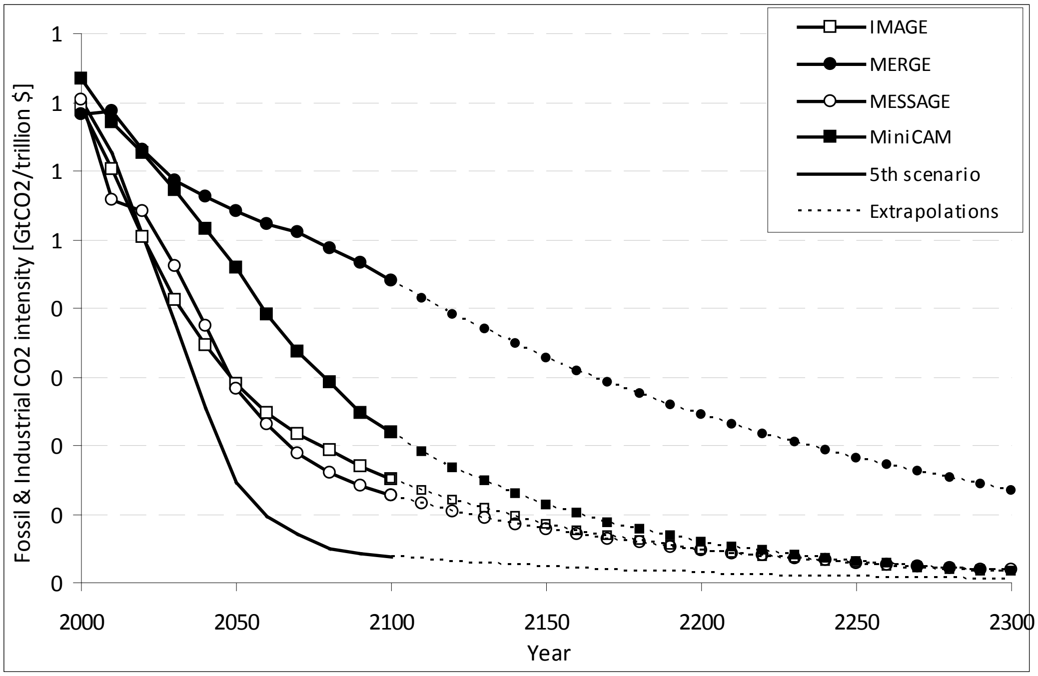

Figure 14A.9.8 **Global CO_2 Intensity (fossil & industrial CO_2 emissions/GDP), 2000-2300 (Post-2100 extrapolations assume decline in CO_2/GDP growth rate over 2090-2100 is maintained through 2300)**

Note: In the fifth scenario, 2000-2100 emissions are equal to the average of the emissions under the 550 ppm CO_2e, full-participation, not-to-exceed scenarios considered by each of the four models.

Table 14A.9.2 2010 Global SCC Estimates at 2.5 Percent Discount Rate (2007$/ton CO_2)

Percentile	1st	5th	10th	25th	50th	Avg	75th	90th	95th	99th
Scenario	**PAGE**									
IMAGE	3.3	5.9	8.1	13.9	28.8	65.5	68.2	147.9	239.6	563.8
MERGE optimistic	1.9	3.2	4.3	7.2	14.6	34.6	36.2	79.8	124.8	288.3
Message	2.4	4.3	5.8	9.8	20.3	49.2	50.7	114.9	181.7	428.4
MiniCAM base	2.7	4.6	6.4	11.2	22.8	54.7	55.7	120.5	195.3	482.3
5th scenario	2.0	3.5	4.7	8.1	16.3	42.9	41.5	103.9	176.3	371.9

Scenario	**DICE**									
IMAGE	16.4	21.4	25	33.3	46.8	54.2	69.7	96.3	111.1	130.0
MERGE optimistic	9.7	12.6	14.9	19.7	27.9	31.6	40.7	54.5	63.5	73.3
Message	13.5	17.2	20.1	27	38.5	43.5	55.1	75.8	87.9	103.0
MiniCAM base	13.1	16.7	19.8	26.7	38.6	44.4	56.8	79.5	92.8	109.3
5th scenario	10.8	14	16.7	22.2	32	37.4	47.7	67.8	80.2	96.8

Scenario	**FUND**									
IMAGE	-33.1	-18.9	-13.3	-5.5	4.1	19.3	18.7	43.5	67.1	150.7
MERGE optimistic	-33.1	-14.8	-10	-3	5.9	14.8	20.4	43.9	65.4	132.9
Message	-32.5	-19.8	-14.6	-7.2	1.5	8.8	13.8	33.7	52.3	119.2
MiniCAM base	-31.0	-15.9	-10.7	-3.4	6	22.2	21	46.4	70.4	152.9
5th scenario	-32.2	-21.6	-16.7	-9.7	-2.3	3	6.7	20.5	34.2	96.8

Table 14A.9.3 2010 Global SCC Estimates at 3 Percent Discount Rate (2007$/ton CO$_2$)

Percentile	1st	5th	10th	25th	50th	Avg	75th	90th	95th	99th
Scenario	**PAGE**									
IMAGE	2.0	3.5	4.8	8.1	16.5	39.5	41.6	90.3	142.4	327.4
MERGE optimistic	1.2	2.1	2.8	4.6	9.3	22.3	22.8	51.3	82.4	190.0
Message	1.6	2.7	3.6	6.2	12.5	30.3	31	71.4	115.6	263.0
MiniCAM base	1.7	2.8	3.8	6.5	13.2	31.8	32.4	72.6	115.4	287.0
5th scenario	1.3	2.3	3.1	5	9.6	25.4	23.6	62.1	104.7	222.5

Scenario	**DICE**									
IMAGE	11.0	14.5	17.2	22.8	31.6	35.8	45.4	61.9	70.8	82.1
MERGE optimistic	7.1	9.2	10.8	14.3	19.9	22	27.9	36.9	42.1	48.8
Message	9.7	12.5	14.7	19	26.6	29.8	37.8	51.1	58.6	67.4
MiniCAM base	8.8	11.5	13.6	18	25.2	28.8	36.9	50.4	57.9	67.8
5th scenario	7.9	10.1	11.8	15.6	21.6	24.9	31.8	43.7	50.8	60.6

Scenario	**FUND**									
IMAGE	-25.2	-15.3	-11.2	-5.6	0.9	8.2	10.4	25.4	39.7	90.3
MERGE optimistic	-24.0	-12.4	-8.7	-3.6	2.6	8	12.2	27	41.3	85.3
Message	-25.3	-16.2	-12.2	-6.8	-0.5	3.6	7.7	20.1	32.1	72.5
MiniCAM base	-23.1	-12.9	-9.3	-4	2.4	10.2	12.2	27.7	42.6	93.0
5th scenario	-24.1	-16.6	-13.2	-8.3	-3	-0.2	2.9	11.2	19.4	53.6

Table 14A.9.4 2010 Global SCC Estimates at 5 Percent Discount Rate (2007$/ton CO_2)

Percentile	1st	5th	10th	25th	50th	Avg	75th	90th	95th	99th
Scenario	**PAGE**									
IMAGE	0.5	0.8	1.1	1.8	3.5	8.3	8.5	19.5	31.4	67.2
MERGE optimistic	0.3	0.5	0.7	1.2	2.3	5.2	5.4	12.3	19.5	42.4
Message	0.4	0.7	0.9	1.6	3	7.2	7.2	17	28.2	60.8
MiniCAM base	0.3	0.6	0.8	1.4	2.7	6.4	6.6	15.9	24.9	52.6
5th scenario	0.3	0.6	0.8	1.3	2.3	5.5	5	12.9	22	48.7

Scenario	**DICE**									
IMAGE	4.2	5.4	6.2	7.6	10	10.8	13.4	16.8	18.7	21.1
MERGE optimistic	2.9	3.7	4.2	5.3	7	7.5	9.3	11.7	12.9	14.4
Message	3.9	4.9	5.5	7	9.2	9.8	12.2	15.4	17.1	18.8
MiniCAM base	3.4	4.2	4.7	6	7.9	8.6	10.7	13.5	15.1	16.9
5th scenario	3.2	4	4.6	5.7	7.6	8.2	10.2	12.8	14.3	16.0

Scenario	**FUND**									
IMAGE	-11.7	-8.4	-6.9	-4.6	-2.2	-1.3	0.7	4.1	7.4	17.4
MERGE optimistic	-10.6	-7.1	-5.6	-3.6	-1.3	-0.3	1.6	5.4	9.1	19.0
Message	-12.2	-8.9	-7.3	-4.9	-2.5	-1.9	0.3	3.5	6.5	15.6
MiniCAM base	-10.4	-7.2	-5.8	-3.8	-1.5	-0.6	1.3	4.8	8.2	18.0
5th scenario	-10.9	-8.3	-7	-5	-2.9	-2.7	-0.8	1.4	3.2	9.2

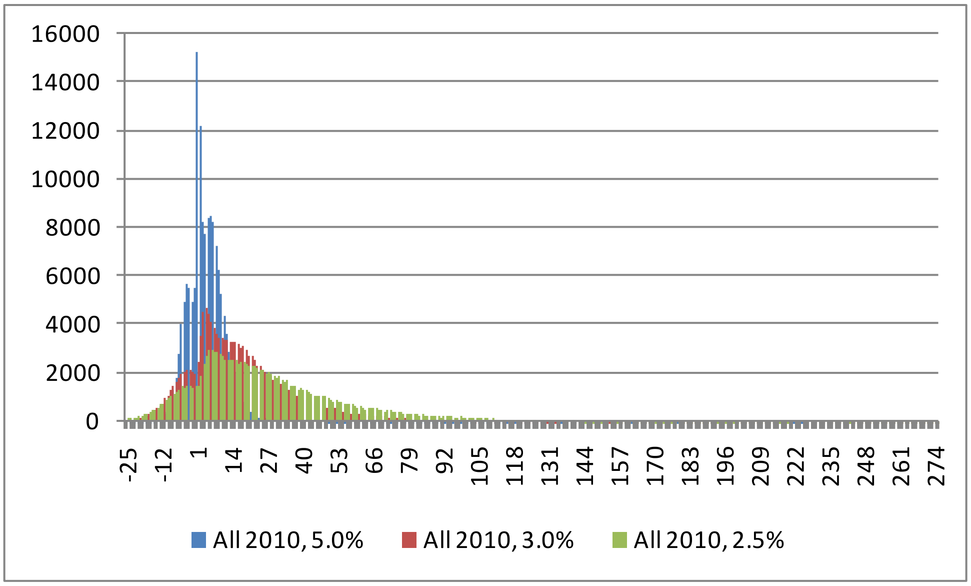

Figure 14A.9.9 Histogram of Global SCC Estimates in 2010 (2007$/ton CO_2), by discount rate

* The distribution of SCC values ranges from -$5,192 to $66,116, but the X-axis has been truncated at approximately the 1st and 99th percentiles to better show the data.

Table 14A.9.5 Additional Summary Statistics of 2010 Global SCC Estimates

Discount Rate		Scenario		
		DICE	PAGE	FUND
5%	Mean	9	6.5	-1.3
	Variance	13.1	136	70.1
	Skewness	0.8	6.3	28.2
	Kurtosis	0.2	72.4	1,479.00
3%	Mean	28.3	29.8	6
	Variance	209.8	3,383.70	16,382.50
	Skewness	1.1	8.6	128
	Kurtosis	0.9	151	18,976.50
2.50%	Mean	42.2	49.3	13.6
	Variance	534.9	9,546.00	#######
	Skewness	1.2	8.7	149
	Kurtosis	1.1	143.8	23,558.30

APPENDIX 14B. TECHNICAL UPDATE OF SOCIAL COST OF CARBON FOR REGULATORY IMPACT ANALYSIS UNDER EXECUTIVE ORDER 12866

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APPENDIX 14B. TECHNICAL UPDATE OF SOCIAL COST OF CARBON FOR REGULATORY IMPACT ANALYSIS UNDER EXECUTIVE ORDER 12866

14B.1 PREFACE

The following text is reproduced almost verbatim from the May 2013 report of the Interagency Working Group on the Social Cost of Carbon of the United States Government. Minor changes were made to the working group's report to make it more consistent with the rest of this technical support document.

14B.2 PURPOSE

The purpose of this document is to update the schedule of social cost of carbon (SCC) [a] estimates from the 2010 interagency technical support document (TSD) (Interagency Working Group on Social Cost of Carbon 2010).[1] E.O. 13563 commits the Administration to regulatory decision making "based on the best available science."[b] Additionally, the interagency group recommended in 2010 that the SCC estimates be revisited on a regular basis or as model updates that reflect the growing body of scientific and economic knowledge become available.[c] New versions of the three integrated assessment models used by the U.S. government to estimate the SCC (DICE, FUND, and PAGE), are now available and have been published in the peer reviewed literature. While acknowledging the continued limitations of the approach taken by the interagency group in 2010 (documented in the original 2010 TSD), this document provides an update of the SCC estimates based solely on the latest peer-reviewed version of the models, replacing model versions that were developed up to ten years ago in a rapidly evolving field. It does not revisit other assumptions with regard to the discount rate, reference case socioeconomic and emission scenarios, or equilibrium climate sensitivity. Improvements in the way damages are modeled are confined to those that have been incorporated into the latest versions of the models by the developers themselves in the peer-reviewed literature. The Environmental Protection Agency (EPA), in collaboration with other Federal agencies such as the Department of Energy (DOE), continues to investigate potential improvements to the way in which economic damages associated with changes in CO_2 emissions are quantified.

Section 14B.3 summarizes the major updates relevant to SCC estimation that are contained in the new versions of the integrated assessment models released since the 2010 interagency report. Section 14B.4 presents the updated schedule of SCC estimates for 2010 – 2050 based on these versions of the models.

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[a] In this document, we present all values of the SCC as the cost per metric ton of CO_2 emissions. Alternatively, one could report the SCC as the cost per metric ton of carbon emissions. The multiplier for translating between mass of CO_2 and the mass of carbon is 3.67.

[b] www.whitehouse.gov/sites/default/files/omb/inforeg/eo12866/eo13563_01182011.pdf

[c] See p. 1, 3, 4, 29, and 33 (Interagency Working Group on Social Cost of Carbon 2010).[1]

14B.3 SUMMARY OF MODEL UPDATES

This section briefly summarizes changes integrated into the most recent versions of the three integrated assessment models (IAMs) used by the interagency group in 2010. We focus on describing those model updates that are relevant to estimating the social cost of carbon. For example, both the DICE and PAGE models now include an explicit representation of sea level rise damages. Other revisions to PAGE include: updated adaptation assumptions, revisions to ensure damages are constrained GDP, updated regional scaling of damages, and a revised treatment of potentially abrupt shifts in climate damages. In the most recent version of DICE, the model's simple carbon cycle has been updated to be more consistent with a relatively more complex climate model. The FUND model includes updated damage functions for sea level rise impacts, the agricultural sector, and reduced space heating requirements, as well as changes to the response of temperature to the buildup of GHG concentrations and the inclusion of indirect effects of methane emissions. Changes made to parts of the models that are superseded by the interagency working group's modeling assumptions – regarding climate sensitivity, discounting, and socioeconomic variables – are not discussed.

14B.3.1 DICE

Changes in the DICE model relevant for the SCC estimates developed by the interagency working group include: 1) updated parameter values for the carbon cycle model, 2) an explicit representation of sea level dynamics, and 3) a re-calibrated damage function that includes an explicit representation of economic damages from sea level rise. Changes were also made to other parts of the DICE model—including the equilibrium climate sensitivity parameter, the rate of change of total factor productivity, and the elasticity of the marginal utility of consumption—but these components of DICE are superseded by the interagency working group's assumptions and so will not be discussed here. More details on DICE2007 can be found in Nordhaus (2008)[2] and on DICE2010 in Nordhaus (2010)[3] and the associated on-line appendix containing supplemental information.

14B.3.1.1 Carbon Cycle Parameters

DICE uses a three-box model of carbon stocks and flows to represent the accumulation and transfer of carbon among the atmosphere, the shallow ocean and terrestrial biosphere, and the deep ocean. These parameters are "calibrated to match the carbon cycle in the Model for the Assessment of Greenhouse Gas Induced Climate Change (MAGICC)" (Nordhaus 2008 p 44).[2][d] Carbon cycle transfer coefficient values in DICE2010 are based on re-calibration of the model to match the newer version of MAGICC (Nordhaus 2010 p 2).[3] For example, in DICE2010 in each decade, 12 percent of the carbon in the atmosphere is transferred to the shallow ocean, 4.7 percent of the carbon in the shallow ocean is transferred to the atmosphere, 94.8 percent remains in the shallow ocean, and 0.5 percent is transferred to the deep ocean. For comparison, in DICE 2007, 18.9 percent of the carbon in the atmosphere is transferred to the shallow ocean each

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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]

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.3.1.2 Sea Level Dynamics

A new feature of DICE2010 is an explicit representation of the dynamics of the global average sea level anomaly to be used in the updated damage function (discussed below). This section contains a brief description of the sea level rise (SLR) module; a more detailed description can be found on the model developer's website.[e] The average global sea level anomaly is modeled as the sum of four terms that represent contributions from: 1) thermal expansion of the oceans, 2) melting of glaciers and small ice caps, 3) melting of the Greenland ice sheet, and 4) melting of the Antarctic ice sheet.

The parameters of the four components of the SLR module are calibrated to match consensus results from the IPCC's Fourth Assessment Report.[4,f] The rise in sea level from thermal expansion in each time period (decade) is 2 percent of the difference between the sea level in the previous period and the long run equilibrium sea level, which is 0.5 meters per degree Celsius (°C) above the average global temperature in 1900. The rise in sea level from the melting of glaciers and small ice caps occurs at a rate of 0.008 meters per decade per °C above the average global temperature in 1900.

The contribution to sea level rise from melting of the Greenland ice sheet is more complex. The equilibrium contribution to SLR is 0 meters for temperature anomalies less than 1 °C and increases linearly from 0 meters to a maximum of 7.3 meters. The contribution to SLR in each period is proportional to the difference between the previous period's sea level anomaly and the equilibrium sea level anomaly, where the constant of proportionality increases with the temperature anomaly in the current period.

The contribution to SLR from the melting of the Antarctic ice sheet is -0.001 meters per decade when the temperature anomaly is below 3 °C and increases linearly to a maximum rate of 0.025 meters per decade at a temperature anomaly of 6 °C.

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[e] Documentation on the new sea level rise module of DICE is available on William Nordhaus' website at: www.econ.yale.edu/.

[f] For a review of post-IPCC AR4 research on sea level rise, see Nicholls et al. (2011)[5] and NAS (2011).[6]

14B.3.1.3 Re-calibrated Damage Function

Economic damages from climate change in the DICE model are represented by a fractional loss of gross economic output in each period. A portion of the remaining economic output in each period (net of climate change damages) is consumed and the remainder is invested in the physical capital stock to support future production, so each period's climate damages will reduce consumption in that period and in all future periods due to the lost investment. The fraction of output in each period that is lost due to climate change impacts is represented as one minus a fraction, which is one divided by a quadratic function of the temperature anomaly, producing a sigmoid ("S"-shaped) function. The loss function in DICE2010 has been expanded by adding a quadratic function of SLR to the quadratic function of temperature. In DICE2010 the temperature anomaly coefficients have been recalibrated to avoid double-counting damages from sea level rise that were implicitly included in these parameters in DICE2007.

The aggregate damages in DICE2010 are illustrated by Nordhaus (2010 p 3),[3] who notes that "…damages in the uncontrolled (baseline) (*i.e.*, reference) case … in 2095 are $12 trillion, or 2.8 percent of global output, for a global temperature increase of 3.4 °C above 1900 levels." This compares to a loss of 3.2 percent of global output at 3.4 °C in DICE2007. However, in DICE2010 (as downloaded from the homepage of William Nordhaus), annual damages are lower in most of the early periods but higher in later periods of the time horizon than would be calculated using the DICE2007 damage function. Specifically, the percent difference between damages in the base run of DICE2010 and those that would be calculated using the DICE2007 damage function starts at +7 percent in 2005, decreases to a low of -14 percent in 2065, then continuously increases to +20 percent by 2300 (the end of the interagency analysis time horizon), and to +160 percent by the end of the model time horizon in 2595. The large increases in the far future years of the time horizon are due to the permanence associated with damages from sea level rise, along with the assumption that the sea level is projected to continue to rise long after the global average temperature begins to decrease. The changes to the loss function generally decrease the interagency working group SCC estimates slightly, all else equal.

14B.3.2 FUND

FUND version 3.8 includes a number of changes over the previous version 3.5 used in the interagency report. Documentation supporting FUND and the model's source code for all versions of the model is available from the model authors.[g] Notable changes, due to their impact on the estimates of expected SCC, are adjustments to the space heating, agriculture, and sea level rise damage functions in addition to changes to the temperature response function and the inclusion of indirect effects from methane emissions.[h] We discuss each of these in turn.

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[g] 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.

14B.3.2.1 Space Heating

In FUND, the damages associated with the change in energy needs for space heating are based on the estimated impact due to one degree of warming. These baseline damages are scaled based on the forecasted temperature anomaly's deviation from the one degree benchmark and adjusted for changes in vulnerability due to economic and energy efficiency growth. In FUND 3.5, the function that scales the base year damages adjusted for vulnerability allows for the possibility that in some simulations the benefits associated with reduced heating needs may be an unbounded convex function of the temperature anomaly. In FUND 3.8, the form of the scaling has been modified to ensure that the function is everywhere concave, meaning that for every simulation there will exist an upper bound on the benefits a region may receive from reduced space heating needs. The new formulation approaches a value of two in the limit as the temperature anomaly increases, or in other words, assuming no decrease in vulnerability, the reduced expenditures on space heating at any level of warming will not exceed two times the reductions experienced at one degree of warming. Since the reduced need for space heating represents a benefit of climate change in the model, or a negative damage, this change will increase the estimated SCC. This update accounts for a significant portion of the difference in the expected SCC estimates reported by the two versions of the model when run probabilistically.

14B.3.2.2 Sea Level Rise and Land Loss

The FUND model explicitly includes damages associated with the inundation of dry land due to sea level rise. The amount of land lost within a region is dependent upon the proportion of the coastline being protected by adequate sea walls and the amount of sea level rise. In FUND 3.5 the function defining the potential land lost in a given year due to sea level rise is linear in the rate of sea level rise for that year. This assumption implicitly assumes that all regions are well represented by a homogeneous coastline in length and a constant uniform slope moving inland. In FUND 3.8 the function defining the potential land lost has been changed to be a non-linear function of sea level rise, thereby assuming that the slope of the shore line is not constant moving inland, with a positive first derivative. The effect of this change is to typically reduce the vulnerability of some regions to sea level rise based land loss, therefore having an effect of lowering the expected SCC estimate. The model has also been updated to assume that the value of dry land at risk of inundation is not uniform across a region but will be a decreasing function of protection measure, thereby implicitly assuming that the most valuable land will be protected first.

14B.3.2.3 Agriculture

In FUND, the damages associated with the agricultural sector are measured as proportional to the sector's value. The fraction is made up of three additively separable components that represent the effects from carbon fertilization, the rate of temperature change, and the level of the temperature anomaly. In both FUND 3.5 and FUND 3.8, the fraction of the sector's value lost due to the level of the temperature anomaly is modeled as a quadratic function with an intercept of zero. In FUND 3.5, the linear and quadratic coefficients are modeled as the ratio of two normal distributions. Within this specification, as draws from the distribution in the denominator approached zero the share of the sector's value "lost" approaches (+/-) infinity independent of the temperature anomaly itself. In FUND 3.8, the linear and quadratic coefficients are drawn directly from truncated normal distributions so that they remain in the range $[0,\infty)$ and $(-\infty,0]$, respectively, where the means for the new distributions are set equal to the ratio of the means from the normal distributions used in the previous version. In general the impact of this change has been to increase the likelihood that increases in the temperature level will have either larger positive or negative effects on the agricultural sector relative to the previous version (through eliminating simulations in which the "lost" value approached (+/-) infinity). The net effect of this change on the SCC estimates is difficult to predict.

14B.3.2.4 Temperature Response Model

The temperature response model translates changes in global levels of radiative forcing into the current expected temperature anomaly. In FUND, a given year's increase in the cumulative temperature anomaly is based on a mean reverting function where the mean equals the equilibrium temperature anomaly that would eventually be reached if that year's level of radiative forcing were sustained. The rate of mean reversion defines the rate at which the transient temperature approaches the equilibrium. In FUND 3.5, the rate of temperature response is defined as a decreasing linear function of equilibrium climate sensitivity to capture the fact that the progressive heat uptake of the deep ocean causes the rate to slow at higher values of the equilibrium climate sensitivity. In FUND 3.8, the rate of temperature response has been updated to a quadratic function of the equilibrium climate sensitivity. This change reduces the sensitivity of the rate of temperature response to the level of the equilibrium climate sensitivity. Therefore in FUND 3.8, the temperature response will typically be faster than in the previous version. The overall effect of this change is likely to increase estimates of the SCC as higher temperatures are reached during the timeframe analyzed and as the same damages experienced in the previous version of the model are now experienced earlier and therefore discounted less.

14B.3.2.5 Methane

The IPCC notes a series of indirect effects of methane emissions, and has developed methods for proxying such effects when computing the global warming potential of methane (Forster et al. 2007).[8] FUND 3.8 now includes the same methods for incorporating the indirect effects of methane emissions. Specifically, the average atmospheric lifetime of methane has been set to 12 years to account for the feedback of CH4 emissions on its own lifetime. The radiative forcing associated with atmospheric methane has also been increase by 40% to account for its net impact on ozone production and increase in stratospheric water vapor. The general effect of this increased radiative forcing will be to increase the estimated SCC values, where the degree to which this occurs will be dependent upon the relative curvature of the damage functions with respect to the temperature anomaly.

14B.3.3 PAGE

PAGE09 (Hope 2012)[9] includes a number of changes from PAGE2002, the version used in the 2009 SCC interagency report. The changes that most directly affect the SCC estimates include: explicitly modeling the impacts from sea level rise, revisions to the damage function to ensure damages are constrained by GDP, a change in the regional scaling of damages, a revised treatment for the probability of a discontinuity within the damage function, and revised assumptions on adaptation. The model also includes revisions to the carbon cycle feedback and the calculation of regional temperatures. More details on PAGE2009 can be found in three working papers (Hope 2011a, 2011b, 2011c).[10, 11, 12] A description of PAGE2002 can be found in Hope (2006).[13]

14B.3.3.1 Sea Level Rise

While PAGE2002 aggregates all damages into two categories – economic and non-economic impacts - PAGE2009 adds a third explicit category: damages from sea level rise. In the previous version of the model, damages from sea level rise were subsumed by the other damage categories. PAGE09 models damages from sea level rise as increasing less than linearly with sea level based on the assumption that low-lying shoreline areas will be associated with higher damages than current inland areas. Damages from the economic and non-economic sector were adjusted to account for the introduction of this new category.

14B.3.3.2 Revised Damage Function to Account for Saturation

In PAGE09, small initial economic and non-economic benefits (negative damages) are modeled for small temperature increases, but all regions eventually experience positive economic damages from climate change, where damages are the sum of additively separable polynomial functions of temperature and sea level rise. Damages transition from this polynomial function to a logistic path once they exceed a certain proportion of remaining Gross Domestic Product (GDP) to ensure that damages do not exceed 100 percent of GDP. This differs from PAGE2002, which allowed Eastern Europe to potentially experience large benefits from temperature increases, and which also did not bound the possible damages that could be experienced.

14B.3.3.3 Regional Scaling Factors

As in the previous version of PAGE, the PAGE09 model calculates the damages for the European Union (EU) and then, assumes that damages for other regions are proportional based on a given scaling factor. The scaling factor in PAGE09 is based on the length of a region's coastline relative to the EU (Hope 2011b).[11] Because of the long coastline in the EU, other regions are, on average, less vulnerable than the EU for the same sea level and temperature increase, but all regions have a positive scaling factor. PAGE2002 based its scaling factors on four studies reported in the IPCC's third assessment report, and allowed for benefits from temperature increase in Eastern Europe, smaller impacts in developing countries, and higher damages in developing countries.

14B.3.3.4 Probability of a Discontinuity

In PAGE2002, the damages associated with a "discontinuity" were modeled as an expected value. That is, additional damages from an extreme event, such as extreme melting of the Greenland ice sheet, were multiplied by the probability of the event occurring and added to the damage estimate. In PAGE09, the probability of "discontinuity" is treated as a discrete event for each year in the model. The damages for each model run are estimated with or without a discontinuity occurring, rather than as an expected value. A large-scale discontinuity becomes possible when the temperature rises beyond some threshold value between 2 and 4°C. The probability that a discontinuity will occur beyond this threshold then increases by between 10 and 30 percent for every 1°C rise in temperature beyond the threshold. If a discontinuity occurs, the EU loses an additional 5 to 25 percent of its GDP (drawn from a triangular distribution with a mean of 15 percent) in addition to other damages, and other regions lose an amount determined by the regional scaling factor. The threshold value for a possible discontinuity is lower than in PAGE2002, while the rate at which the probability of a discontinuity increases with the temperature anomaly and the damages that result from a discontinuity are both higher than in PAGE2002. The model assumes that only one discontinuity can occur and that the impact is phased in over a period of time, but once it occurs, its effect is permanent.

14B.3.3.5 Adaptation

As in PAGE2002, adaptation is available to increase the tolerable level of temperature change and can help mitigate any climate change impacts that still occur. In PAGE this adaptation is the same regardless of the temperature change or sea level rise and is therefore akin to what is more commonly considered a reduction in vulnerability. It is modeled by modifying the temperature change and sea level rise used in the damage function or by reducing the damages by some percentage. PAGE09 assumes a smaller decrease in vulnerability than the previous version of the model and assumes that it will take longer for this change in vulnerability to be realized. In the aggregated economic sector, at the time of full implementation, this adaptation will mitigate all damages up to a temperature increase of 1°C, and for temperature anomalies between 1°C and 3°C, it will reduce damages by 15-30 percent (depending on the region). However, it takes 20 years to fully implement this adaptation. In PAGE2002, adaptation was assumed to reduce economic sector damages up to 3°C by 50-90 percent after 20 years. Beyond 3°C, no adaptation is assumed to be available to mitigate the impacts of climate change. For the non-economic sector, in PAGE09 adaptation is available to reduce 15 percent of the damages due to a temperature increase between 0°C and 2°C and is assumed to take 40 years to fully implement, instead of 25 percent of the damages over 20 years assumed in PAGE2002. Similarly, adaptation is assumed to alleviate 25-50 percent of the damages from the first 0.20 to 0.25 meters of sea level rise but is assumed to be ineffective thereafter. Hope (2011c)[12] estimates that the less optimistic assumptions regarding the ability to offset impacts of temperature and sea level rise via adaptation increase the SCC by approximately 30 percent.

14B.3.3.6 Other Noteworthy Changes

Two other changes in the model are worth noting. A revised carbon cycle feedback is introduced to simulate decreased CO_2 absorption by the terrestrial biosphere and ocean as the temperature rises. This feedback is linear in the average global and annual temperature anomaly but is capped at a maximum value. In the previous version of PAGE, an additional amount was added to the CO_2 emissions each period to account for a decrease in ocean absorption and a loss of soil carbon. Also updated is the method by which the average global and annual temperature anomaly is downscaled to determine annual average regional temperature anomalies to be used in the regional damage functions. In the previous version of PAGE, the scaling was determined solely based on regional difference in emissions of sulfate aerosols. In PAGE09, this regional temperature anomaly is further adjusted using an additive factor that is based on the average absolute latitude of a region relative to the area weighted average absolute latitude of the Earth's landmass.

14B.4 REVISED SCC ESTIMATES

The updated versions of the three integrated assessment models were run using the same methodology detailed in the 2010 TSD.[1] The approach along with the inputs for the socioeconomic emissions scenarios, equilibrium climate sensitivity distribution, and discount rate remains the same. This includes the five reference scenarios based on the EMF-22 modeling exercise, the Roe and Baker equilibrium climate sensitivity distribution calibrated to the Fourth Assessment Report of the IPCC, and three constant discount rates of 2.5, 3, and 5 percent.

As was previously the case, the use of three models, three discount rates, and five scenarios produces 45 separate distributions for the SCC. The approach laid out in the TSD applied equal weight to each model and socioeconomic scenario in order to reduce the dimensionality down to three separate distributions representative of the three discount rates. The interagency group selected four values from these distributions for use in regulatory analysis. Three values are based on the average SCC across models and socio-economic-emissions scenarios at the 2.5, 3, and 5 percent discount rates, respectively. The fourth value was chosen to represent the higher-than-expected economic impacts from climate change further out in the tails of the SCC distribution. For this purpose, the 95th percentile of the SCC estimates at a 3 percent discount rate was chosen. (A detailed set of percentiles by model and scenario combination is available in the Annex.) As noted in the original TSD, "the 3 percent discount rate is the central value, and so the central value that emerges is the average SCC across models at the 3 percent discount rate" (TSD, p. 25). However, for purposes of capturing the uncertainties involved in regulatory impact analysis, the interagency group emphasizes the importance and value of including all four SCC values.

Table 14B.4.1 shows the four selected SCC estimates in five year increments from 2010 to 2050. Values for 2010, 2020, 2030, 2040, and 2050 are calculated by first combining all outputs (10,000 estimates per model run) from all scenarios and models for a given discount rate. Values for the years in between are calculated using basic linear interpolation. The full set of annual SCC estimates between 2010 and 2050 is reported in the Annex.

Table 14B.4.1 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	11	33	52	90
2015	12	38	58	109
2020	12	43	65	129
2025	14	48	70	144
2030	16	52	76	159
2035	19	57	81	176
2040	21	62	87	192
2045	24	66	92	206
2050	27	71	98	221

The SCC estimates using the updated versions of the models are higher than those reported in the TSD due to the changes to the models outlined in the previous section. Figure 14B.4.2 illustrates where the four SCC values for 2020 fall within the full distribution for each discount rate based on the combined set of runs for each model and scenario (150,000 estimates in total for each discount rate). In general, the distributions are skewed to the right and have long tails. The Figure also shows that the lower the discount rate, the longer the right tail of the distribution.

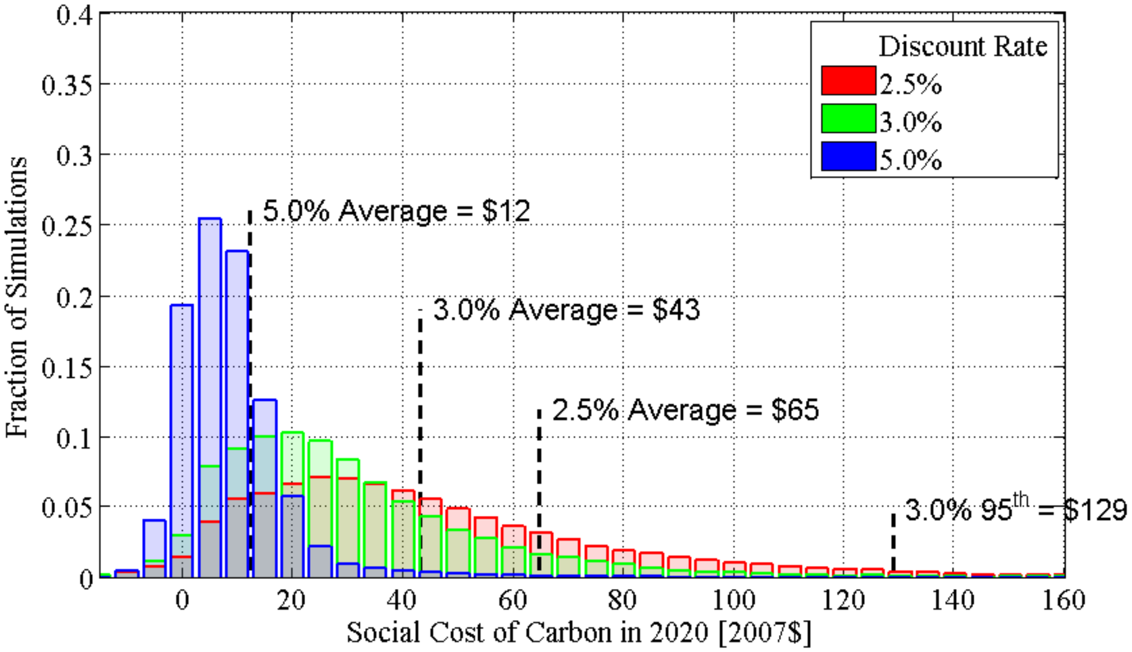

Figure 14B.4.2 Distribution of SCC Estimates for 2020 (in 2007$ per ton CO_2)

As was the case in the original TSD, the SCC increases over time because future emissions are expected to produce larger incremental damages as physical and economic systems become more stressed in response to greater climatic change. The approach taken by the interagency group is to allow the growth rate to be determined endogenously by the models through running them for a set of perturbation years out to 2050. Table 14B.4.2 illustrates how the growth rate for these four SCC estimates varies over time.

Table 14B.4.2 Average Annual Growth Rates of SCC Estimates between 2010 and 2050

Average Annual Rate (%)	5.0% Avg	3.0% Avg	2.5% Avg	3.0% 95th
2010-2020	1.2%	3.2%	2.4%	4.3%
2020-2030	3.4%	2.1%	1.7%	2.4%
2030-2040	3.0%	1.8%	1.5%	2.0%
2040-2050	2.6%	1.6%	1.3%	1.5%

The future monetized value of emission reductions in each year (the SCC in year t multiplied by the change in emissions in year t) must be discounted to the present to determine its total net present value for use in regulatory analysis. As previously discussed in the original TSD, damages from future emissions should be discounted at the same rate as that used to calculate the SCC estimates themselves to ensure internal consistency – *i.e.*, future damages from climate change, whether they result from emissions today or emissions in a later year, should be discounted using the same rate.

14B.5 OTHER MODEL LIMITATIONS OR RESEARCH GAPS

The 2010 interagency SCC technical support report discusses a number of important limitations for which additional research is needed. In particular, the document highlights the need to improve the quantification of both non-catastrophic and catastrophic damages, the treatment of adaptation and technological change, and the way in which inter-regional and inter-sectoral linkages are modeled. It also discusses the need to more carefully assess the implications of risk aversion for SCC estimation as well as the inability to perfectly substitute between climate and non-climate goods at higher temperature increases, both of which have implications for the discount rate used. EPA, DOE, and other agencies continue to engage in long-term research work on modeling and valuation of climate impacts that we expect will inform improvements in SCC estimation in the future.

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ANNEX

Table 14B.5.1 Annual SCC Values: 2010-2050 (2007$/ton CO_2)

Discount Rate	5.0%	3.0%	2.5%	3.0%
Year	Avg	Avg	Avg	95th
2010	11	33	52	90
2011	11	34	54	94
2012	11	35	55	98
2013	11	36	56	102
2014	11	37	57	106
2015	12	38	58	109
2016	12	39	60	113
2017	12	40	61	117
2018	12	41	62	121
2019	12	42	63	125
2020	12	43	65	129
2021	13	44	66	132
2022	13	45	67	135
2023	13	46	68	138
2024	14	47	69	141
2025	14	48	70	144
2026	15	49	71	147
2027	15	49	72	150
2028	15	50	73	153
2029	16	51	74	156
2030	16	52	76	159
2031	17	53	77	163
2032	17	54	78	166
2033	18	55	79	169
2034	18	56	80	172
2035	19	57	81	176
2036	19	58	82	179
2037	20	59	84	182
2038	20	60	85	185
2039	21	61	86	188
2040	21	62	87	192
2041	22	63	88	195
2042	22	64	89	198
2043	23	65	90	200
2044	23	65	91	203
2045	24	66	92	206
2046	24	67	94	209
2047	25	68	95	212
2048	25	69	96	215
2049	26	70	97	218
2050	27	71	98	221

Table 14B.5.2 202 Global SCC Estimates at 2.5 Percent Discount Rate (2007$/ton CO_2)

Percentile	1st	5th	10th	25th	50th	Avg	75th	90th	95th	99th
Scenario					PAGE					
IMAGE	6	11	15	27	58	129	139	327	515	991
MERGE	4	6	9	16	34	78	82	196	317	649
MESSAGE	4	8	11	20	42	108	107	278	483	918
MiniCAM Base	5	9	12	22	47	107	113	266	431	872
5th Scenario	2	4	6	11	25	85	68	200	387	955
Scenario					DICE					
IMAGE	25	31	37	47	64	72	92	123	139	161
MERGE	14	18	20	26	36	40	50	65	74	85
MESSAGE	20	24	28	37	51	58	71	95	109	221
MiniCAM Base	20	25	29	38	53	61	76	102	117	135
5th Scenario	17	22	25	33	45	52	65	91	106	126
Scenario					FUND					
IMAGE	-17	-1	5	17	34	44	59	90	113	176
MERGE	-7	2	7	16	30	35	49	72	91	146
MESSAGE	-19	-4	2	12	27	32	46	70	87	135
MiniCAM Base	-9	1	8	18	35	45	59	87	108	172
5th Scenario	-30	-12	-5	6	19	24	35	57	72	108

Table 14B.5.3 SCC Estimates at 3 Percent Discount Rate (2007$/ton CO2)

Percentile	1st	5th	10th	25th	50th	Avg	75th	90th	95th	99th
Scenario					PAGE					
IMAGE	4	7	10	18	38	91	95	238	385	727
MERGE	2	4	6	11	23	56	58	142	232	481
MESSAGE	3	5	7	13	29	75	74	197	330	641
MiniCAM Base	3	5	8	14	30	73	75	184	300	623
5th Scenario	1	3	4	7	17	58	48	136	264	660
Scenario					DICE					
IMAGE	16	21	24	32	43	48	60	79	90	102
MERGE	10	13	15	19	25	28	35	44	50	58
MESSAGE	14	18	20	26	35	40	49	64	73	83
MiniCAM Base	13	17	20	26	35	39	49	65	73	85
5th Scenario	12	15	17	22	30	34	43	58	67	79
Scenario					FUND					
IMAGE	-14	-3	1	9	20	25	35	54	69	111
MERGE	-8	-1	3	9	18	22	31	47	60	97
MESSAGE	-16	-5	-1	6	16	18	28	43	55	88
MiniCAM Base	-9	-1	3	10	21	27	35	53	67	107
5th Scenario	-22	-10	-5	2	10	13	20	33	42	63

Table 14B.5.4 2020 Global SCC Estimates at 5 Percent Discount Rate (2007$/ton CO_2)

Percentile	1st	5th	10th	25th	50th	Avg	75th	90th	95th	99th
Scenario	PAGE									
IMAGE	1	2	2	5	10	28	27	71	123	244
MERGE	1	1	2	3	7	17	17	45	75	153
MESSAGE	1	1	2	4	9	24	22	60	106	216
MiniCAM Base	1	1	2	3	8	21	21	54	94	190
5th Scenario	0	1	1	2	5	18	14	41	78	208

Scenario	DICE									
IMAGE	6	8	9	11	14	15	18	22	25	27
MERGE	4	5	6	7	9	10	12	15	16	18
MESSAGE	6	7	8	10	12	13	16	20	22	25
MiniCAM Base	5	6	7	8	11	12	14	18	20	22
5th Scenario	5	6	6	8	10	11	14	17	19	21

Scenario	FUND									
IMAGE	-9	-5	-3	-1	2	3	6	11	15	25
MERGE	-6	-3	-2	0	3	4	7	12	16	27
MESSAGE	-10	-6	-4	-1	2	2	5	9	13	23
MiniCAM Base	-7	-3	-2	0	3	4	7	11	15	26
5th Scenario	-11	-7	-5	-2	0	0	3	6	8	14

CHAPTER 15. UTILITY IMPACT ANALYSIS

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CHAPTER 15. UTILITY IMPACT ANALYSIS

15.1 INTRODUCTION

In the utility impact analysis, the U.S. Department of Energy (DOE) analyzes the changes in electric installed capacity and power generation that result for each trial standard level (TSL).

The utility impact analysis is based on output of the DOE/Energy Information Administration (EIA)'s National Energy Modeling System (NEMS).[a] NEMS is a public domain, multi-sectored, partial equilibrium model of the U.S. energy sector. Each year, DOE/EIA uses NEMS to produce an energy forecast for the United States, the Annual Energy Outlook (AEO). The EIA publishes a reference case, which incorporates all existing energy-related policies at the time of publication, and a variety of side cases which analyze the impact of different policies, energy price and market trends. As of 2014, DOE is using a new methodology based on results published for the *Annual Energy Outlook 2014 (AEO 2014)* Reference case and a set of side cases that implement a variety of efficiency-related policies.[2]

The new approach retains key aspects of DOE's previous methodology, and provides some improvements:

- The assumptions used in the AEO reference case and side cases are fully documented and receive detailed public scrutiny.
- NEMS is updated each year, with each edition of the AEO, to reflect changes in energy prices, supply trends, regulations, *etc.*
- The comprehensiveness of NEMS permits the modeling of interactions among the various energy supply and demand sectors.
- Using EIA published side cases to estimate the utility impacts enhances the transparency of DOE's analysis.
- The variability in impacts estimates from one edition of AEO to the next will be reduced under the new approach.

On the average, however, over the full analysis period, the results from the new approach are comparable to results from the old approach.

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[a] For more information on NEMS, refer to the U.S. Department of Energy, Energy Information Administration documentation. A useful summary is *National Energy Modeling System: An Overview*.[1]

15.2 METHODOLOGY

DOE estimates the marginal impacts of reduction in energy demand on the energy supply sector. In principle, marginal values should provide a better estimate of the actual impact of energy conservation standards.

NEMS uses predicted growth in demand for each end use to build up a projection of the total electric system load growth. The system load shapes are converted internally to load duration curves, which are then used to estimate the most cost-effective additions to capacity. When electricity demand deviates from the AEO reference case, in general there are three inter-related effects: the annual generation (TWh) from the stock of electric generating capacity changes, the total generation capacity itself (GW) may change, and the mix of capacity by fuel type may change. Each of these effects can vary for different types of end use. The change in total generating capacity is sensitive to the degree to which the end-use is peak coincident, while the capacity mix is sensitive to the hourly load shape associated with the end use. Changes in generation by fuel type lead in turn to changes in total power sector emissions of SO_2, NO_x, Hg and CO_2.

DOE's new approach examines a series of AEO side cases to estimate the relationship between demand reductions and the marginal energy, emissions and capacity changes. The assumptions for each side case are documented in Appendix E of the AEO. The side cases, or scenarios, that incorporate significant changes to equipment efficiencies relative to the Reference case are:

- 2013 Technology (leaves all technologies at 2013 efficiencies);
- Best Available Technology (highest efficiency irrespective of cost);
- High Technology (higher penetration rates for efficiency and demand management);
- Extended Policies (includes efficiency standards that are not in the reference).

Scenarios that incorporate policies that directly affect the power sector without changes in energy demand (for example, subsidies for renewables, or high fuel price assumptions) are not appropriate for this analysis. The methodology proceeds in seven steps:

1. Supply-side data on generation, capacity and emissions, and demand-side data on electricity use by sector and end-use, are extracted from each side case. The data are converted to differences relative to the AEO Reference case.

2. The changes in electricity use on the demand-side data are allocated to one of three categories: on-peak, shoulder, and off-peak. These categories are used in the utility sector to correlate end-use consumption with supply types. For each of the end-uses that are modeled explicitly in NEMS, load shape information is used to identify the fraction of annual electricity use assigned to each category. On-peak hours are defined as noon-5pm, June through September. Off-peak hours are nights and Sundays. All other hours are assigned to the shoulder period.

3. For each year and each side case, the demand-side reductions to on-peak, off-peak and shoulder-period electricity use are matched on the supply-side to reductions in generation by fuel type. The fuel types are petroleum fuels, natural gas, renewables, nuclear and coal. The allocation is based on the following rules:
    - 3.1. All petroleum-based generation is allocated to peak periods;
    - 3.2. Natural gas generation is allocated to any remaining peak reduction; this is consistent with the fact that oil and gas steam units are used in NEMS to meet peak demand;
    - 3.3. Base-load generation (nuclear and coal) is allocated proportionally to all periods;
    - 3.4. The remaining generation of all types is allocated to the remaining off-peak and shoulder reductions proportionally.

4. The output of step 3 defines fuel-share weights giving the fraction of energy demand in each load category that is met by each fuel type as a function of time. These are combined with the weights that define the load category shares by end-use to produce coefficients that allocate a marginal reduction in end-use electricity demand to each of the five fuel types.

5. A regression model is used to relate reductions in generation by fuel type to reductions in emissions of power sector pollutants. The model produces coefficients that define the change in total annual emissions of a given pollutant resulting from a unit change in total annual generation for each fuel type, as a function of time. These coefficients are combined with the weights calculated in step 4 to produce coefficients that relate emissions changes to changes in end-use demand.

6. A regression model is used to relate reductions in generation by fuel type to reductions in installed capacity. The categories used for installed capacity are the same as for generation except for peak: NEMS uses two peak capacity types (combustion turbine/diesel and oil and gas steam) which are combined here into a single "peak" category. The model produces coefficients that define the change in total installed capacity of a given type resulting from a unit change in total annual generation for the corresponding fuel type. These coefficients are combined with the weights calculated in step 4 to produce coefficients that relate installed capacity changes to changes in end-use demand, as a function of time.

7. The coefficient time-series for fuel share, pollutant emissions and capacity for the appropriate end use are multiplied by the stream of energy savings calculated in the NIA to produce estimates of the utility impacts.

This analysis ignores pumped storage, fuel cells and distributed generation, as these generation types are not affected by the policy changes modeled in the EIA side cases. The methodology is described in more detail in K. Coughlin, "Utility Sector Impacts of Electricity Demand Reductions".[3]

15.3 UTILITY IMPACT RESULTS

This section presents results of the analysis for all of the capacity types under the trial standard levels for potential AFUE standards and standby mode and off mode standards for non-weatherized gas furnaces (NWGFs) and mobile home gas furnaces (MHGFs). Electricity use increases under the considered TSLs for AFUE standards because of switching to electric heating systems, which leads to increase in installed capacity and in electricity generation.

15.3.1 Installed Capacity

Figure 15.3.1 through Figure 15.3.6 show the changes in U.S. electricity installed capacity that result for each AFUE TSL by major plant type for selected years. Figure 15.3.7 through Figure 15.3.12 present the same results for standby mode and off mode TSLs. Note that a negative number means an increase in capacity under a TSL.

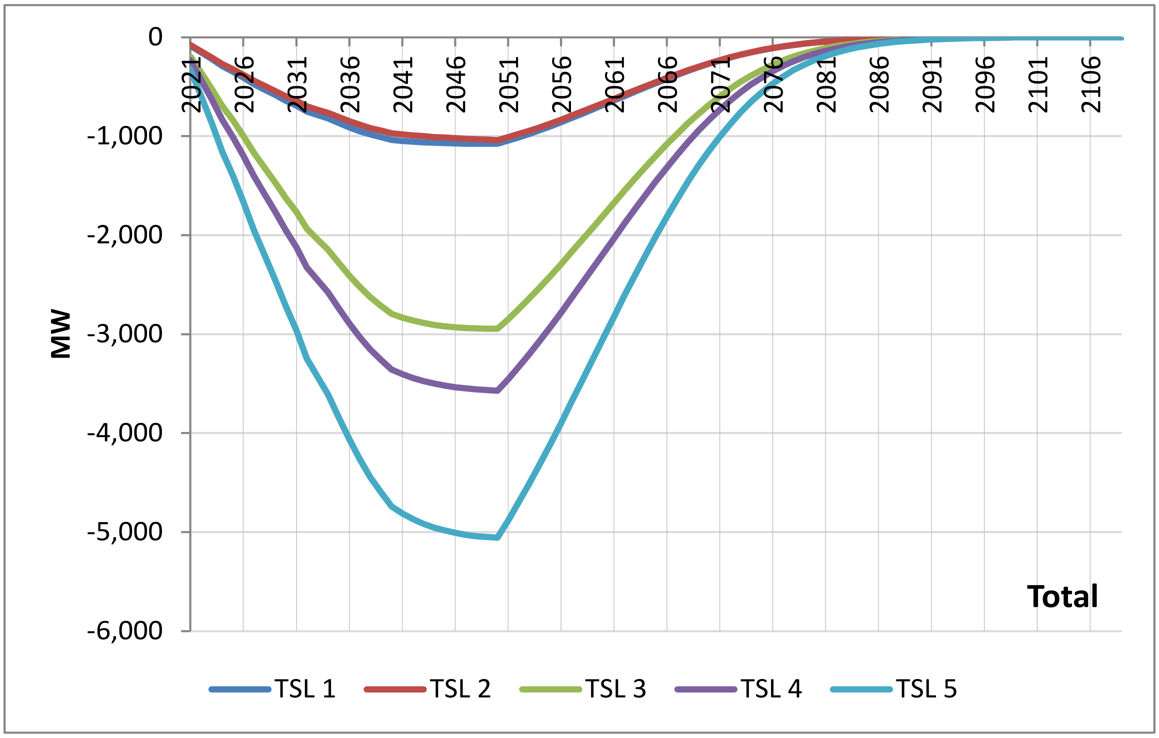

Figure 15.3.1 **Total Electric Capacity Reduction for Non-Weatherized Gas Furnaces and Mobile Home Gas Furnaces AFUE Trial Standard Levels**

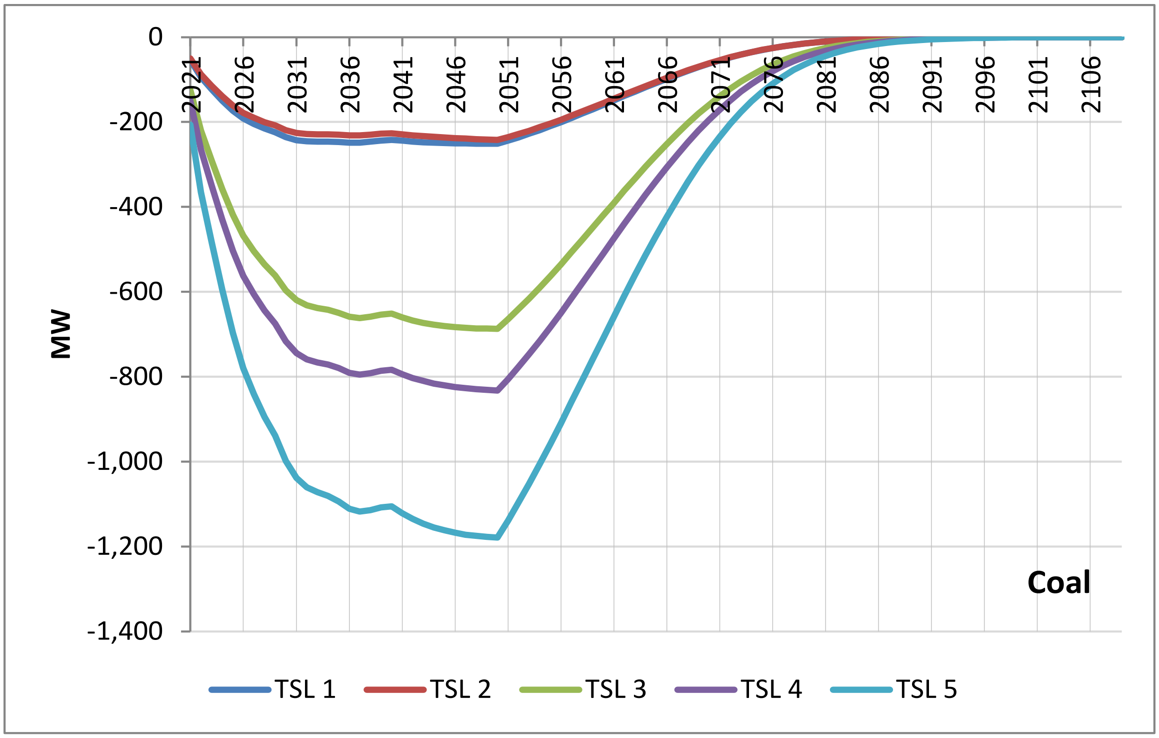

Figure 15.3.2 Coal Capacity Reduction for Non-Weatherized Gas Furnaces and Mobile Home Gas Furnaces AFUE Trial Standard Levels

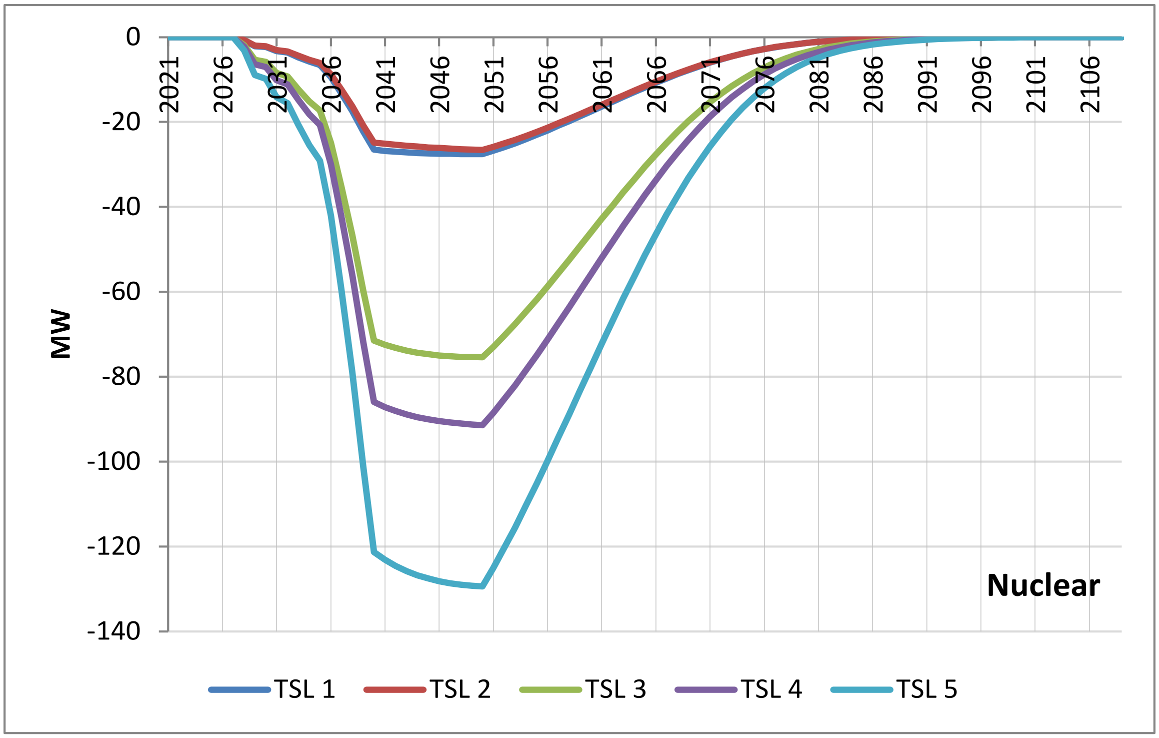

Figure 15.3.3 Nuclear Capacity Reduction for Non-Weatherized Gas Furnaces and Mobile Home Gas Furnaces AFUE Trial Standard Levels

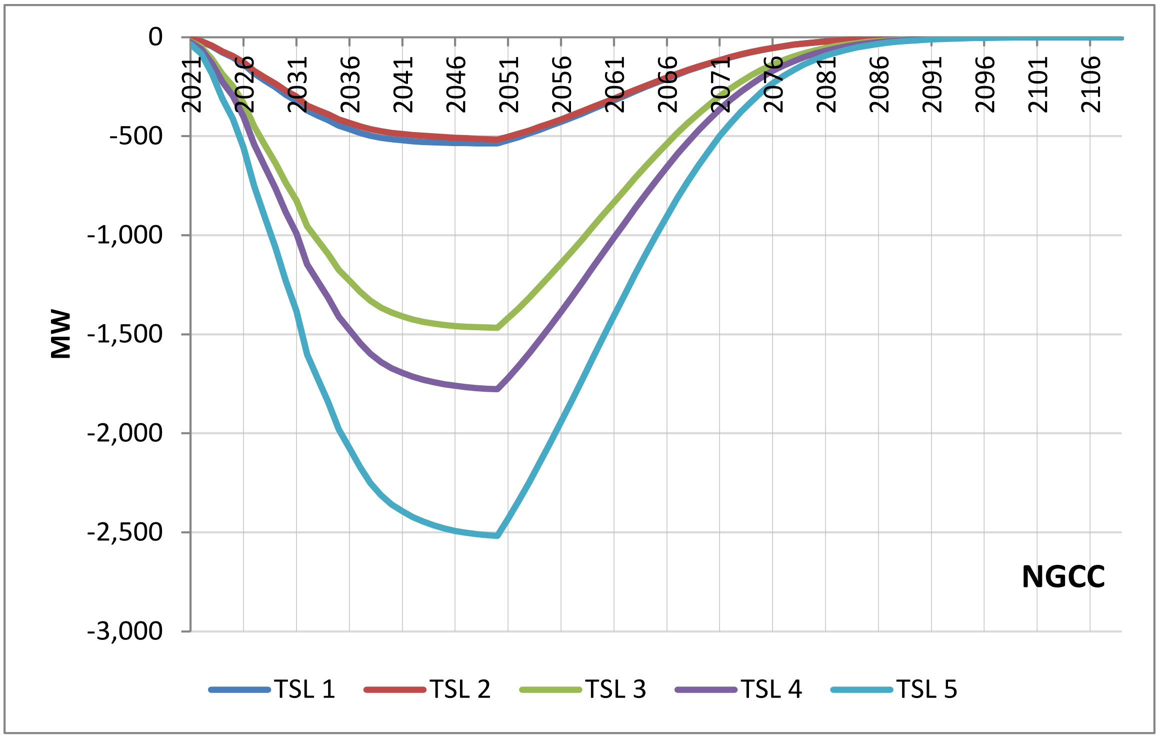

Figure 15.3.4 Gas Combined Cycle Capacity Reduction for Non-Weatherized Gas Furnaces and Mobile Home Gas Furnaces AFUE Trial Standard Levels

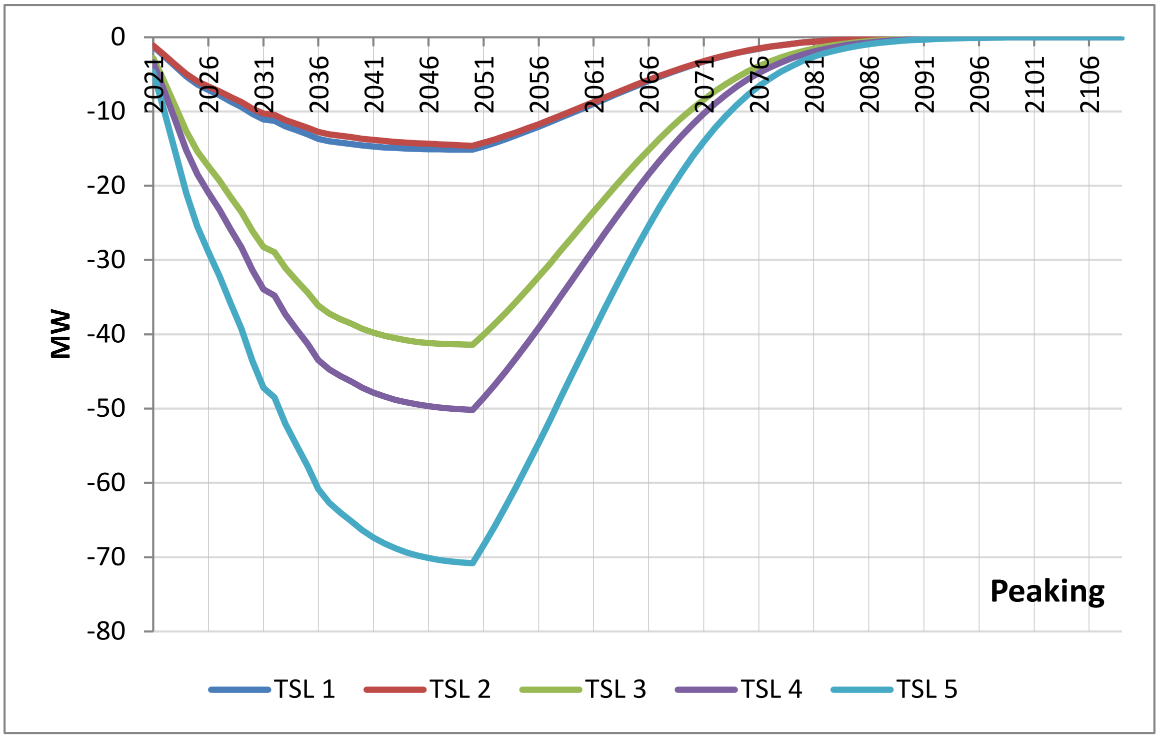

Figure 15.3.5 Peaking Capacity Reduction for Non-Weatherized Gas Furnaces and Mobile Home Gas Furnaces AFUE Trial Standard Levels

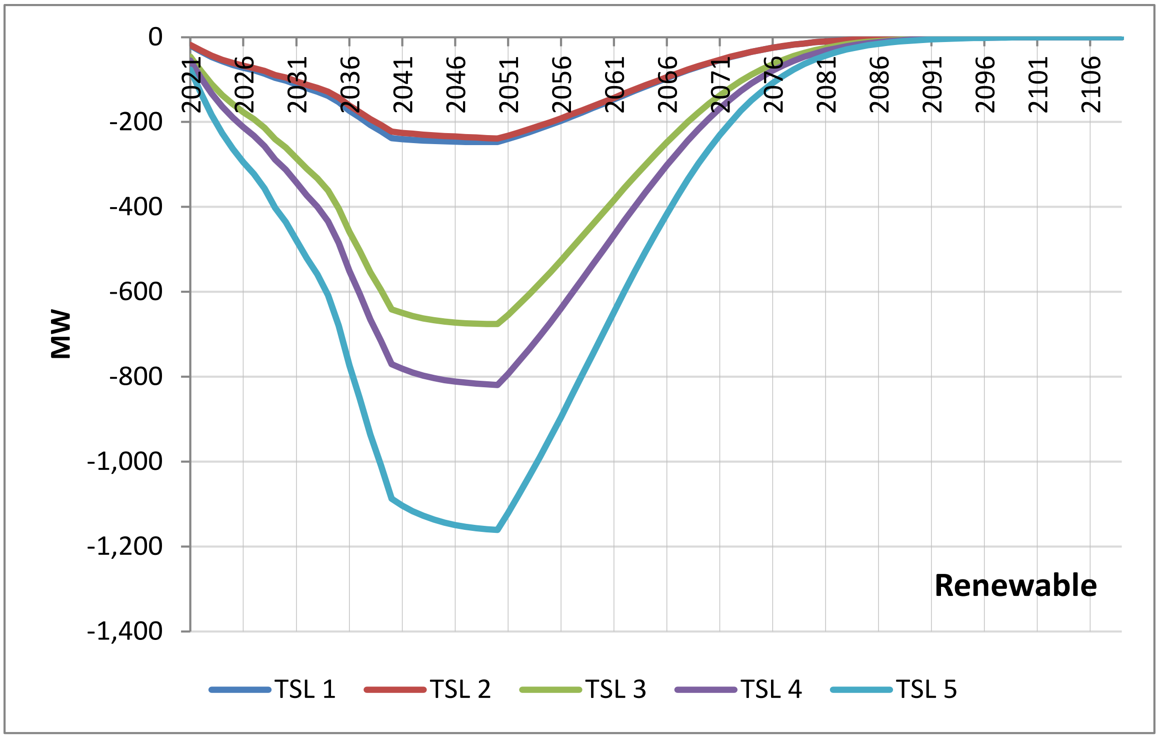

Figure 15.3.6 Renewables Capacity Reduction for Non-Weatherized Gas Furnaces and Mobile Home Gas Furnaces AFUE Trial Standard Levels

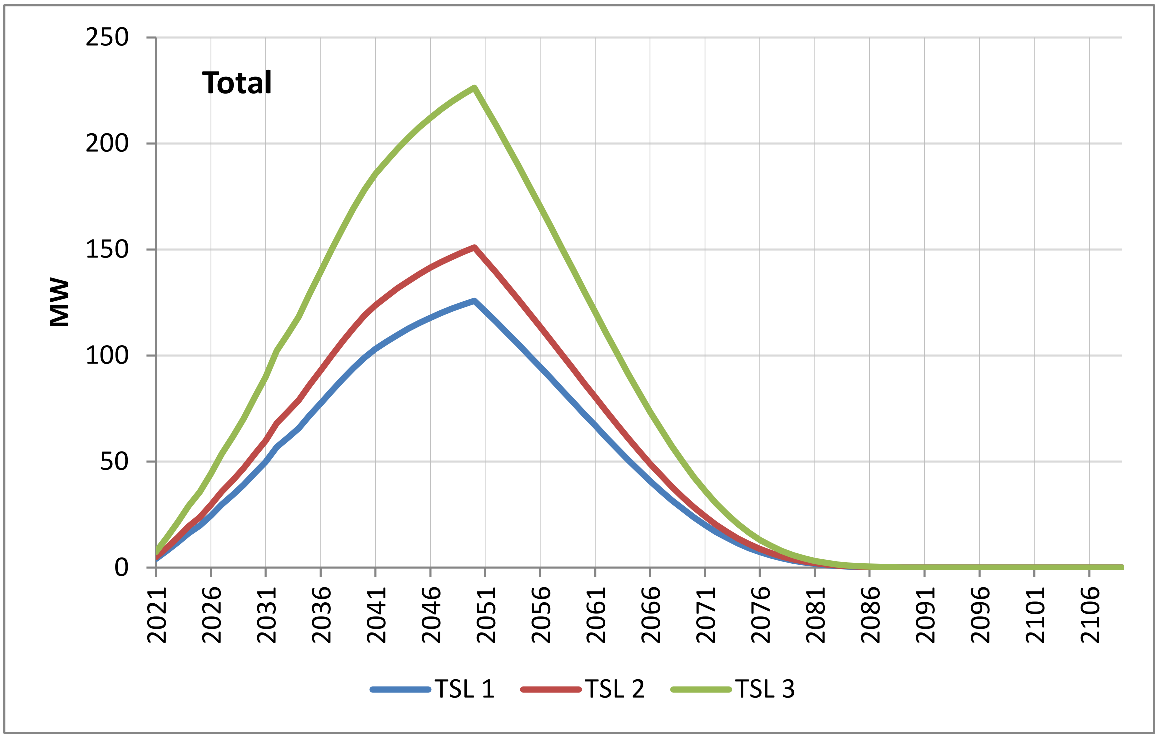

Figure 15.3.7 Total Electric Capacity Reduction for Non-Weatherized Gas Furnaces and Mobile Home Gas Furnaces Standby and Off Mode Trial Standard Levels

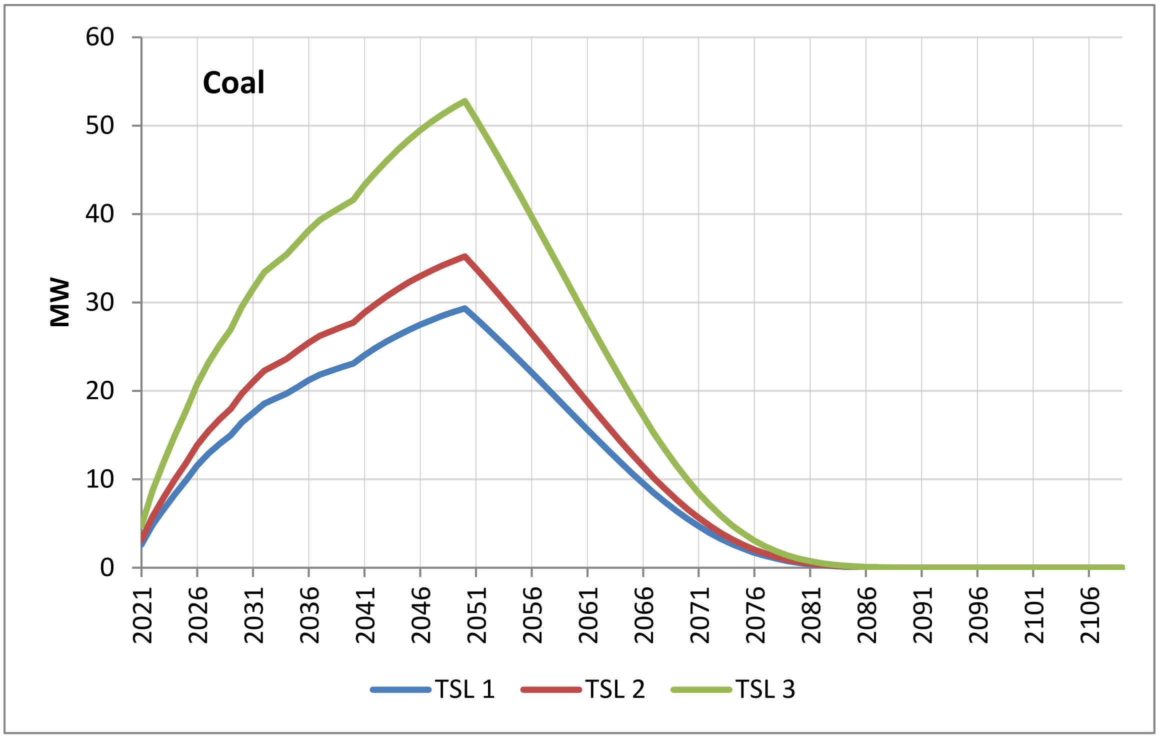

Figure 15.3.8 Coal Capacity Reduction for Non-Weatherized Gas Furnaces and Mobile Home Gas Furnaces Standby and Off Mode Trial Standard Levels

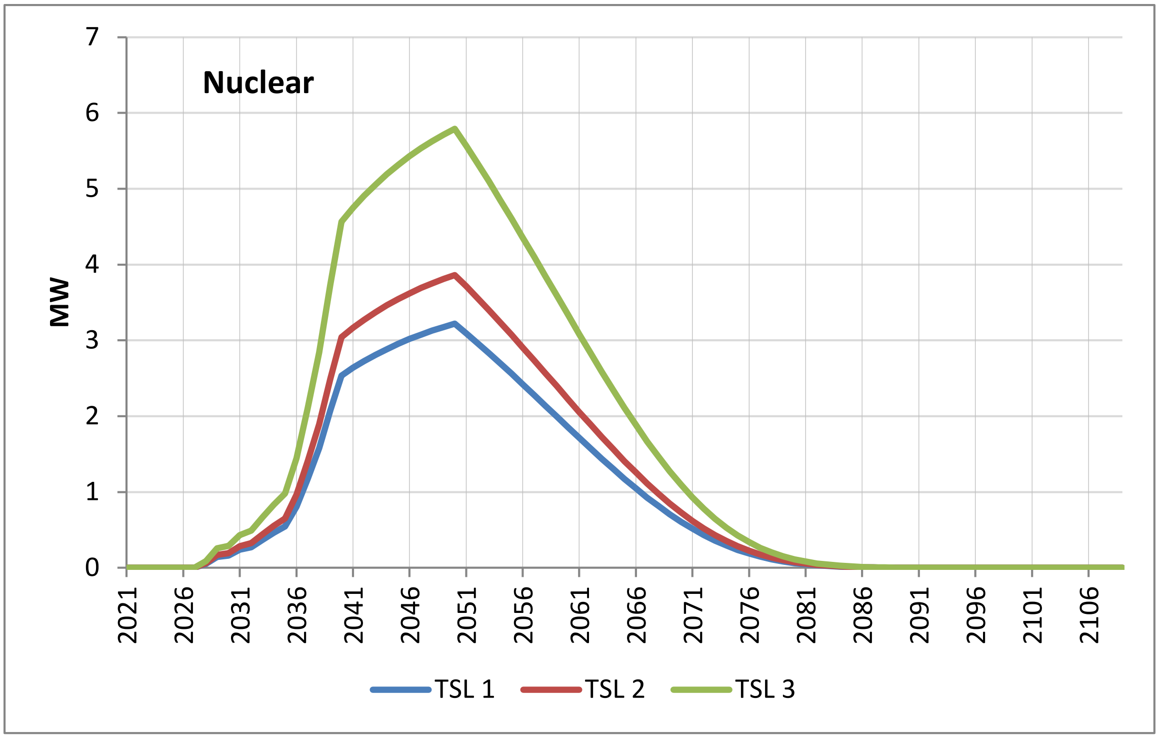

Figure 15.3.9 Nuclear Capacity Reduction for Non-Weatherized Gas Furnaces and Mobile Home Gas Furnaces Standby and Off Mode Trial Standard Levels

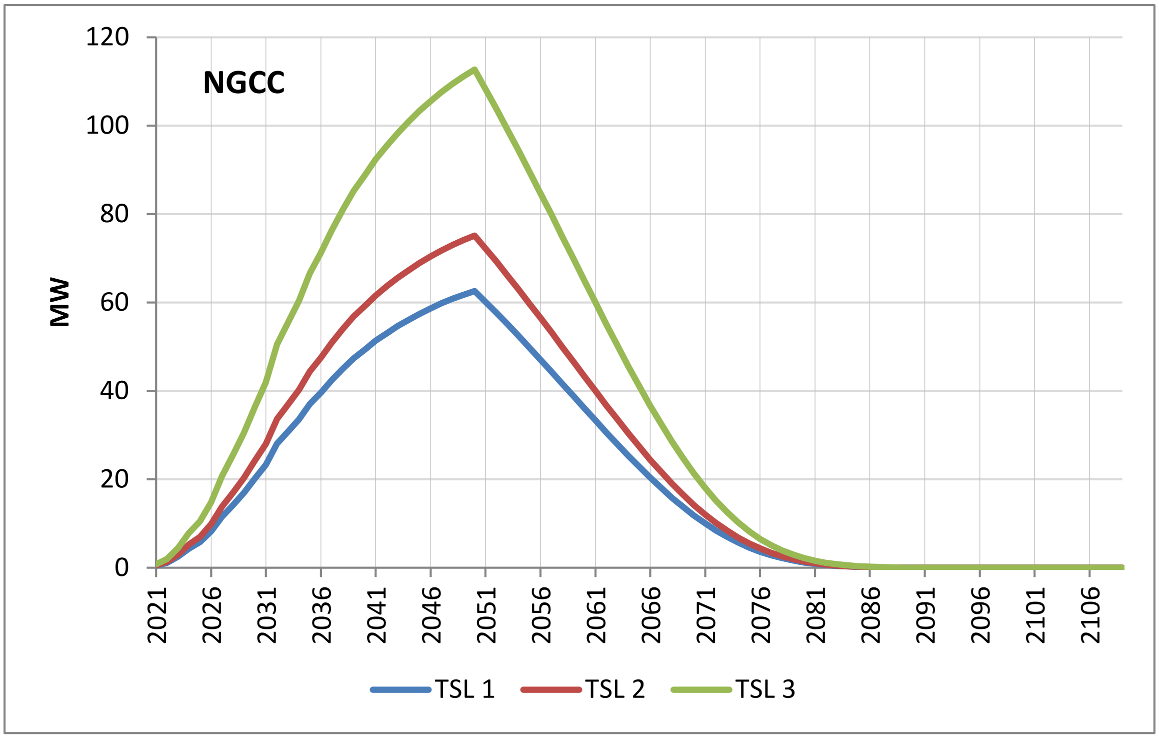

Figure 15.3.10 Gas Combined Cycle Capacity Reduction for Non-Weatherized Gas Furnaces and Mobile Home Gas Furnaces Standby and Off Mode TSLs

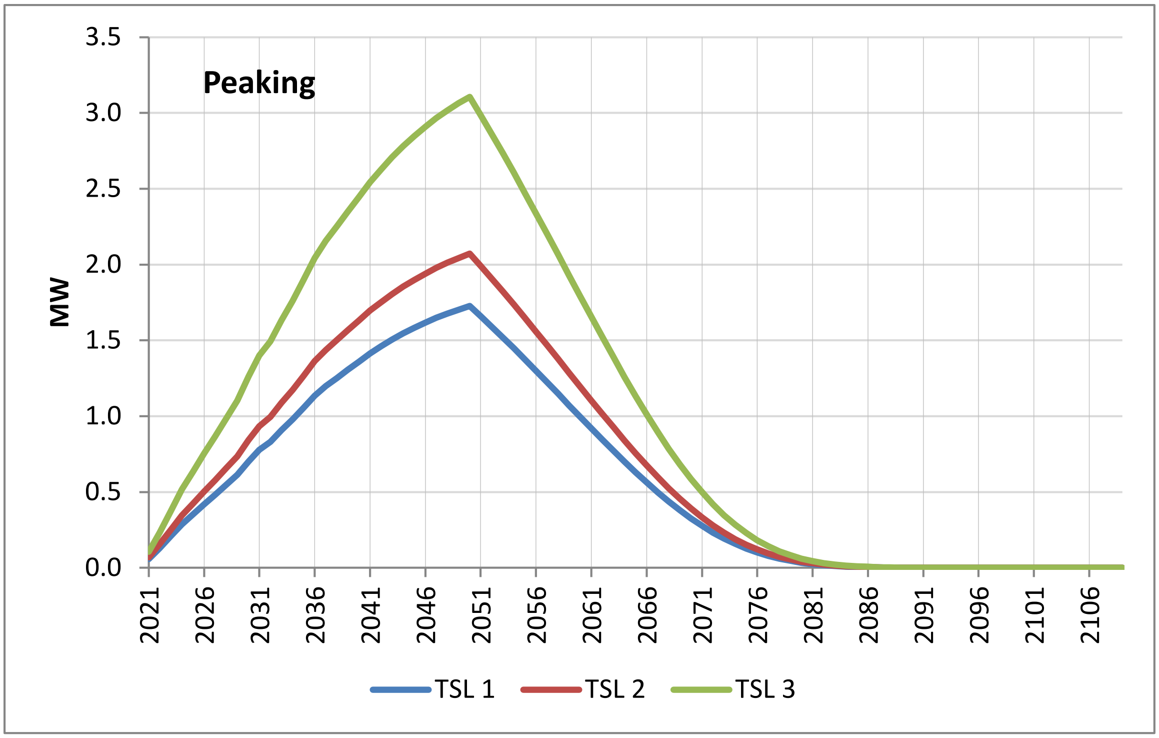

Figure 15.3.11 Peaking Capacity Reduction for Non-Weatherized Gas Furnaces and Mobile Home Gas Furnaces Standby and Off Mode Trial Standard Levels

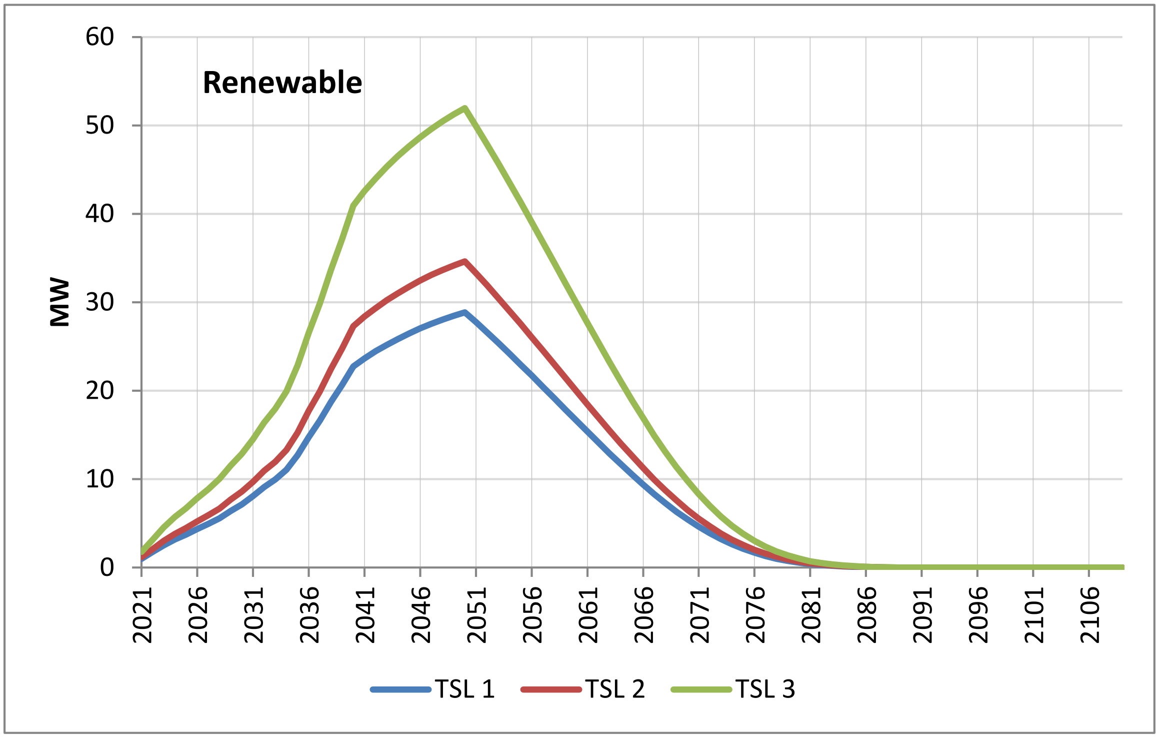

Figure 15.3.12 Renewables Capacity Reduction for Non-Weatherized Gas Furnaces and Mobile Home Gas Furnaces Standby and Off Mode Trial Standard Levels

15.3.2 Electricity Generation

The figures in this section show the annual change in electricity generation that result for each TSL by fuel type. Figure 15.3.13 through Figure 15.3.18 present results for each AFUE TSL, and Figure 15.3.19 through Figure 15.3.24 present the same results for the standby mode and off mode TSLs. Note that a negative number means an increase in generation under a TSL.

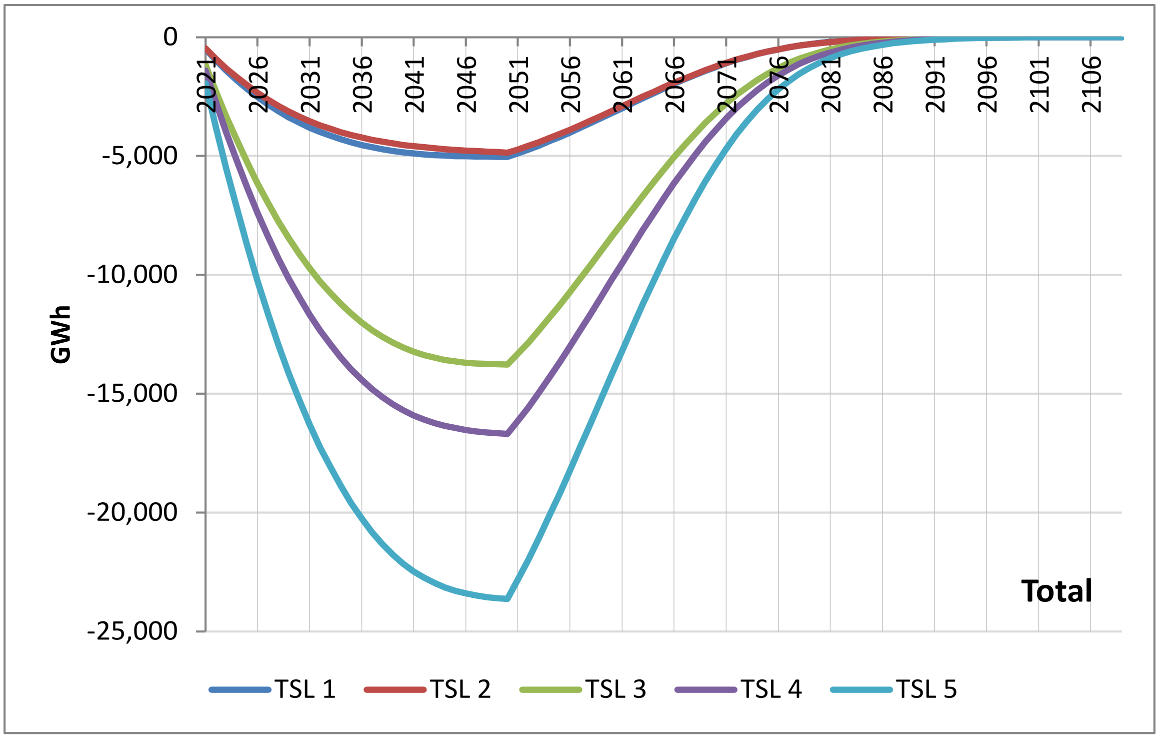

Figure 15.3.13 Total Generation Reduction for Non-Weatherized Gas Furnaces and Mobile Home Gas Furnaces AFUE Trial Standard Levels

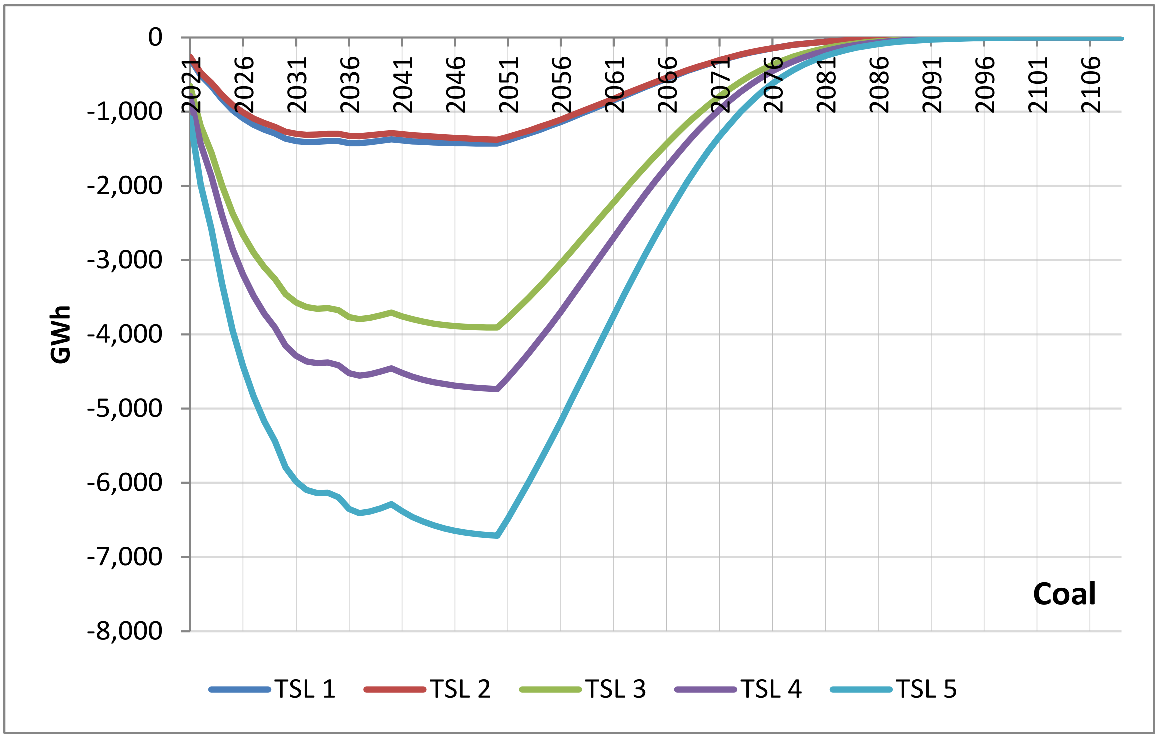

Figure 15.3.14 Coal Generation Reduction for Non-Weatherized Gas Furnaces and Mobile Home Gas Furnaces AFUE Trial Standard Levels

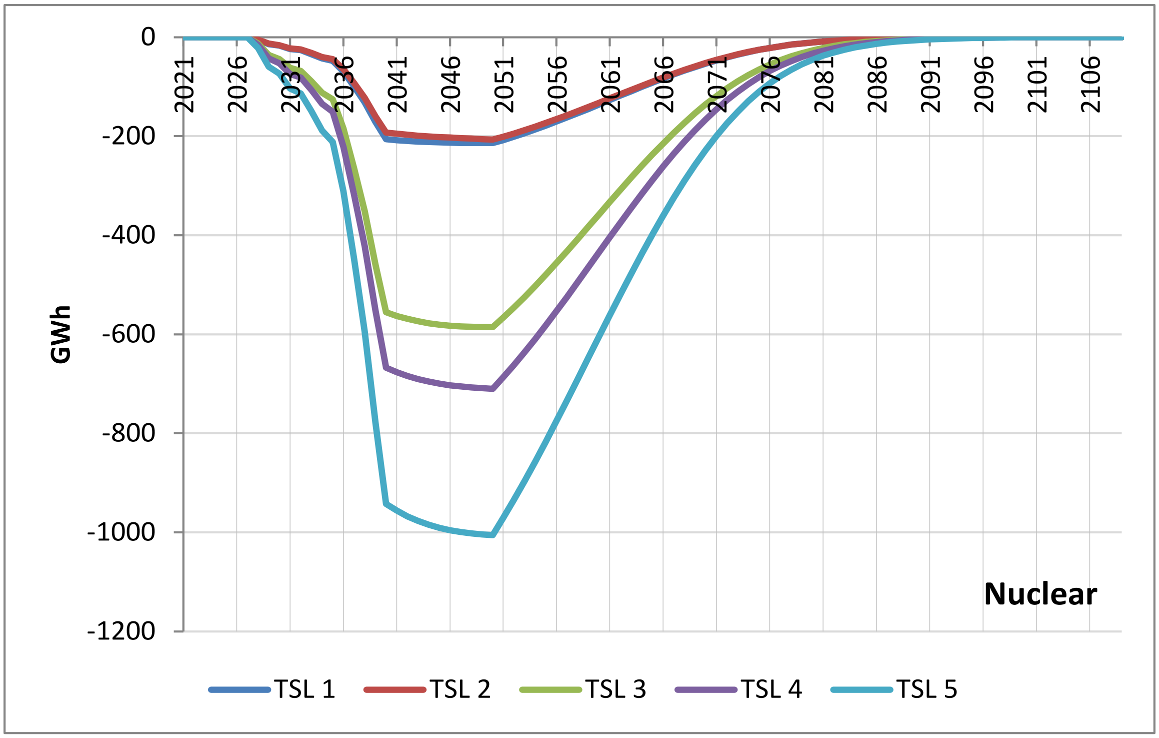

Figure 15.3.15 Nuclear Generation Reduction for Non-Weatherized Gas Furnaces and Mobile Home Gas Furnaces AFUE Trial Standard Levels

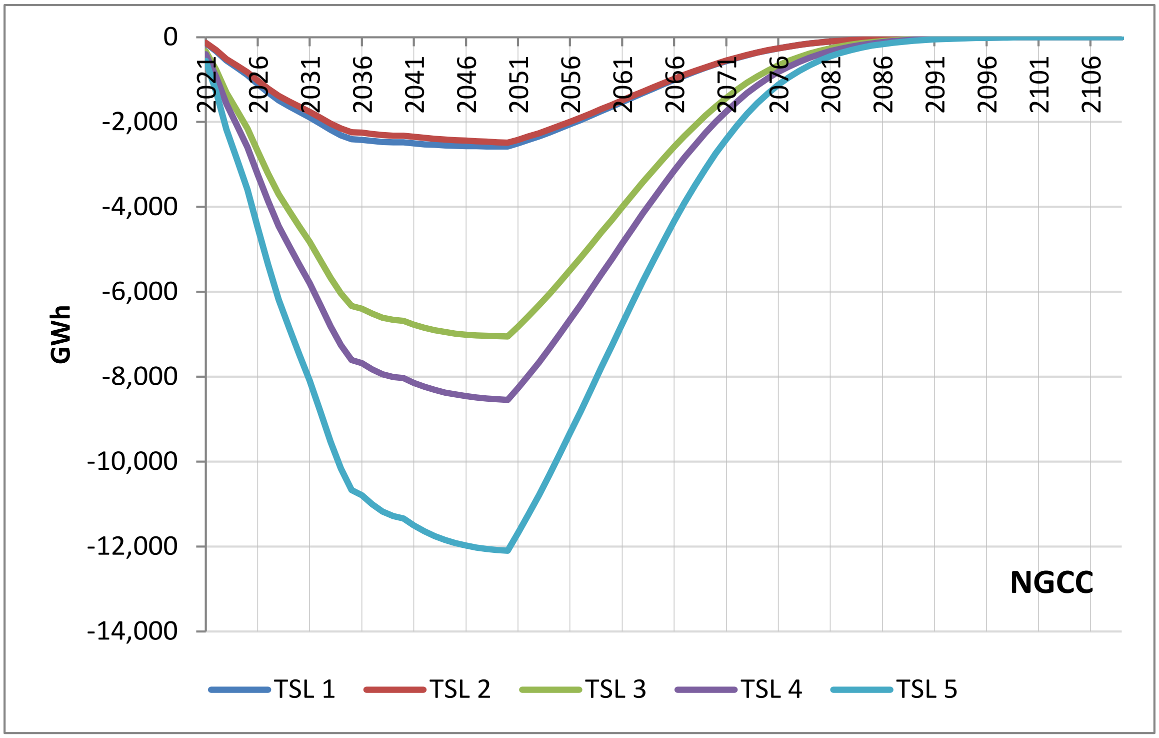

Figure 15.3.16 Gas Combined Cycle Generation Reduction for Non-Weatherized Gas Furnaces and Mobile Home Gas Furnaces AFUE Trial Standard Levels

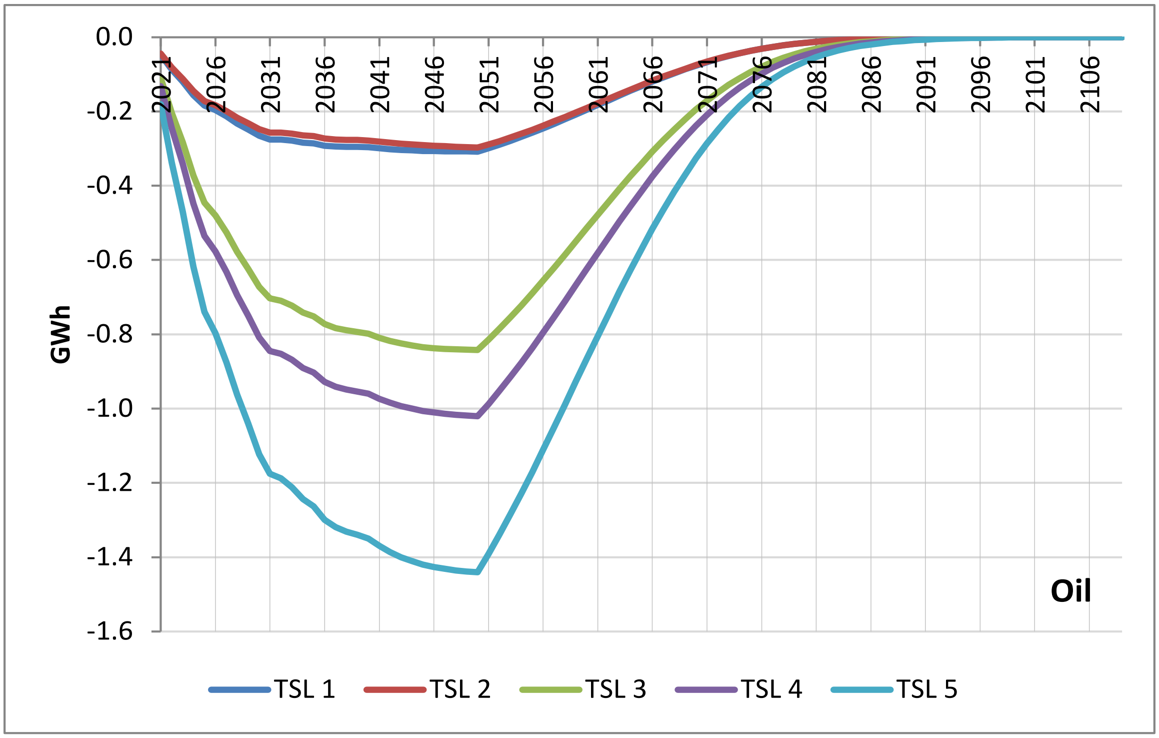

Figure 15.3.17 Oil Generation Reduction for Non-Weatherized Gas Furnaces and Mobile Home Gas Furnaces AFUE Trial Standard Levels

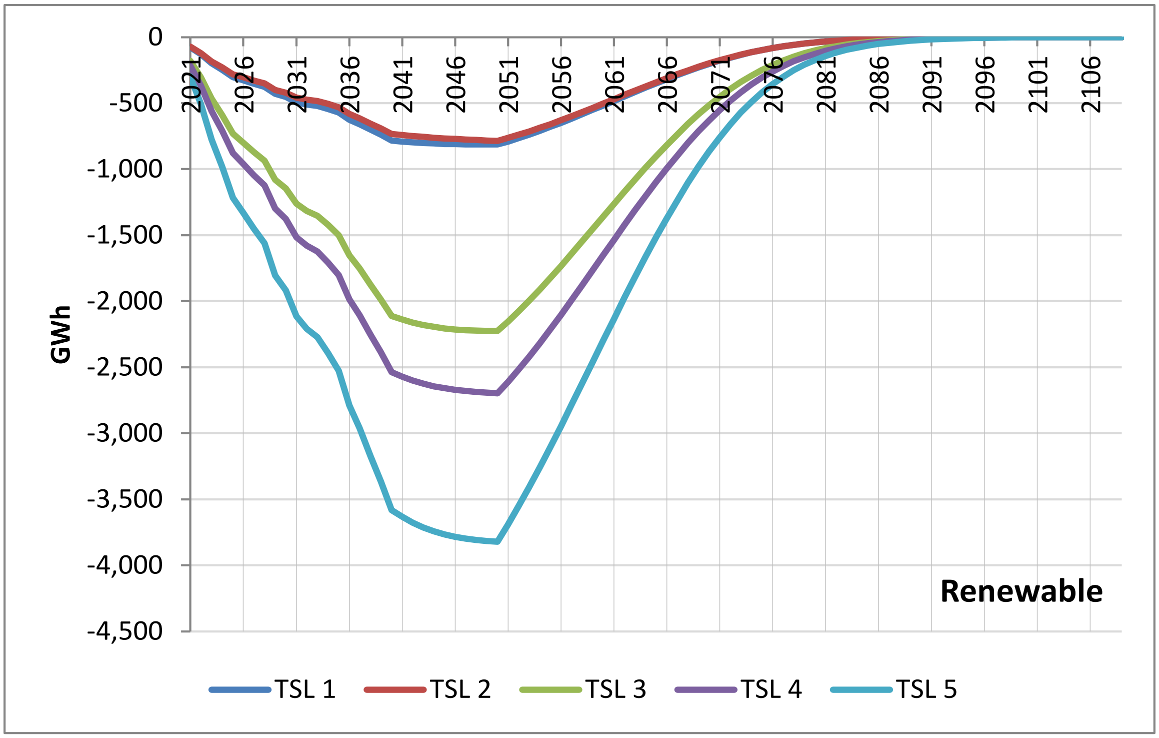

Figure 15.3.18 Renewables Generation Reduction for Non-Weatherized Gas Furnaces and Mobile Home Gas Furnaces AFUE Trial Standard Levels

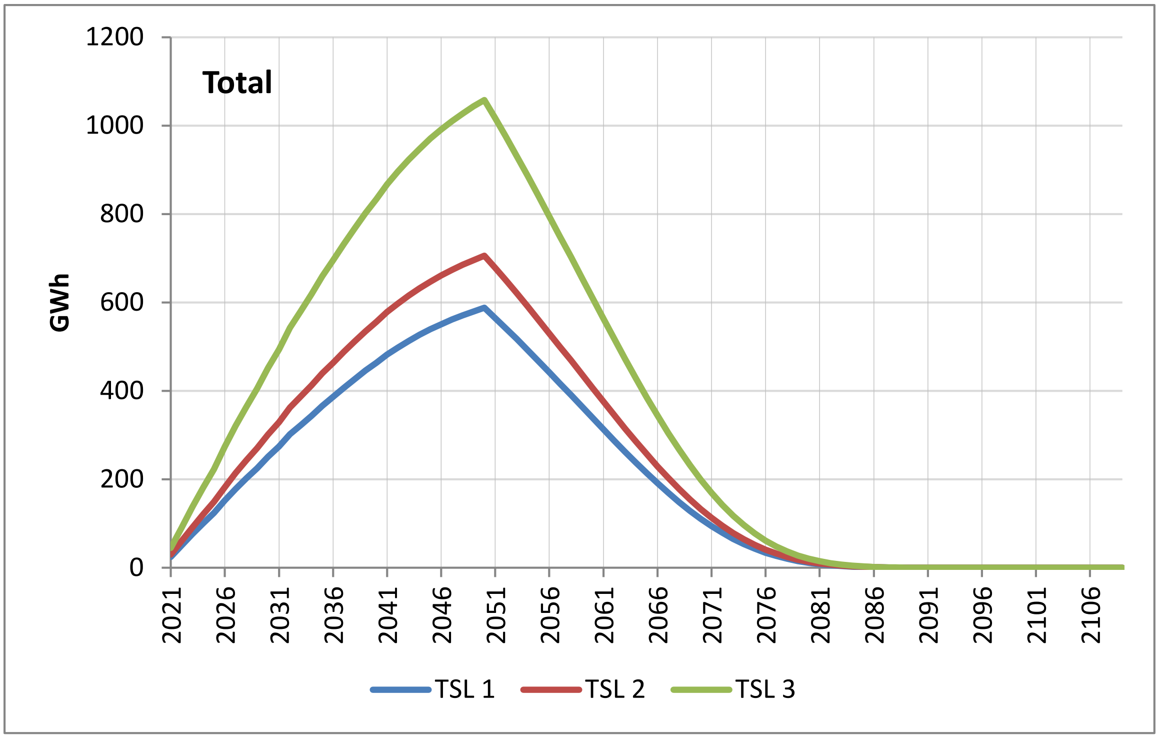

Figure 15.3.19 Total Generation Reduction for Non-Weatherized Gas Furnaces and Mobile Home Gas Furnaces Standby and Off Mode Trial Standard Levels

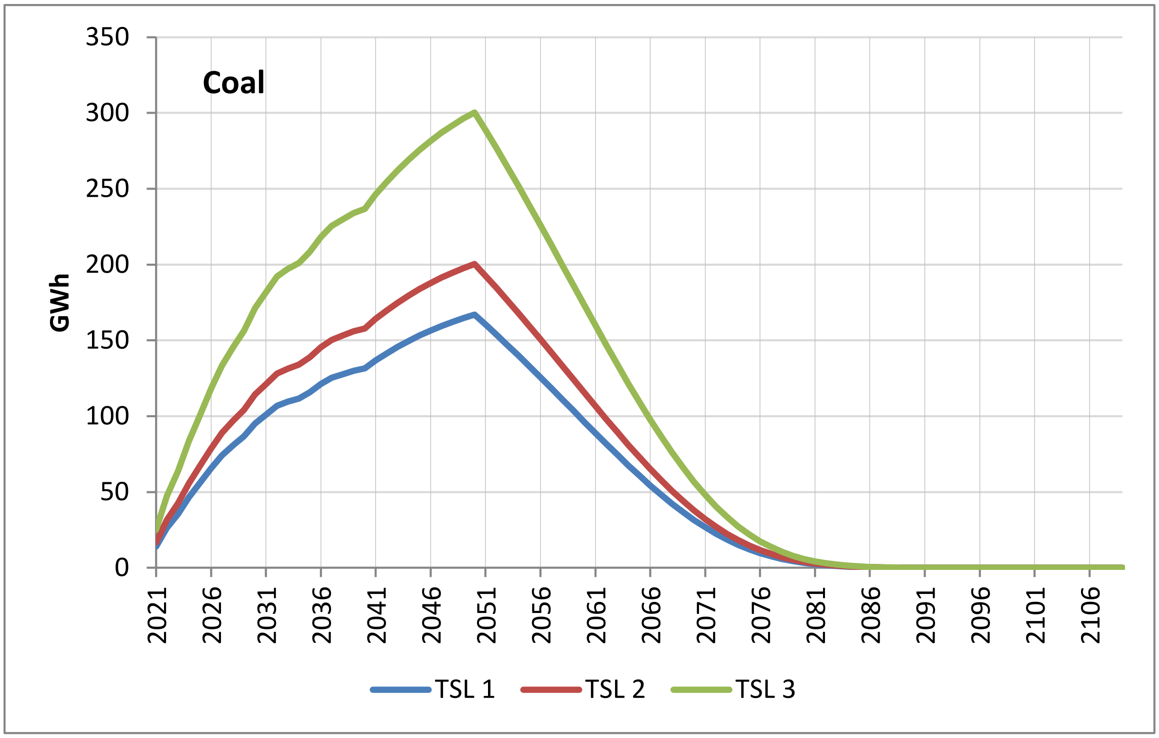

Figure 15.3.20 Coal Generation Reduction for Non-Weatherized Gas Furnaces and Mobile Home Gas Furnaces Standby and Off Mode Trial Standard Levels

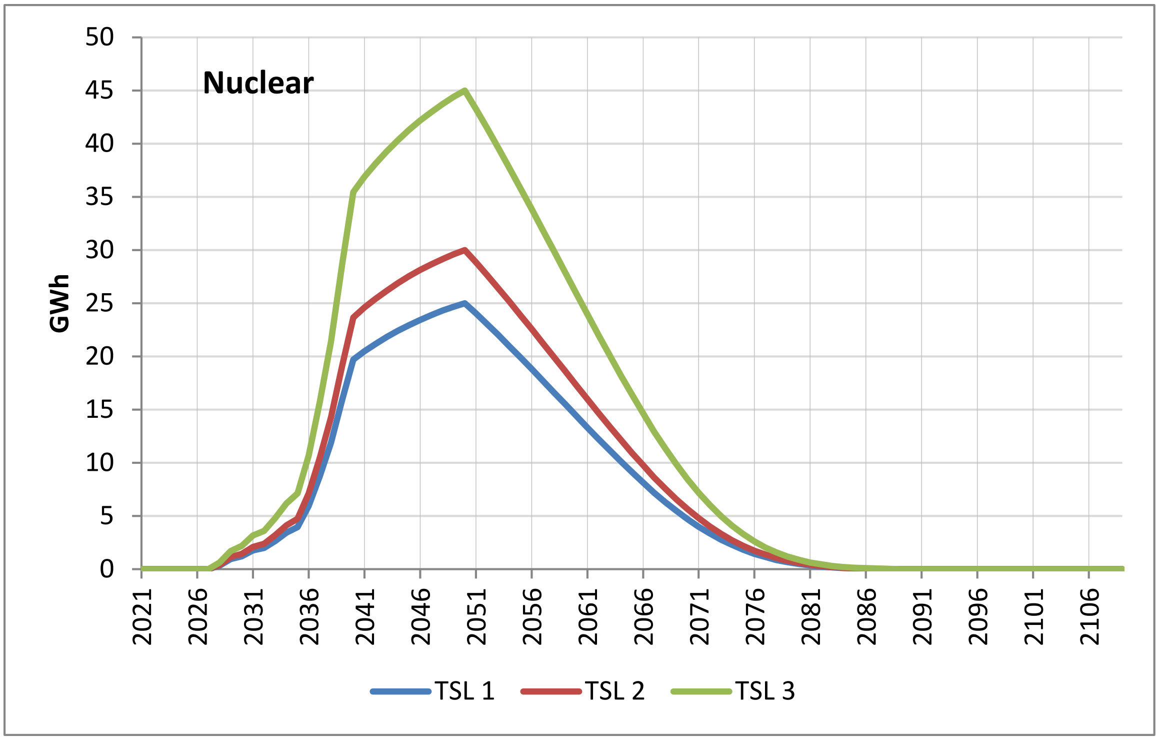

Figure 15.3.21 Nuclear Generation Reduction for Non-Weatherized Gas Furnaces and Mobile Home Gas Furnaces Standby and Off Mode Trial Standard Levels

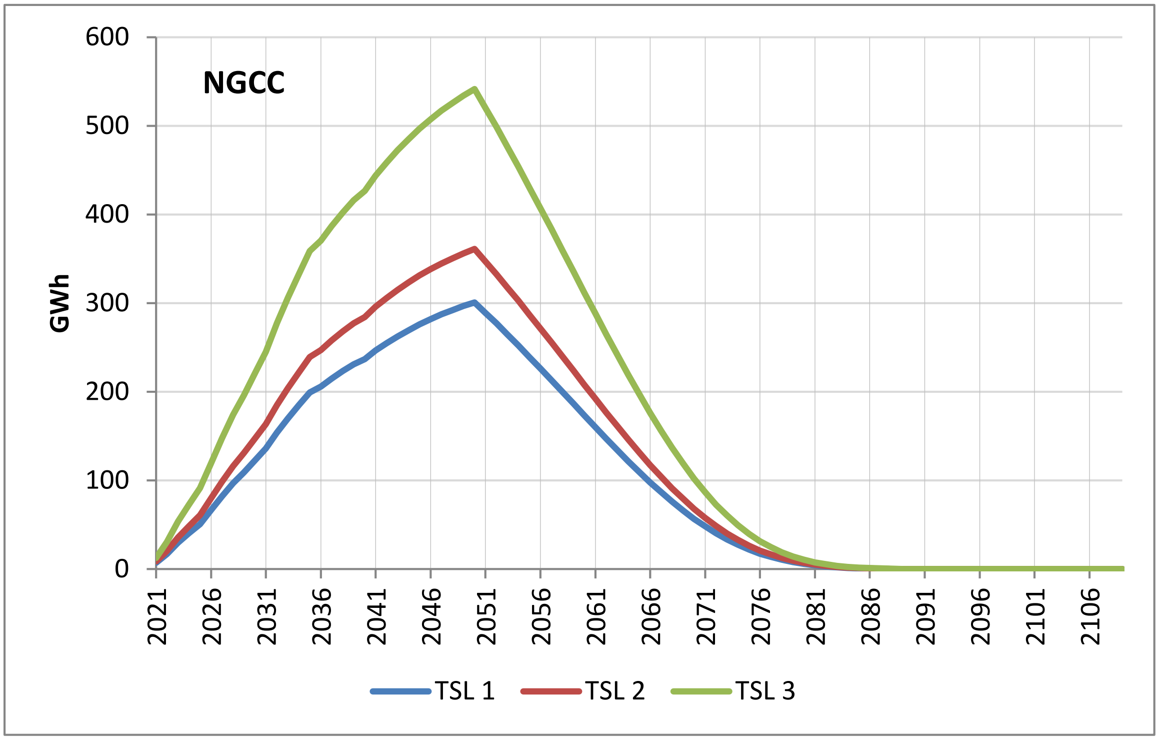

Figure 15.3.22 Gas Combined Cycle Generation Reduction for Non-Weatherized Gas Furnaces and Mobile Home Gas Furnaces Standby and Off Mode TSLs

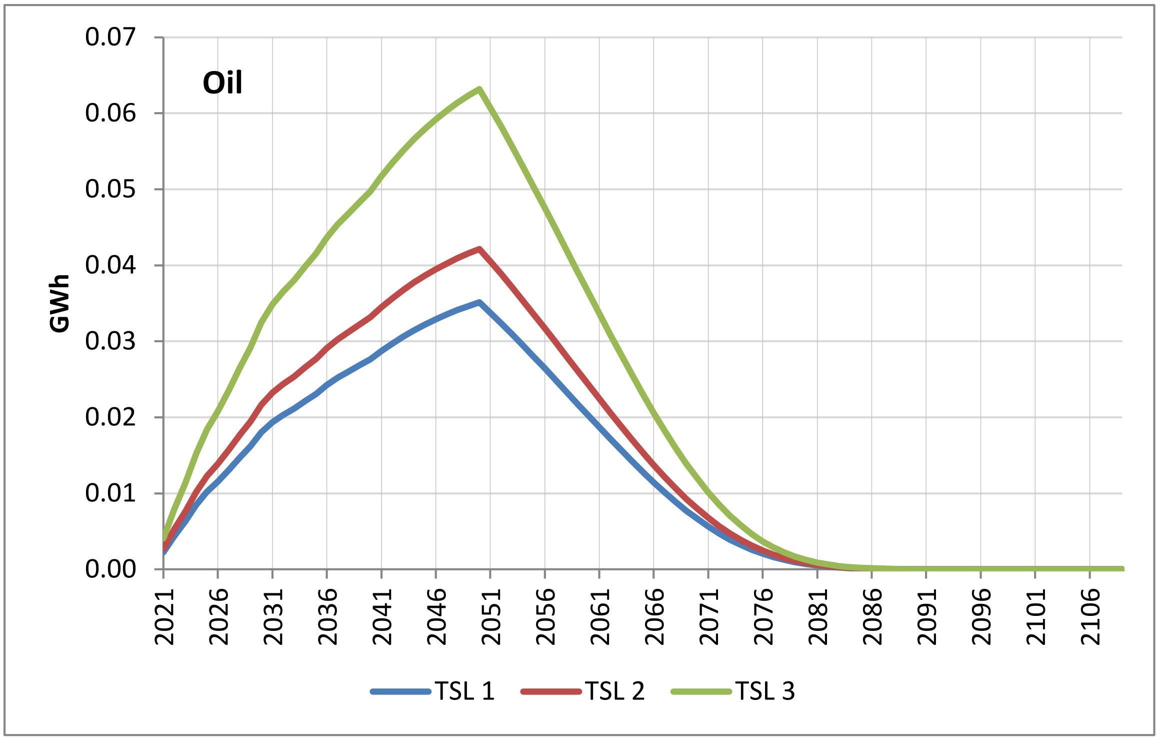

Figure 15.3.23 Oil Generation Reduction for Non-Weatherized Gas Furnaces and Mobile Home Gas Furnaces Standby and Off Mode Trial Standard Levels

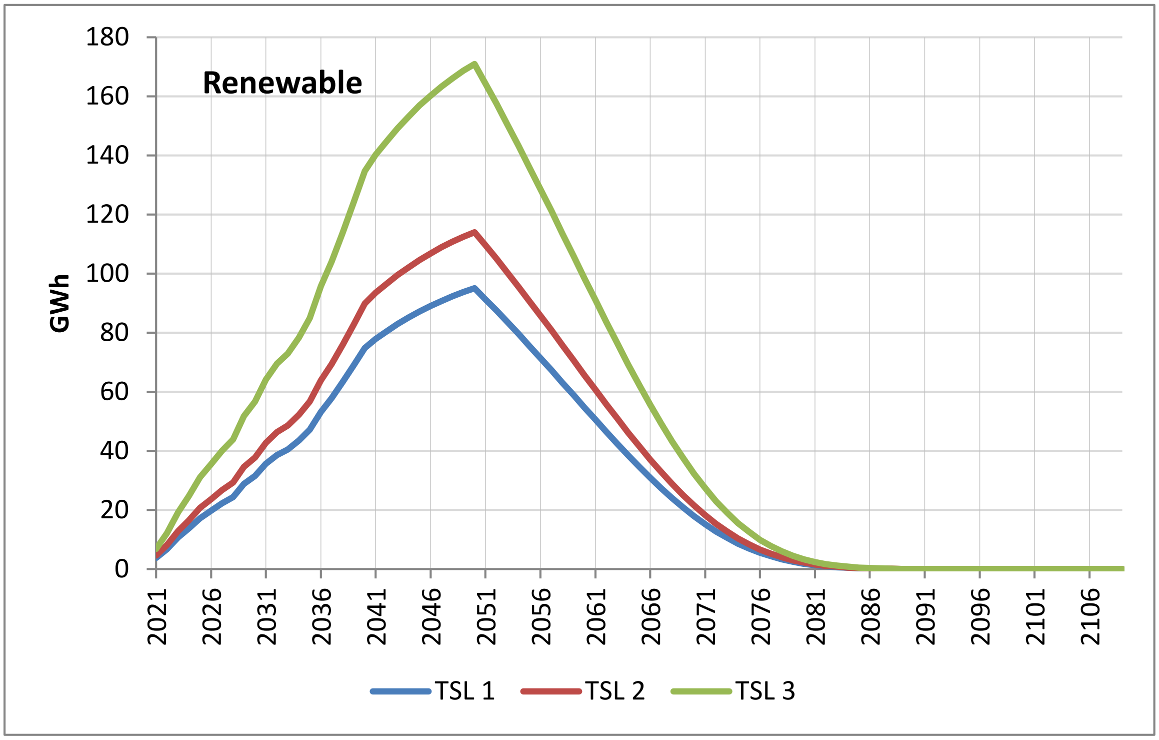

Figure 15.3.24 Renewables Generation Reduction for Non-Weatherized Gas Furnaces and Mobile Home Gas Furnaces Standby and Off Mode Trial Standard Levels

15.3.3 Results Summary

Table 15.3.1 and Table 15.3.2 present a summary of the utility impact results for NWGFs and MHGFs.

Table 15.3.1 Summary of Utility Impact Results for Non-Weatherized Gas Furnaces and Mobile Home Gas Furnaces AFUE Trial Standard Levels

Year	TSL				
	1	2	3	4	5
Installed Capacity Reduction (MW)					
2021	(84)	(79)	(195)	(234)	(323)
2025	(348)	(323)	(840)	(1,009)	(1,397)
2030	(642)	(596)	(1,624)	(1,951)	(2,719)
2035	(867)	(807)	(2,280)	(2,738)	(3,841)
2040	(1,037)	(971)	(2,795)	(3,359)	(4,740)
Electricity Generation Reduction (GWh)					
2021	(508)	(474)	(1,173)	(1,411)	(1,943)
2025	(2,177)	(2,026)	(5,261)	(6,324)	(8,756)
2030	(3,600)	(3,346)	(9,115)	(10,949)	(15,259)
2035	(4,425)	(4,118)	(11,635)	(13,973)	(19,603)
2040	(4,846)	(4,537)	(13,061)	(15,699)	(22,153)

Note: Parentheses indicate negative values, which represent an increase in installed capacity or generation.

Table 15.3.2 Summary of Utility Impact Results for Non-Weatherized Gas Furnaces and Mobile Home Gas Furnaces Standby Mode and Off Mode Trial Standard Levels

Year	TSL		
	1	2	3
Installed Capacity Reduction (MW)			
2021	4.13	4.95	7.43
2025	19.8	23.7	35.6
2030	44.7	53.6	80.4
2035	71.8	86.1	129
2040	99.1	119	178
Electricity Generation Reduction (GWh)			
2021	24.9	29.9	44.8
2025	124	149	223
2030	251	301	451
2035	366	440	659
2040	463	556	833

Note: Parentheses indicate negative values.

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CHAPTER 16. EMPLOYMENT IMPACT ANALYSIS

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CHAPTER 16. EMPLOYMENT IMPACT ANALYSIS

16.1 INTRODUCTION

DOE's employment impact analysis is designed to estimate indirect national job creation or elimination resulting from possible standards due to reallocation of the associated expenditures for purchasing and operating residential non-weatherized gas furnaces (NWGFs) and mobile home gas furnaces (MHGFs). Job increases or decreases reported in this chapter are separate from the direct furnace production sector employment impacts reported in the manufacturer impact analysis (chapter 12), and reflect the net employment impact of efficiency standards on all sectors of the economy.

16.2 ASSUMPTIONS

DOE expects energy conservation standards to decrease energy consumption, and therefore to reduce energy expenditures. The savings in energy expenditures may be spent on new investment or not at all (*i.e.*, they may remain "saved"). The standards may increase the purchase price of products, including the retail price plus sales tax, and increase installation costs.

Using an input/output econometric model of the U.S. economy, this analysis estimated the short-term effect of these expenditure impacts on net economic output and employment. DOE intends for this analysis to quantify the indirect employment impacts of these expenditure changes. It evaluated direct employment impacts at manufacturers' facilities in the manufacturer impact analysis (see chapter 12).

DOE notes that ImSET is not a general equilibrium forecasting model, and understands the uncertainties involved in projecting employment impacts, especially changes in the later years of the analysis.[1] Because ImSET does not incorporate price changes, the employment effects predicted by ImSET would over-estimate the magnitude of actual job impacts over the long run for this rule. Because input/output models do not allow prices to bring markets into equilibrium, they are best used for short-run analysis. DOE therefore include a qualitative discussion of how labor markets are likely to respond in the longer term. In future rulemakings, DOE may consider the use of other modeling approaches for examining long run employment impacts.

16.3 METHODOLOGY

The Department based its analysis on an input/output model of the U.S. economy that estimates the effects of standards on major sectors of the economy related to buildings and the net impact of standards on jobs. The Pacific Northwest National Laboratory developed the model, ImSET 3.1.1[2] (Impact of Sector Energy Technologies) as a successor to ImBuild,[3] a special-purpose version of the IMPLAN[4] national input/output model. ImSET estimates the employment and income effects of building energy technologies. In comparison with simple economic multiplier approaches, ImSET allows for more complete and automated analysis of the economic impacts of energy-efficiency investments in buildings.

In an input/output model, the level of employment in an economy is determined by the relationship of different sectors of the economy and the spending flows among them. Different sectors have different levels of labor intensity and so changes in the level of spending (e.g., due to the effects of an efficiency standard) in one sector of the economy will affect flows in other sectors, which affects the overall level of employment.

ImSET uses a 187-sector model of the national economy to predict the economic effects of residential and commercial buildings technologies. ImSET collects estimates of initial investments, energy savings, and economic activity associated with spending the savings resulting from standards (e.g., changes in final demand in personal consumption, business investment and spending, and government spending). It provides overall estimates of the change in national output for each input-output sector. The model applies estimates of employment and wage income per dollar of economic output for each sector and calculates impacts on national employment and wage income.

Energy-efficiency technology primarily affects the U.S. economy along three spending pathways. First, general investment funds are diverted to sectors that manufacture, install, and maintain energy-efficient products. The increased cost of products leads to higher employment in the product manufacturing sectors and lower employment in other economic sectors. Second, commercial firm and residential spending are redirected from utilities and energy producers toward firms that supply production inputs for energy-efficient products. Third, investment funds from utilities and energy producers are released for use in other sectors of the economy. When consumers use less energy, utilities experience relative reductions in demand which leads to reductions in utility sector investment and employment.

DOE also notes that the employment impacts estimated with ImSET for the entire economy differ from the employment impacts in the residential furnace manufacturing sector estimated in Chapter 12 using the Government Regulatory Impact Model (GRIM). The methodologies used and the sectors analyzed in the ImSET and GRIM models are different.

16.4 SHORT-TERM RESULTS

The results in this section refer to impacts of NWGF and MHGF standards relative to the base case. DOE disaggregated the impact of standards on employment into three component effects: increased capital investment costs, decreased energy costs, and changes in operations and maintenance costs. DOE presents the summary impact.

Conceptually, one can consider the impact of a standard in its first year on three aggregate sectors, the residential furnace production sector, the energy generation sector, and the general consumer goods sector (as mentioned above ImSET's calculations are made at a much more disaggregate level). By raising energy efficiency, the standard generally increases the purchase price of furnaces; this increase in expenditures causes an increase in employment in this sector. At the same time, the improvements in energy efficiency reduce consumer expenditures on energy. The reduction in energy demand causes a reduction in employment in that sector. Finally, based on the net impact of increased expenditures on furnaces and reduced expenditures on energy, consumer expenditures on everything else are either positively or negatively affected, increasing or reducing jobs in that sector accordingly. The model also captures any indirect jobs created or lost by changes in consumption due to changes in employment (as more workers are hired they consume more goods, which generates more employment, the converse is true for workers laid off).

Table 16.4.1 presents the modeled net employment impact from the standards in 2021, rounded to the nearest ten jobs. For context, the U.S. labor force had 156 million people in October 2014.[a] Virtually all NWGFs and MHGFs are domestically produced, so DOE does not consider imports in this analysis. Note that results are presented separately for AFUE standards and standby mode and off mode standards.

Table 16.4.1 Net National Short-term Change in Employment (Number of Jobs)

Standard	Trial Standard Level	2021	2026
AFUE	TSL 1	220	-330
	TSL 2	390	-60
	TSL 3	260	-1,800
	TSL 4	520	-1,850
	TSL 5	890	-2,510
Standby Mode and Off Mode	TSL 1	50	280
	TSL 2	100	360
	TSL 3	130	530

For context, the Office of Management of Budget currently assumes that the unemployment rate may decline to 5.4 percent by 2017.[5] The unemployment rate in 2021 is projected to be 5.4 percent, which is close to “full employment.” When an economy is at full employment any effects on net employment are likely to be transitory as workers change jobs, rather than enter or exit longer-term employment.

16.5 LONG-TERM RESULTS

Over the long term DOE expects the energy savings to consumers to increasingly dominate the increase in product costs, resulting in increased aggregate savings to consumers. As a result, DOE expects demand for energy to decline over time and demand for other goods to increase. Because the utility and energy production sectors are relatively capital intensive

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[a] Bureau of Labor Statistics: Labor Force Statistics (Available at www.bls.gov/web/empsit/cpseea03.pdf).

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 utilities and energy producers towards consumer goods. Note that in long-run equilibrium there is no net effect on total employment because wages adjust to bring the labor market into equilibrium. Nonetheless, even to the extent that markets are slow to adjust, DOE anticipates that net labor market impacts will in general be negligible over time due to the small magnitude of the short-term effects presented in Table 16.4.1. The ImSET model projections, assuming no price or wage effects until 2026, are included in the second column of Table 16.4.1.

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CHAPTER 17. REGULATORY IMPACT ANALYSIS

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CHAPTER 17. REGULATORY IMPACT ANALYSIS

17.1 INTRODUCTION

The U.S. Department of Energy (DOE) has determined that the regulatory action described in the Federal Register notice associated with this TSD constitutes an “economically significant regulatory action” under Executive Order (E.O.) 12866, Regulatory Planning and Review. 58 FR 51735 (October 4, 1993). For such actions, E.O. 12866 requires Federal agencies to provide “an assessment, including the underlying analysis, of costs and benefits of potentially effective and reasonably feasible alternatives to the planned regulation, identified by the agencies or the public (including improving the current regulation and reasonably viable non-regulatory actions), and an explanation why the planned regulatory action is preferable to the identified potential alternatives.” 58 FR 51735, 51741.

To conduct this analysis, DOE used an integrated National Impact Analysis (NIA)-RIA model built on the NIA model discussed in Chapter 10. DOE studied the impacts of non-regulatory policies on the AFUE savings of the residential furnace product class with the predominant market shares, which is the *residential non-weatherized gas-fired furnace* (NWGF) product class.

DOE identified five non-regulatory policy alternatives that possibly could provide incentives for the same energy efficiency level as the one in the proposed trial standard level (TSL 3) for the NWGFs that are the subject of this rulemaking. The non-regulatory policy alternatives are listed in Table 17.1.1, which also includes the “no new regulatory action” alternative. DOE evaluated each alternative in terms of its ability to achieve significant energy savings at a reasonable cost, and compared the effectiveness of each to the effectiveness of the proposed standard.

The market for NWGFs differs across sectors (residential and commercial) and regions (Norht and Rest of Country). To account for those differences, DOE analyzed the market impacts from the non-regulatory alternatives for each sector and region, and summarized them at the national level. Furthermore, unlike the analysis performed in the NIA, that accounts for a potential substitution of NWGFs by electric equipment due to the increase in equipment costs driven by a new minimum energy efficiency standard, DOE does not account for substitutions when estimating the effects of the non-regulatory alternatives, as for these policy cases consumers have the option to purchase a less efficient, less expensive model than the ones targeted by the policies.

Table 17.1.1 Non-Regulatory Alternatives to National Standards

No New Regulatory Action
Consumer Rebates
Consumer Tax Credits
Manufacturer Tax Credits
Voluntary Energy Efficiency Targets
Bulk Government Purchases

Sections 17.2 and 17.3 discuss the analysis of five selected policies listed above (excluding the alternative of no new regulatory action). Section 17.4 presents the results of the policy alternatives.

17.2 NON-REGULATORY POLICES

This section describes the method DOE used to analyze the energy savings and cost effectiveness of the non-regulatory policy alternatives for NWGFs. This section also describes the assumptions underlying the analysis.

17.2.1 Methodology

DOE used its integrated NIA-RIA spreadsheet model to calculate the national energy savings (NES) and net present value (NPV) associated with each non-regulatory policy alternative. Chapter 10 of the technical support document (TSD) describes the NIA spreadsheet model. Appendix 17A discusses the NIA-RIA integrated model approach.

DOE quantified the effect of each alternative on the purchase of equipment that meet the efficiency level corresponding to the proposed TSL. After establishing the quantitative assumptions underlying each alternative, DOE appropriately revised inputs to the NIA-RIA spreadsheet model. The primary model inputs revised were market shares of equipment meeting the target efficiency level set for the proposed TSL. The shipments of equipment for any given year reflect a distribution of efficiency levels. DOE assumed, for the proposed TSL, that new energy efficiency standards would affect 100 percent of the shipments of products that did not meet the TSL target level in the base case,[a] whereas the non-regulatory policies would affect a smaller percentage of those shipments. DOE made certain assumptions about the percentage of shipments affected by each alternative policy. DOE used those percentages to calculate the shipment-weighted average energy consumption and costs of NWGFs attributable to each policy alternative.

Increasing the efficiency of a product often increases its average installed cost. However, operating costs generally decrease because energy consumption declines. DOE therefore

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[a] The base case for the NIA is a market-weighted average energy efficiency calculated from units at several efficiency levels.

calculated an NPV for each non-regulatory alternative in the same way it did for the proposed standards. In some policy scenarios, increases in total installed cost are mitigated by government rebates or tax credits. Because DOE assumed that consumers would re-pay credits and rebates in some way (such as additional taxes), DOE did not include rebates or tax credits as a consumer benefit when calculating national NPV. DOE's analysis also excluded any administrative costs for the non-regulatory policies; including such costs would decrease the NPVs slightly.

The following are key measures for evaluating the impact of each alternative.

- National Energy Savings (NES), given in quadrillion Btus (quads), describes the cumulative national primary energy saved over the lifetime of equipment purchased during the 30-year analysis period starting in the effective date of the policy (2021-2050).

- Net Present Value (NPV), represents the value of net monetary savings in 2014, expressed in 2013$, from equipment purchased during the 30-year analysis period starting in the effective date of the policy (2021-2050). DOE calculated the NPV as the difference between the present value of installed equipment cost and operating expenditures in the base case and the present value of those costs in each policy case. DOE calculated operating expenses (including energy costs) for the life of the product.

17.2.2 Assumptions Regarding Non-Regulatory Policies

The effects of non-regulatory policies are by nature uncertain because they depend on program implementation, marketing efforts, and on consumers' responses to a program. Because the projected effects depend on assumptions regarding the rate of consumer participation, they are subject to more uncertainty than are the impacts of mandatory standards, which DOE assumes will be met with full compliance. To increase the robustness of the analysis, DOE conducted a literature review regarding each non-regulatory policy and consulted with recognized experts to gather information on similar incentive programs that have been implemented in the United States. By studying experiences with the various types of programs, DOE sought to make credible assumptions regarding potential market impacts. Section 17.3 presents the sources DOE relied on in developing assumptions about each alternative policy and reports DOE's conclusions as they affected the assumptions that underlie the modeling of each alternative policy.

Each non-regulatory policy that DOE considered would improve the average efficiency of new NWGFs relative to their base case efficiency scenario (which involves no new regulatory action). The analysis considered that each alternative policy would induce consumers to purchase units having the same efficiency level as required by the proposed standards (the target level) set for the proposed TSL. As opposed to the standards case, however, the policy cases may not lead to 100 percent market penetration of units that meet the target level.

Table 17.2.1 shows the efficiency level stipulated in the proposed standard for NWGFs.

Table 17.2.1 Efficiency Level for Trial Standard Level 3 for the Residential Non-Weatherized Gas-Fired Furnaces Product Class

	AFUE
Residential Non-Weatherized Gas-Fired Furnaces	92%

DOE assumed that the effects of non-regulatory policies would last from the effective date of standards—2021—through the end of the analysis period, which is 2050.

17.2.3 Policy Interactions

DOE calculated the effects of each non-regulatory policy separately from those of the other policies. In practice, some policies are most effective when implemented in combination, such as voluntary efficiency targets implemented with consumer rebates or tax credits. However, DOE attempted to make conservative assumptions to avoid double-counting policy impacts. The resulting policy impacts are not additive; the combined effect of several or all policies cannot be inferred from summing their results.

Section 17.4 presents graphs that show the market penetration estimated under each non-regulatory policy for the NWGF product class.

17.3 NON-REGULATORY POLICY ASSUMPTIONS

The following subsections describe DOE's analysis of the impacts of the five non-regulatory policy alternatives to proposed standards for NWGFs. (Because the alternative of No New Regulatory Action has no energy or economic impacts, essentially representing the NIA base case, DOE did not perform any additional analysis for that alternative.) DOE developed estimates of the market penetration of high-efficiency products both with and without each of the non-regulatory policy alternatives.

17.3.1 No New Regulatory Action

The case in which no new regulatory action is taken with regard to the energy efficiency of NWGFs constitutes the base case, as described in Chapter 10, National Impact Analysis. The base case provides the basis of comparison for all other policies. By definition, no new regulatory action yields zero NES and an NPV of zero dollars.

17.3.2 Consumer Rebates

DOE considered the scenario in which the Federal government would provide financial incentives in the form of rebates to consumers for purchasing energy-efficient appliances. This policy provides a consumer rebate for purchasing NWGFs that operate at the same efficiency as stipulated in the proposed TSL.

17.3.2.1 Methodology

DOE based its evaluation methodology for consumer rebates on a comprehensive study of California's potential for achieving energy efficiency. The study, performed by XENERGY, Inc.,[b] summarized experiences with various utility rebate programs.[1] XENERGY's analytical method utilized graphs, or penetration curves, that estimate the market penetration of a technology based on its benefit/cost (B/C) ratio. DOE consulted with experts and reviewed other methods of estimating the effect of consumer rebate programs on the market penetration of efficient technologies. The other methods, developed after the referenced XENERGY report was published,[2, 3, 4, 5, 6, 7] used different approaches: other economic parameters (e.g., payback period), expert surveys, or model calibration based on specific utility program data rather than multi-utility data. Some models in use by energy efficiency program evaluation experts were so client-specific that generic relationships between economic parameters and consumer response could not be established.[5] DOE decided that the most appropriate available method for this RIA analysis was the XENERGY approach of penetration curves based on B/C ratio, which incorporates lifetime operating cost savings.

XENERGY's model estimates market impacts induced by financial incentives based on the premise that two types of information diffusion drive the adoption of new technologies. *Internal sources* of information encourage consumers to purchase new equipment primarily through word-of-mouth from early adopters. *External sources* affect consumer purchase decisions through marketing efforts and information from outside the consumer group. Appendix 17A contains additional details on internal and external information diffusion.

XENERGY's model equation accounts for the influences of both internal and external sources of information by superimposing the two components. Combining the two mechanisms for information diffusion, XENERGY's model generates a set of penetration (or implementation) curves for a policy measure. XENERGY calibrated the curves based on participation data from utility rebate programs. The curves illustrate the increased penetration (i.e., increased market share) of efficient equipment driven by consumer response to changes in B/C ratio induced by rebate programs. The penetration curves depict various diffusion patterns based on perceived market barriers (from no-barriers to extremely-high-barriers) to consumer purchase of high-efficiency equipment. DOE adjusted the XENERGY former penetration curves based on expert advice founded on more recent utility program experience.[5, 8]

DOE modeled the effects of a consumer rebate policy for NWGFs by determining, for the proposed TSL, the increase in market penetration of equipment meeting the target level relative to their market penetration in the base case. It used the interpolation method presented in Blum et al (2011)[9] to create customized penetration curves based on relationships between actual base case market penetrations and actual B/C ratios. To inform its estimate of B/C ratios provided by a rebate program DOE performed a thorough nationwide search for existing rebate programs for NWGFs. It gathered data on utility or agency rebates throughout the nation for this equipment,

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[b] XENERGY is now owned by KEMA, Inc. (www.kema.com)

and used this data to calibrate the customized penetration curves it developed for NWGFs so they can best reflect the market barrier level faced by the specified product class. Section 17.3.2.2 shows the interpolated curves used in the analysis.

17.3.2.2 Analysis

For the product class it analyzed, DOE estimated the effect of increasing its B/C ratio via a rebate that would pay all (or part) of the increased installed cost of a unit that met the target efficiency level compared to one meeting the baseline efficiency level.[c] To inform its estimate of an appropriate rebate amount, DOE performed a thorough nationwide search for existing rebate programs for NWGFs in July, 2014. It gathered data from a sample of utility and agency rebate programs that includes 155 rebates for NWGFs initiated by 65 utilities or agencies in various States. (Appendix 17A, identifies the rebate programs.) DOE further performed a statistical analysis over the rebate amounts in these programs in order to estimate a rebate value consistent with the efficiency level of the target level. DOE assumed that rebates would remain in effect at the same level throughout the forecast period (2021-2050).

For the NWGF product class it analyzed, DOE first calculated the B/C ratio without a rebate using the difference in total installed costs (C) and lifetime operating cost savings (B) between the unit meeting the target level and the baseline unit. It then calculated the B/C ratio given a rebate for the unit meeting the target efficiency level. Because the rebate reduced the incremental cost, the unit receiving the rebate had a larger B/C ratio. Table 17.3.1 shows the effect of consumer rebates on the B/C ratio for the proposed TSL.

Table 17.3.1 Benefit/Cost Ratios Without and With Rebates for Residential Non-Weatherized Gas-Fired Furnaces (TSL 3)

	Residential		Commercial	
	Rest of Country	North	Rest of Country	North
B/C Ratio Without Rebate	2.6	2.9	2.3	3.6
Rebate Amount (2013$)	318.45	318.45	318.45	318.45
B/C Ratio With Rebate	13.1	5.6	4.2	5.8
Estimated Market Barriers	Low-Moderate	No-Low	Low-Moderate	No-Low

DOE used these B/C ratios along with the penetration curves shown in Figure 17.3.1 to estimate the percentage of consumers who would purchase NWGFs that meet the target level both with and without a rebate incentive. The penetration curves calculated by DOE to represent the market behavior for NWGFs at the proposed TSL are indicated in Table 17.3.1.

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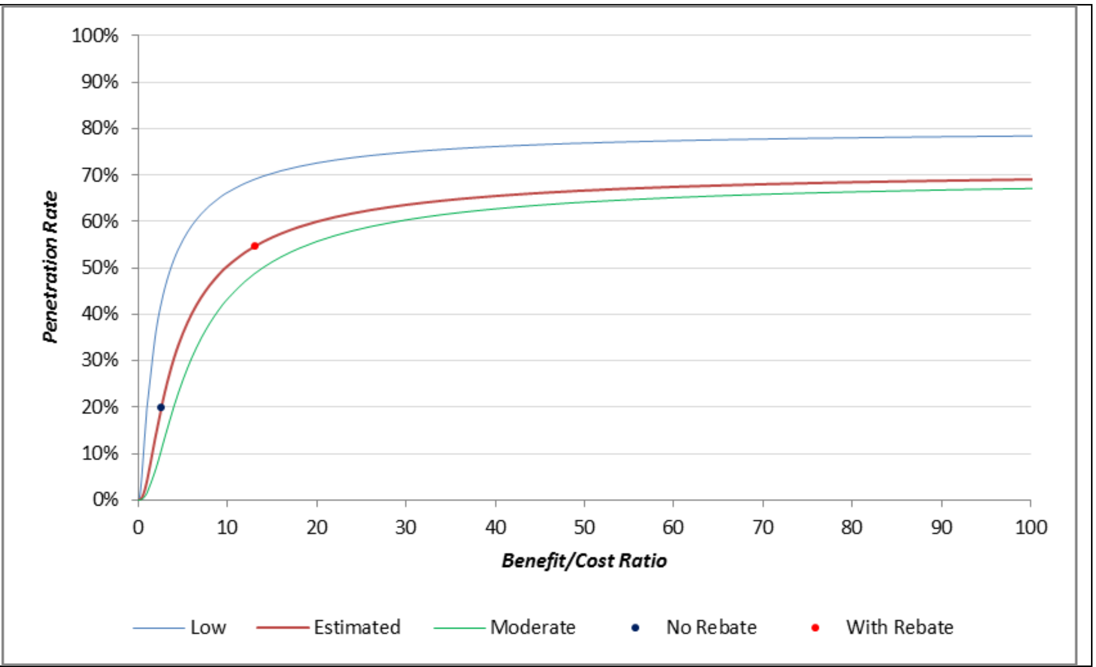
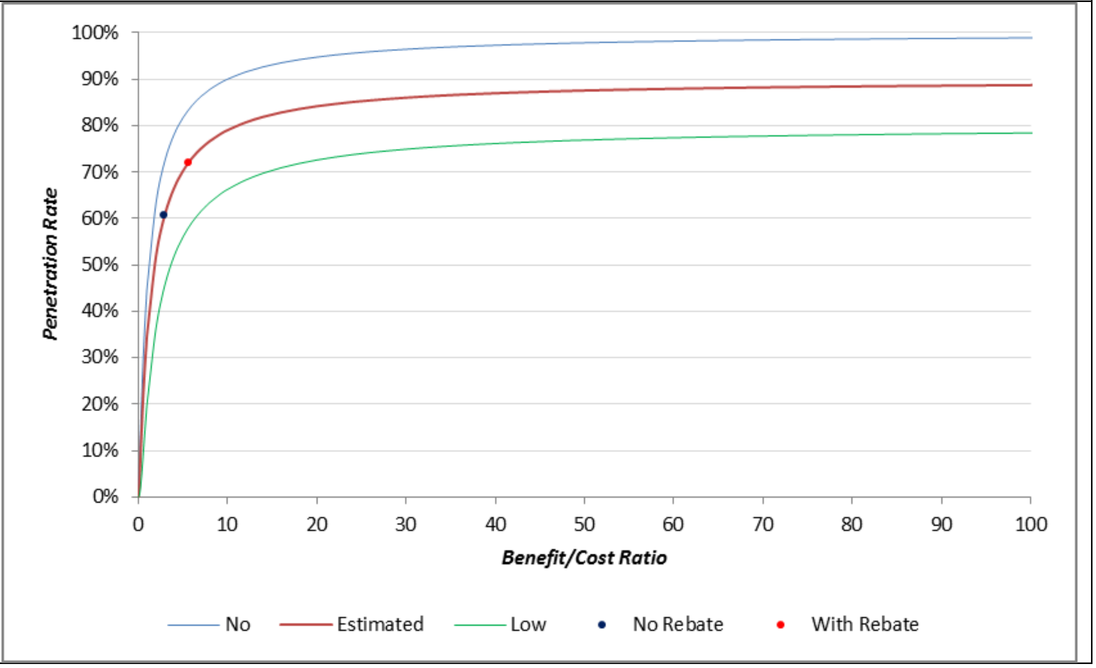
[c] The baseline technology for the product class is defined in the engineering analysis, Chapter 5, as the technology that represents the basic characteristics of products in that class. A baseline unit typically is one that just meets current Federal energy conservation standards and provides basic consumer utility.

Residential (Rest of Country)	
Residential (North)	

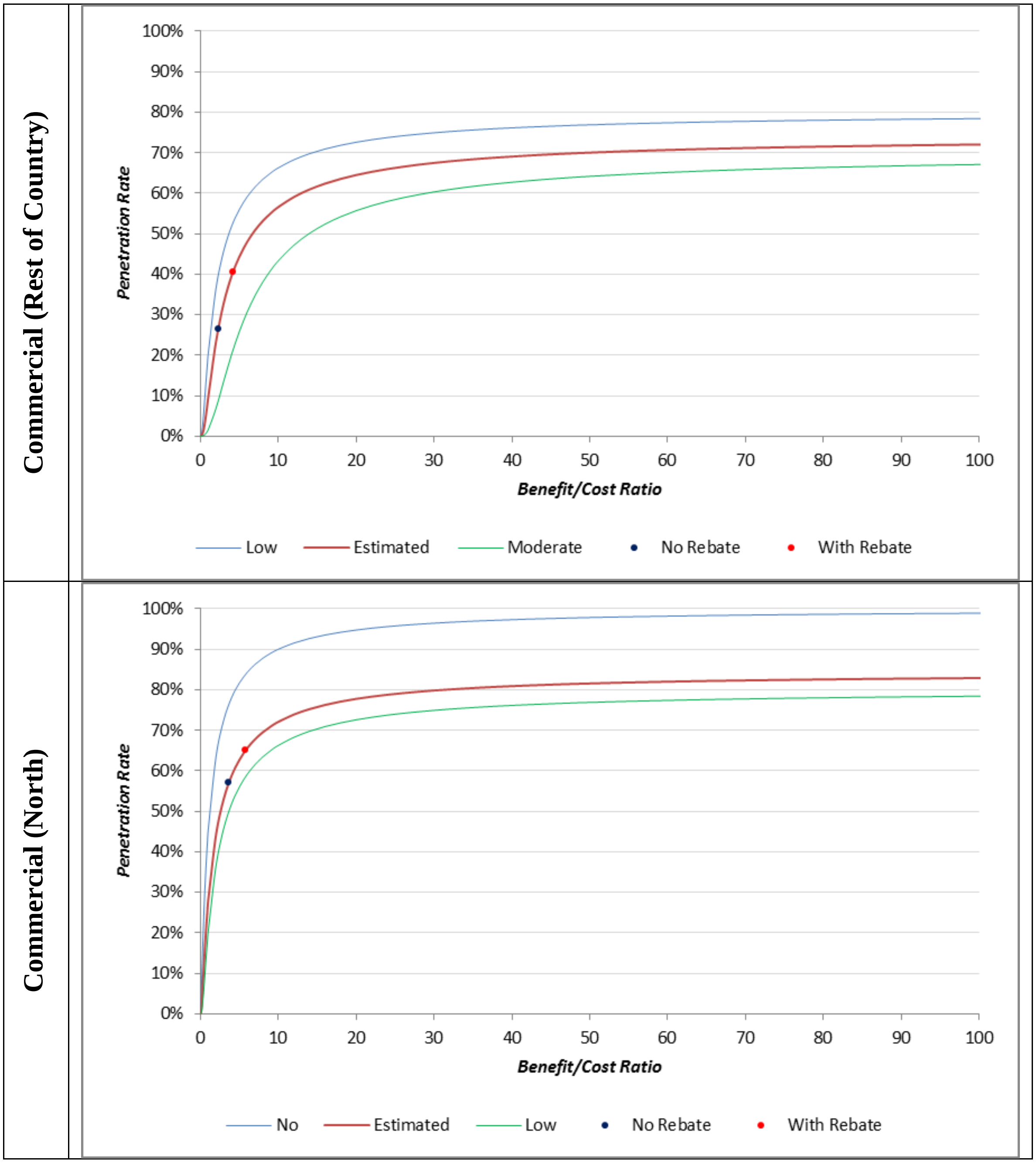


Figure 17.3.1 Market Penetration Curves for Residential Non-Weatherized Gas-Fired Furnaces (TSL 3)

DOE next estimated the percent increases represented by the change in penetration rate shown on the corresponding penetration curve. It then added this percent increase to the market share of units that meet the target level in the base case to obtain the market share of units that meet the target level in the rebate policy case.

Table 17.3.2 summarizes DOE's assumptions for NWGFs regarding the market penetration of products in 2021 that meet the target efficiency level at the proposed TSL given a consumer rebate.

Table 17.3.2 Market Penetrations in 2021 Attributable to Consumer Rebates for Residential Non-Weatherized Gas-Fried Furnaces (TSL 3)

	Residential (Rest of Country)	Residential (North)	Commercial (Rest of Country)	Commercial (North)
Base-Case Market Share	19.8%	60.7%	26.4%	57.0%
Policy Case Market Share	54.7%	72.0%	40.6%	65.0%
Increased Market Share	34.9%	11.3%	14.2%	8.0%

DOE used the resulting annual increases in market shares as inputs to represent the rebate policy case scenario in its NIA-RIA model. Appendix 17A shows the annual market share increases due to this policy. Section 17.4 presents the resulting market penetration trends for the policy case of consumer rebates for NWGFs.

17.3.3 Consumer Tax Credits

DOE estimated the effects of tax credits on consumer purchases based on its previous analysis of consumer participation in tax credits. DOE supported its approach using data from Oregon State's tax credit program for energy-efficient appliances. DOE also incorporated previous research that disaggregated the effect of rebates and tax credits into a *direct price effect*, which derives from the savings in purchase price, and an *announcement effect*, which is independent of the amount of the incentive.[10, 11] The announcement effect derives from the credibility that a technology receives from being included in an incentive program, as well as changes in product marketing and modifications in markup and pricing. DOE assumed that the rebate and consumer tax credit policies would encompass both direct price effects and announcement effects, and that half the increase in market penetration associated with either policy would be due to the direct price effect and half to the announcement effect.

In estimating the effects of a tax credit on purchases of consumer products that meet new efficiency standards, DOE assumed the amount of the tax credit would be the same as the corresponding rebate amount discussed above.

DOE estimated that fewer consumers would participate in a tax credit program than would take advantage of a rebate. Research has shown that the delay required for a consumer to receive a tax credit, plus the added time and cost in preparing the tax return, make a tax credit incentive less effective than a rebate received at the time of purchase. Based on previous analyses, DOE assumed that only 60 percent of the consumers who would take advantage of a rebate would take advantage of a tax credit.[12]

In preparing its assumptions to estimate the effects of tax credits on consumer purchases of NWGFs, DOE also reviewed other tax credit programs that have been offered at both the Federal and State levels for energy-efficient appliances.

The Energy Policy Act of 2005 (EPACT 2005) included Federal tax credits for consumers who purchase energy-efficient products, including furnace fans.[13] Those tax credits were in effect in 2006 and 2007, expired in 2008, were reinstated for 2009–2010 by the American Recovery and Reinvestment Act of 2009 (ARRA), extended by Congress for 2011 with some modifications, and expired at the end of 2011.[14, 15] The American Taxpayer Relief Act of 2012 extended, with some modifications, residential tax credits for air conditioners, heat pumps, furnaces, and water heaters placed in service between January 1, 2012 and December 31, 2013.[16] DOE reviewed Internal Revenue Service data on the numbers of taxpayers who claimed the tax credits during tax years 2006 and 2007. DOE also reviewed data from an earlier Federal energy conservation tax credit program in place in the 1980s. However, DOE did not find data specific enough to NWGFs to warrant adjusting its analysis method for the Consumer Tax Credits policy case. Appendix 17A contains more information on Federal consumer tax credits.

DOE also reviewed its previous analysis of Oregon's tax credits for clothes washers to provide support for its assumptions.[17] In that previous analysis, DOE compared the market shares of ultra-high efficiency (UHE) residential clothes washers in Oregon, which offered both State tax credits and utility rebates, with those in Washington State, which offered only utility rebates during the same period. Based on this analysis, DOE estimated that in Oregon the impact of tax credits was 62 percent of the impact of rebates for UHE clothes washers having equivalent efficiency. This finding supports its original assumption that participation in a tax credit program would be about 60 percent of participation in a rebate program. Additional discussion of State tax credits for Oregon and other states is in Appendix 17A.

DOE applied the assumed 60 percent participation described above to the penetration rates estimated for the rebate policy to estimate penetration rates attributable to consumer tax credits. In doing so, DOE incorporated the assumptions for consumer response to financial incentives from the penetration curves selected for NWGFs.

Table 17.3.3 summarizes DOE's assumptions for NWGFs regarding the market penetration of units in 2021 that meet the efficiency level at the proposed TSL given a consumer tax credit.

Table 17.3.3 Market Penetrations in 2021 Attributable to Consumer Tax Credits for Residential Non-Weatherized Gas-Fired Furnaces (TSL 3)

	Residential (Rest of Country)	Residential, (North)	Commercial, (Rest of Country)	Commercial, (North)
Base-Case Market Share	19.8%	60.7%	26.4%	57.0%
Policy Case Market Share	40.7%	67.5%	34.9%	61.8%
Increased Market Share	20.9%	6.8%	8.5%	4.8%

The increased market shares attributable to consumer tax credits shown in Table 17.3.3 were used as inputs in the NIA-RIA model. Appendix 17A shows the annual market share increases due to this policy. Section 17.4 presents the resulting market penetration trends for the policy case of consumer tax credits for NWGFs that meet the efficiency level for the proposed TSL.

17.3.4 Manufacturer Tax Credits

To analyze the potential effects of a policy that offers tax credits to manufacturers that produce NWGFs that meet the target efficiency level at the proposed TSL, DOE assumed that a manufacturer tax credit would lower the consumer’s purchase cost by an amount equivalent to that provided by the consumer rebates or tax credits described above. DOE further assumed that manufacturers would pass on some of their reduced costs to consumers, causing a direct price effect. DOE assumed that no announcement effect would occur, because the program would not be visible to consumers.[d] Because the direct price effect is approximately equivalent to the announcement effect,[10] DOE estimated that a manufacturer tax credit would induce half the number of consumers assumed to take advantage of a consumer tax credit to purchase more efficient products. Thus the assumed participation rate is equal to 30 percent of the number of consumers who would participate in a rebate program.

DOE attempted to investigate manufacturer response to the Energy Efficient Appliance Credits for manufacturers mandated by EPACT 2005.[18] Those manufacturer tax credits have been in effect for dishwashers, clothes washers and refrigerators produced beginning in 2009. DOE was unable to locate data from the Internal Revenue Service or other sources on manufacturer response to the Federal credits. Appendix 17A presents details on Federal manufacturer tax credits.

DOE applied the assumption of 30 percent participation to the penetration rates predicted for the rebate policy to estimate the effects of a manufacturer tax credit policy. In doing so, the

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[d] Note that this is a conservative assumption, since it is possible that manufacturers or utility/agency efficiency programs might promote the models for which manufacturers increase production due to the tax credits, which in turn might induce some announcement effect. However, DOE found no data on such programs on which to base an estimate of the magnitude of this possible announcement effect on consumer behavior.

Department incorporated the assumptions for consumer response to financial incentives from the penetration curves calculated for NWGFs.

Table 17.3.4 summarize DOE's assumptions for NWGFs regarding the market penetration of units in 2021 meeting the efficiency level the proposed TSL given a manufacturer tax credit.

Table 17.3.4 Market Penetrations in 2021 Attributable to Manufacturer Tax Credits for Residential Non-Weatherized Gas-Fired Furnaces (TSL 3)

	Residential (Rest of Country)	Residential, (North)	Commercial, (Rest of Country)	Commercial, (North)
Base-Case Market Share	19.8%	60.7%	26.4%	57.0%
Policy Case Market Share	30.3%	64.1%	30.7%	59.4%
Increased Market Share	10.5%	3.4%	4.3%	2.4%

The increased market shares attributable to a manufacturer tax credit shown in Table 17.3.4 were used as inputs in the NIA-RIA model. Appendix 17A shows the annual market share increases due to this policy. Section 17.4 presents the resulting market penetration trends for the policy case of manufacturer tax credits for NWGFs.

17.3.5 Voluntary Energy Efficiency Targets

For the analyzed product class, DOE assumed that voluntary energy efficiency targets would be achieved as manufacturers gradually stopped producing units that operated below the efficiency level set for the proposed TSL. DOE assumed that the impetus for phasing out production of low-efficiency units would be a program with impacts similar to those of the ENERGY STAR labeling program conducted by the Environmental Protection Agency (EPA) and DOE in conjunction with industry partners. The ENERGY STAR program specifies the minimum energy efficiencies that various products must have to receive the ENERGY STAR label. ENERGY STAR encourages consumers to purchase efficient products via marketing that promotes consumer label recognition, various incentive programs that adopt the ENERGY STAR specifications, and manufacturers' promotion of their qualifying appliances. ENERGY STAR projects market penetration of compliant appliances and estimates the percentage of sales of compliant appliances that are attributable to the ENERGY STAR program.

Researchers have analyzed the ENERGY STAR program's effects on sales of several consumer products. Program efforts generally involve a combination of information dissemination and utility or agency rebates. The analyses have been based on State-specific data on percentages of shipments of various appliances that meet ENERGY STAR specifications. The analyses generally have concluded that the market penetration of ENERGY STAR-qualifying appliances is higher in regions or States where ancillary promotional programs have been active.[19, 20, 21]

DOE believes that informational incentive programs – like ENERGY STAR, or any other labeling program sponsored by industry or other organizations – are likely to reduce the market barriers to more efficient products over time. During the rebate analysis, when assessing the B/C ratio and market penetration in the base case for NWGFs, DOE observed that the market barriers for this product class are below the low level in the North, and slightly above that level in the Rest of Country. DOE estimates that voluntary energy efficiency targets could reduce these barriers respectively to a no level and a low level over 10 years, and followed the methodology presented by Blum et al (2011)[22] to evaluate the effects that such a reduction in market barriers have on the market penetration of efficient NWGFs in each region and sector. The methodology relies on interpolated market penetration curves to calculate – given a B/C ratio – how the market penetration of more efficient units increases as the market barrier level to those units decreases.

Table 17.3.5 summarizes DOE's assumptions for NWGFs regarding the market penetration of units in 2021 that meet the efficiency level at the proposed TSL given voluntary energy efficiency targets.

Table 17.3.5 Market Penetrations in 2021Attributable to Voluntary Energy Efficiency Targets for Residential Non-Weatherized Gas-Fired Furnaces (TSL 3)

	Residential (Rest of Country)	Residential, (North)	Commercial, (Rest of Country)	Commercial, (North)
Base-Case Market Share	19.8%	60.7%	26.4%	57.0%
Policy Case Market Share	26.0%	61.9%	29.8%	59.2%
Increased Market Share	6.2%	1.3%	3.4%	2.3%

The increased market shares attributable to voluntary energy efficiency targets shown in Table 17.3.5 were used as inputs in the NIA-RIA model. Appendix 17A shows the annual market share increases due to this policy. Section 17.4 presents the resulting market penetration trends for the policy case of voluntary energy efficiency targets for NWGFs that meet the efficiency level for the proposed TSL.

17.3.6 Bulk Government Purchases

Bulk government purchases can lead to Federal, State, and local governments purchasing large quantities of products that meet the target efficiency level. Combining the market demands of multiple public sectors also can provide a market signal to manufacturers and vendors that some of their largest customers seek products that meet an efficiency target at favorable prices. Such a program also can induce "market pull," whereby manufacturers and vendors would achieve economies of scale for high efficiency products.

Most of the previous bulk government purchase (procurement) initiatives at the Federal, State, and municipal levels have not tracked data on numbers of purchases or degree of compliance with procurement specifications. In many cases, procurement programs are decentralized, being part of larger State or regional initiatives. DOE based its assumptions regarding the effects of this policy on studies the Federal Energy Management Program (FEMP) performed regarding the savings potential of its procurement specifications for appliances and other products. FEMP, however, does not track purchasing data, because of the complex range of purchasing systems, large number of vendors, and so on. States, counties, and municipalities have demonstrated increasing interest and activity in “green purchasing." Although many of the programs target office equipment, the growing infrastructure for developing and applying efficient purchasing specifications indicates that bulk government purchase programs are feasible.[23, 24]

DOE assumed that government agencies would administer bulk purchasing programs for NWGFs. At the federal level, this type of program could modify the current FEMP procurement guidelines for NWGFs, which refer to the ENERGY STAR requirements for NWGFs.[25] DOE reviewed its own previous research on the potential for market transformation through bulk government purchases. Its major study analyzed several scenarios based on the assumption that 20 percent of Federal equipment purchases in 2000 already incorporated energy efficiency requirements based on FEMP guidelines. One scenario in the DOE report showed energy efficient purchasing ramping up during 10 years from 20 percent to 80 percent of all Federal purchases.[26] Based on this study, DOE estimated that a bulk government purchase program instituted within a 10-year period would result in at least 80 percent of government-purchased NWGFs meeting the target efficiency level.

DOE assumed that bulk government purchases would affect a subset of housing units for which government agencies purchased or influenced the purchase of NWGFs. This subset would consist primarily of public housing and housing on military bases. According to the 2009 Residential Energy Consumption Survey (RECS 2009), about 2.8 percent of all U.S. households heated by gas furnaces are housing units in public housing authority. [27] DOE therefore estimated that 2.8 percent of the U.S. housing units heated by gas furnaces constitute the population to which this policy would apply.

DOE estimated that starting in 2021, each year of a bulk government purchase policy would result in an increasing percent of shipments of government-purchased units beyond the base case that would meet the target efficiency level. DOE estimated that within 10 years (by 2030) bulk government purchasing programs would result in 80 percent of the NWGFs market for publicly owned housing meeting the target level. DOE modeled the bulk government purchase program assuming that the market share for NWGFs achieved in 2030 would be at least maintained throughout the rest of the forecast period.

Table 17.3.6 summarizes DOE’s assumptions for NWGFs regarding the market penetration of units in 2021 that meet the efficiency level the proposed TSL given bulk government purchasing.

Table 17.3.6 Market Penetrations in 2021 Attributable to Bulk Government Purchasing of Residential Non-Weatherized Gas-Fired Furnaces (TSL 3)

	Residential (Rest of Country)	Residential, (North)	Commercial, (Rest of Country)	Commercial, (North)
Base-Case Market Share	19.8%	60.7%	26.4%	57.0%
Policy Case Market Share	19.9%	60.7%	26.5%	57.0%
Increased Market Share	0.1%	0.0%	0.1%	0.0%

The increased market shares attributable to bulk government purchasing shown in Table 17.3.6 were used as inputs in the NIA-RIA model. Appendix 17A shows the annual market share increases due to this policy that DOE used as inputs to the NIA-RIA model. Section 17.4 below presents the resulting market penetration trends for the policy case of bulk government purchase of NWGFs.

17.4 IMPACTS OF NON-REGULATORY ALTERNATIVES

Figure 17.4.1 through Figure 17.4.4 show the effects of each non-regulatory policy on the market penetration of NWGFs projected to be shipped to residential and commercial sectors in the North and Rest of Country regions. Relative to the base case, the policy cases increase the market shares that meet the target level. Recall the proposed standards (not shown in the figures) would result in a 100-percent market penetration of products that meet the target efficiency level.

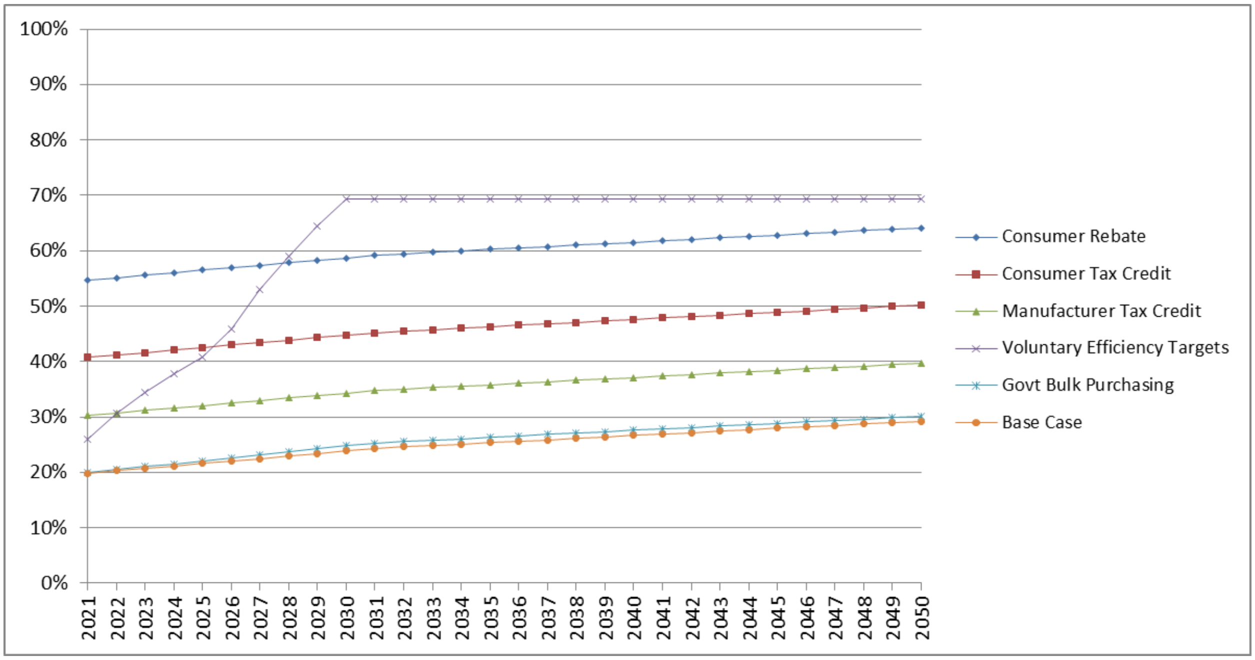

Figure 17.4.1 Market Penetration of NWGFs (Residential, Rest of Country) (TSL 3)

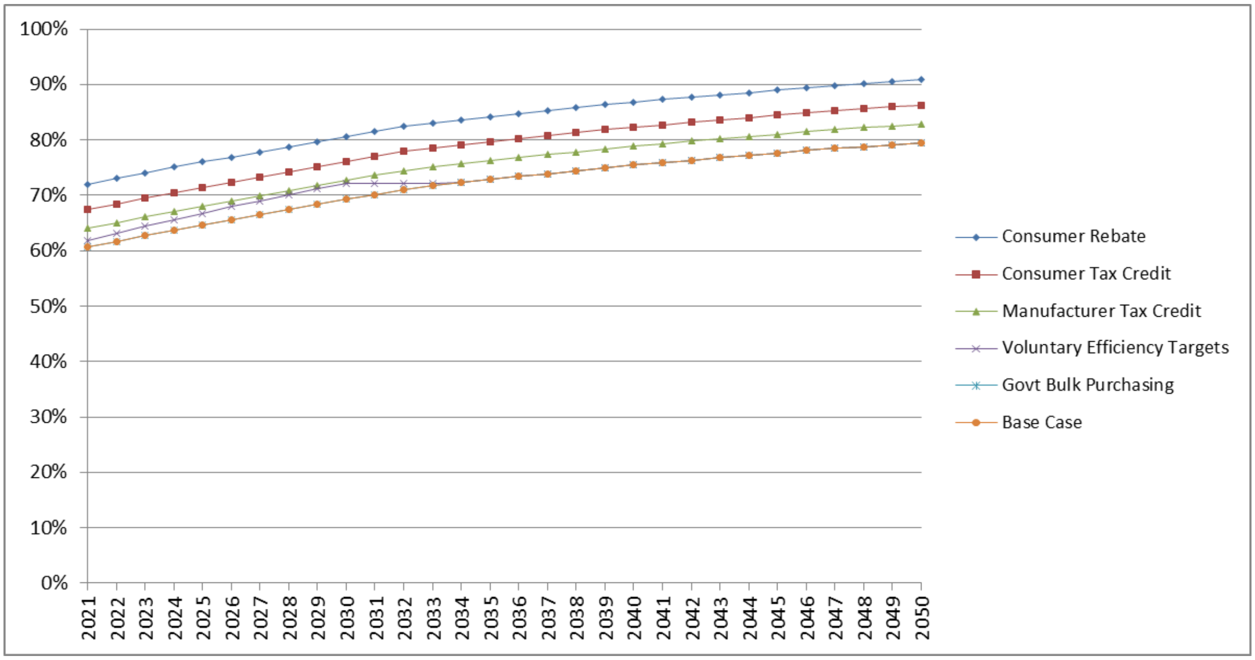

Figure 17.4.2 Market Penetration of NWGFs (Residential, North) (TSL 3)

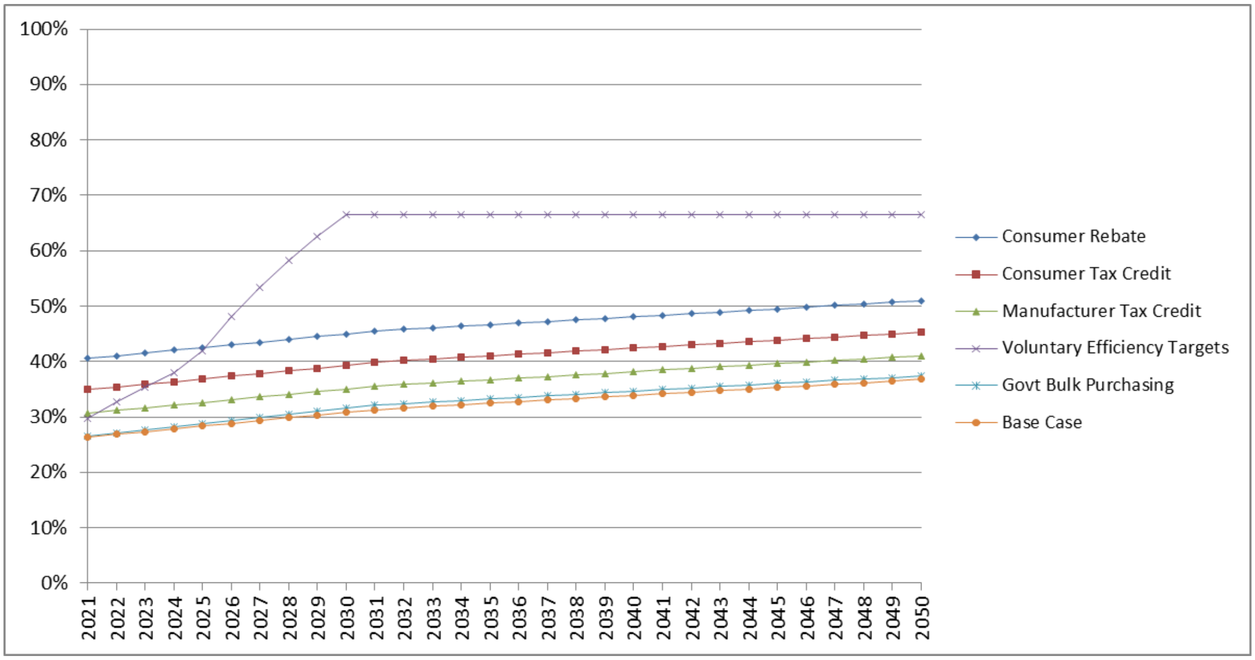

Figure 17.4.3 Market Penetration of NWGFs (Commercial, Rest of Country) (TSL 3)

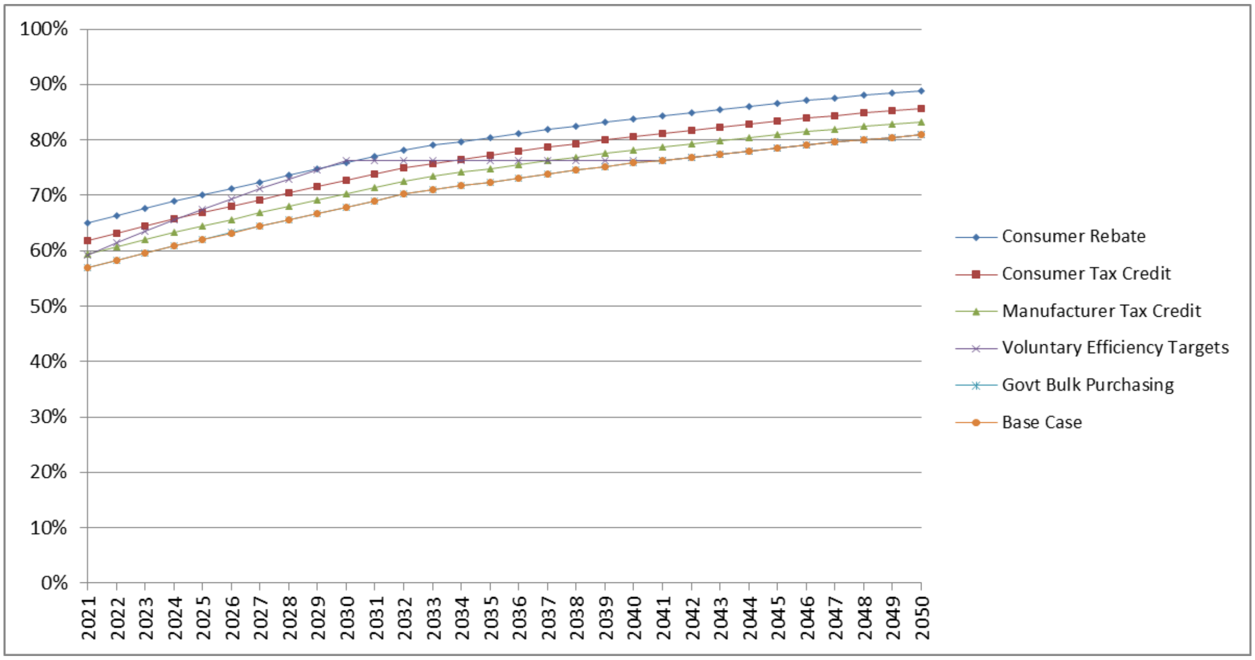

Figure 17.4.4 Market Penetration of NWGFs (Commercial, North) (TSL 3)

Table 17.4.1 shows the national energy savings and net present value for five non-regulatory policies analyzed in detail for NWGFs. The target level for each policy equals the efficiency level proposed for standards in TSL 3. The case in which no regulatory action is taken with regard to NWGFs constitutes the base case (or "No New Regulatory Action" scenario), in which NES and NPV are zero by definition. For comparison, the tables include the impacts of the proposed standards. Energy savings are given in quadrillion British thermal units (quads). The NPVs shown in Table 17.4.1 are based on two discount rates, 7 percent and 3 percent.

The policies with the highest projected cumulative energy savings are consumer rebates and voluntary energy efficiency targets. Government bulk purchases, due to the very low share of housing units in public housing authority, lead to little benefits.

Table 17.4.1 Impacts of Non-Regulatory Alternatives for Residential Non-Weatherized Gas-Fired Furnaces (TSL 3)

Policy Alternative	**Primary Energy Savings*** *quads*		**Net Present Value*** *billion 2013$*	
			7% Discount Rate	3% Discount Rate
Consumer Rebates	1.839	(43.7%)	1.798	7.946
Consumer Tax Credits	1.103	(26.2%)	1.079	4.768
Manufacturer Tax Credits	0.552	(13.1%)	0.540	2.384
Voluntary Energy Efficiency Targets	1.379	(32.7%)	1.230	5.743
Bulk Government Purchases	0.029	(0.7%)	0.026	0.122
Proposed Standards	4.210	(100.0%)	3.880	17.568

* For products shipped from 2021 – 2050

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APPENDIX 17A. REGULATORY IMPACT ANALYSIS: SUPPORTING MATERIALS

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APPENDIX 17A. REGULATORY IMPACT ANALYSIS: SUPPORTING MATERIALS

17A.1 INTRODUCTION

This appendix contains sections discussing the following topics:

- Projections of annual market share increases for the alternative policies;
- NIA-RIA Integrated Model;
- XENERGY penetration curves used to analyze consumer rebates, including:
  - Background material,
  - DOE's adjustment of these curves for this analysis, and
  - The method DOE used for interpolating the curves;
- Detailed tables of rebates offered for the considered products; and
- Background material on Federal and state tax credits for appliances.

17A.2 MARKET SHARE ANNUAL INCREASES BY POLICY

Table 17A.2.1 through Table 17A.2.4 show the annual increases in market shares of *residential non-weatherized gas-fired furnaces* (NWGFs) meeting the target efficiency levels for the proposed TSL (TSL 3). DOE used these market share increases as inputs to the NIA-RIA spreadsheet model.

Table 17A.2.1 Annual Increases in Market Shares Attributable to Alternative Policy Measures for NWGFs (Residential, Rest of Country) (TSL 3)

Year	Consumer Rebates	Consumer Tax Credits	Manufacturer Tax Credits	Voluntary Energy Efficiency Targets	Bulk Government Purchases
2021	34.9%	20.9%	10.5%	6.2%	0.1%
2022	34.9%	20.9%	10.5%	10.4%	0.2%
2023	34.9%	20.9%	10.5%	13.7%	0.3%
2024	34.9%	20.9%	10.5%	16.6%	0.4%
2025	34.9%	20.9%	10.5%	19.1%	0.5%
2026	34.9%	20.9%	10.5%	23.9%	0.6%
2027	34.9%	20.9%	10.5%	30.5%	0.7%
2028	34.9%	20.9%	10.5%	36.1%	0.8%
2029	34.9%	20.9%	10.5%	41.1%	0.9%
2030	34.9%	20.9%	10.5%	45.5%	1.0%
2031	34.9%	20.9%	10.5%	45.1%	1.0%
2032	34.9%	20.9%	10.5%	44.7%	1.0%
2033	34.9%	20.9%	10.5%	44.5%	1.0%
2034	34.9%	20.9%	10.5%	44.2%	1.0%
2035	34.9%	20.9%	10.5%	44.0%	1.0%
2036	34.9%	20.9%	10.5%	43.7%	1.0%
2037	34.9%	20.9%	10.5%	43.4%	0.9%
2038	34.9%	20.9%	10.5%	43.2%	0.9%
2039	34.9%	20.9%	10.5%	42.9%	0.9%
2040	34.9%	20.9%	10.5%	42.7%	0.9%
2041	34.9%	20.9%	10.5%	42.4%	0.9%
2042	34.9%	20.9%	10.5%	42.1%	0.9%
2043	34.9%	20.9%	10.5%	41.9%	0.9%
2044	34.9%	20.9%	10.5%	41.6%	0.9%
2045	34.9%	20.9%	10.5%	41.4%	0.9%
2046	34.9%	20.9%	10.5%	41.1%	0.9%
2047	34.9%	20.9%	10.5%	40.8%	0.9%
2048	34.9%	20.9%	10.5%	40.6%	0.9%
2049	34.9%	20.9%	10.5%	40.3%	0.9%
2050	34.9%	20.9%	10.5%	40.1%	0.9%

Table 17A.2.2 Annual Increases in Market Shares Attributable to Alternative Policy Measures for NWGFs (Residential, North) (TSL 3)

Year	Consumer Rebates	Consumer Tax Credits	Manufacturer Tax Credits	Voluntary Energy Efficiency Targets	Bulk Government Purchases
2021	11.3%	6.8%	3.4%	1.3%	0.0%
2022	11.3%	6.8%	3.4%	1.5%	0.0%
2023	11.3%	6.8%	3.4%	1.7%	0.0%
2024	11.3%	6.8%	3.4%	1.9%	0.0%
2025	11.3%	6.8%	3.4%	2.1%	0.0%
2026	11.3%	6.8%	3.4%	2.3%	0.0%
2027	11.3%	6.8%	3.4%	2.5%	0.0%
2028	11.3%	6.8%	3.4%	2.7%	0.0%
2029	11.3%	6.8%	3.4%	2.9%	0.0%
2030	11.3%	6.8%	3.4%	3.0%	0.0%
2031	11.3%	6.8%	3.4%	2.0%	0.0%
2032	11.3%	6.8%	3.4%	1.1%	0.0%
2033	11.3%	6.8%	3.4%	0.5%	0.0%
2034	11.3%	6.8%	3.4%	0.0%	0.0%
2035	11.3%	6.8%	3.4%	0.0%	0.0%
2036	11.3%	6.8%	3.4%	0.0%	0.0%
2037	11.3%	6.8%	3.4%	0.0%	0.0%
2038	11.3%	6.8%	3.4%	0.0%	0.0%
2039	11.3%	6.8%	3.4%	0.0%	0.0%
2040	11.3%	6.8%	3.4%	0.0%	0.0%
2041	11.3%	6.8%	3.4%	0.0%	0.0%
2042	11.3%	6.8%	3.4%	0.0%	0.0%
2043	11.3%	6.8%	3.4%	0.0%	0.0%
2044	11.3%	6.8%	3.4%	0.0%	0.0%
2045	11.3%	6.8%	3.4%	0.0%	0.0%
2046	11.3%	6.8%	3.4%	0.0%	0.0%
2047	11.3%	6.8%	3.4%	0.0%	0.0%
2048	11.3%	6.8%	3.4%	0.0%	0.0%
2049	11.3%	6.8%	3.4%	0.0%	0.0%
2050	11.3%	6.8%	3.4%	0.0%	0.0%

Table 17A.2.3 Annual Increases in Market Shares Attributable to Alternative Policy Measures for NWGFs (Commercial, Rest of Country) (TSL 3)

Year	Consumer Rebates	Consumer Tax Credits	Manufacturer Tax Credits	Voluntary Energy Efficiency Targets	Bulk Government Purchases
2021	14.2%	8.5%	4.3%	3.4%	0.1%
2022	14.2%	8.5%	4.3%	5.9%	0.2%
2023	14.2%	8.5%	4.3%	8.1%	0.3%
2024	14.2%	8.5%	4.3%	10.0%	0.3%
2025	14.2%	8.5%	4.3%	13.5%	0.4%
2026	14.2%	8.5%	4.3%	19.3%	0.5%
2027	14.2%	8.5%	4.3%	24.1%	0.6%
2028	14.2%	8.5%	4.3%	28.4%	0.6%
2029	14.2%	8.5%	4.3%	32.3%	0.7%
2030	14.2%	8.5%	4.3%	35.7%	0.8%
2031	14.2%	8.5%	4.3%	35.2%	0.8%
2032	14.2%	8.5%	4.3%	34.9%	0.8%
2033	14.2%	8.5%	4.3%	34.6%	0.8%
2034	14.2%	8.5%	4.3%	34.3%	0.8%
2035	14.2%	8.5%	4.3%	34.0%	0.8%
2036	14.2%	8.5%	4.3%	33.7%	0.8%
2037	14.2%	8.5%	4.3%	33.5%	0.7%
2038	14.2%	8.5%	4.3%	33.2%	0.7%
2039	14.2%	8.5%	4.3%	32.9%	0.7%
2040	14.2%	8.5%	4.3%	32.6%	0.7%
2041	14.2%	8.5%	4.3%	32.3%	0.7%
2042	14.2%	8.5%	4.3%	32.0%	0.7%
2043	14.2%	8.5%	4.3%	31.7%	0.7%
2044	14.2%	8.5%	4.3%	31.5%	0.7%
2045	14.2%	8.5%	4.3%	31.2%	0.7%
2046	14.2%	8.5%	4.3%	30.9%	0.7%
2047	14.2%	8.5%	4.3%	30.6%	0.7%
2048	14.2%	8.5%	4.3%	30.3%	0.7%
2049	14.2%	8.5%	4.3%	30.0%	0.7%
2050	14.2%	8.5%	4.3%	29.7%	0.6%

Table 17A.2.4 Annual Increases in Market Shares Attributable to Alternative Policy Measures for NWGFs (Commercial, North) (TSL 3)

Year	Consumer Rebates	Consumer Tax Credits	Manufacturer Tax Credits	Voluntary Energy Efficiency Targets	Bulk Government Purchases
2021	8.0%	4.8%	2.4%	2.3%	0.0%
2022	8.0%	4.8%	2.4%	3.1%	0.0%
2023	8.0%	4.8%	2.4%	3.9%	0.0%
2024	8.0%	4.8%	2.4%	4.6%	0.0%
2025	8.0%	4.8%	2.4%	5.4%	0.0%
2026	8.0%	4.8%	2.4%	6.2%	0.0%
2027	8.0%	4.8%	2.4%	6.8%	0.0%
2028	8.0%	4.8%	2.4%	7.4%	0.0%
2029	8.0%	4.8%	2.4%	8.0%	0.0%
2030	8.0%	4.8%	2.4%	8.4%	0.0%
2031	8.0%	4.8%	2.4%	7.3%	0.0%
2032	8.0%	4.8%	2.4%	6.1%	0.0%
2033	8.0%	4.8%	2.4%	5.3%	0.0%
2034	8.0%	4.8%	2.4%	4.6%	0.0%
2035	8.0%	4.8%	2.4%	3.9%	0.0%
2036	8.0%	4.8%	2.4%	3.2%	0.0%
2037	8.0%	4.8%	2.4%	2.5%	0.0%
2038	8.0%	4.8%	2.4%	1.8%	0.0%
2039	8.0%	4.8%	2.4%	1.1%	0.0%
2040	8.0%	4.8%	2.4%	0.5%	0.0%
2041	8.0%	4.8%	2.4%	0.0%	0.0%
2042	8.0%	4.8%	2.4%	0.0%	0.0%
2043	8.0%	4.8%	2.4%	0.0%	0.0%
2044	8.0%	4.8%	2.4%	0.0%	0.0%
2045	8.0%	4.8%	2.4%	0.0%	0.0%
2046	8.0%	4.8%	2.4%	0.0%	0.0%
2047	8.0%	4.8%	2.4%	0.0%	0.0%
2048	8.0%	4.8%	2.4%	0.0%	0.0%
2049	8.0%	4.8%	2.4%	0.0%	0.0%
2050	8.0%	4.8%	2.4%	0.0%	0.0%

17A.3 NIA-RIA INTEGRATED MODEL

For this analysis, DOE used its integrated NIA-RIA[a] model approach that built on the NIA model discussed in chapter 10 and documented in appendix 10A.The resulting integrated NIA-RIA model featured both the NIA analysis inputs and results and the RIA inputs and had the capability to generate results for each of the RIA policies. A separate module produced results summaries for the tables and figures in the RIA document. For the RIA methodology

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[a] NIA = national impact analysis; RIA = regulatory impact analysis

documentation in chapter 17, the module created summaries of parameters calculated by the model for the consumer rebates policy, generated its penetration curves (discussed in section 17A.4.3 below), and reported market share impacts for the rebate and tax credit policies by product class. For the RIA results reported in chapter 17, the module produced graphs of the market share increases resulting from each of the policies analyzed and created summary tables for the national energy savings (NES) and net present value (NPV) results. This module also generated tables of market share increases for each policy reported in section 17A.2 of this appendix.

17A.4 CONSUMER REBATE POLICY MARKET PENETRATION CURVES

This section first discusses the theoretical basis for the market penetration curves that DOE used to analyze the Consumer Rebates policy. Next it discusses the adjustments it made to the maximum penetration rates. It then refers to the method it used to develop interpolated penetration curves for each specific product class and efficiency level in the analysis. The resulting curves for the NWGFs product classes are in chapter 17.

17A.4.1 Introduction

XENERGY, Inc.[b], developed a re-parameterized, mixed-source information diffusion model to estimate market impacts induced by financial incentives for purchasing energy efficient appliances.[1] The basic premise of the mixed-source model is that information diffusion drives the adoption of technology.

Extensive economic literature describes the diffusion of new products as technologies evolve. Some research focuses primarily on developing analytical models of diffusion patterns applicable to individual consumers or to technologies from competing firms.[2, 3, 4] One study records researchers' attempts to investigate the factors that drive diffusion processes.[5] Because a new product generally has its own distinct characteristics, few studies have been able to conclusively develop a universally applicable model. Some key findings, however, generally are accepted in academia and industry.

One accepted finding is that, regardless of their economic benefits and technological merits, new technologies are unlikely to be adopted by all potential users. For many products, a ceiling must be placed on the adoption rate. A second conclusion is that not all adopters purchase new products at the same time: some act quickly after a new product is introduced; others wait for the product to mature. Third, diffusion processes can be characterized approximately by asymmetric S-curves that depict three stages of diffusion: starting, accelerating, and decreasing (as the adoption ceiling is approached).

A so-called epidemic model of diffusion is used widely in marketing and social studies. The epidemic model assumes that (1) all consumers place identical value on the benefits of a new product, and (2) the cost of a new product is constant or declines monotonically over time.

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[b] XENERGY is now owned by KEMA, Inc. (www.kema.com)

What induces a consumer to purchase a new product is information about the availability and benefits of the product. In other words, information diffusion drives consumers' adoption of a new product.[3] The model incorporates information diffusion from both internal sources (spread by word of mouth from early adopters to prospective adopters) and external sources (the "announcement effect" produced by government agencies, institutions, or commercial advertising). The model incorporates both internal and external sources by combining a logistic function with an exponential function.[4,5]

The relative degree of influence from the internal and external sources determines the general shape of the diffusion curve for a specific product.[4,5] If adoption of a product is influenced primarily by external sources of information (the announcement effect), for instance, a high rate of diffusion occurs at the beginning of the process. In this scenario, external sources provide immediate information exposure to a significant number of prospective adopters. In contrast, internal sources (such as a network of prospective adopters) are relatively small in size and reach, producing a more gradual exposure to prospective adopters. Graphically speaking, information diffusion dominated by external sources is represented by a concave curve (the exponential curve in Figure 17A.4.1). If adoption of a new product is influenced most strongly by internal sources of information, the number of adopters increases gradually, forming a convex curve (the logistic curve in Figure 17A.4.1).

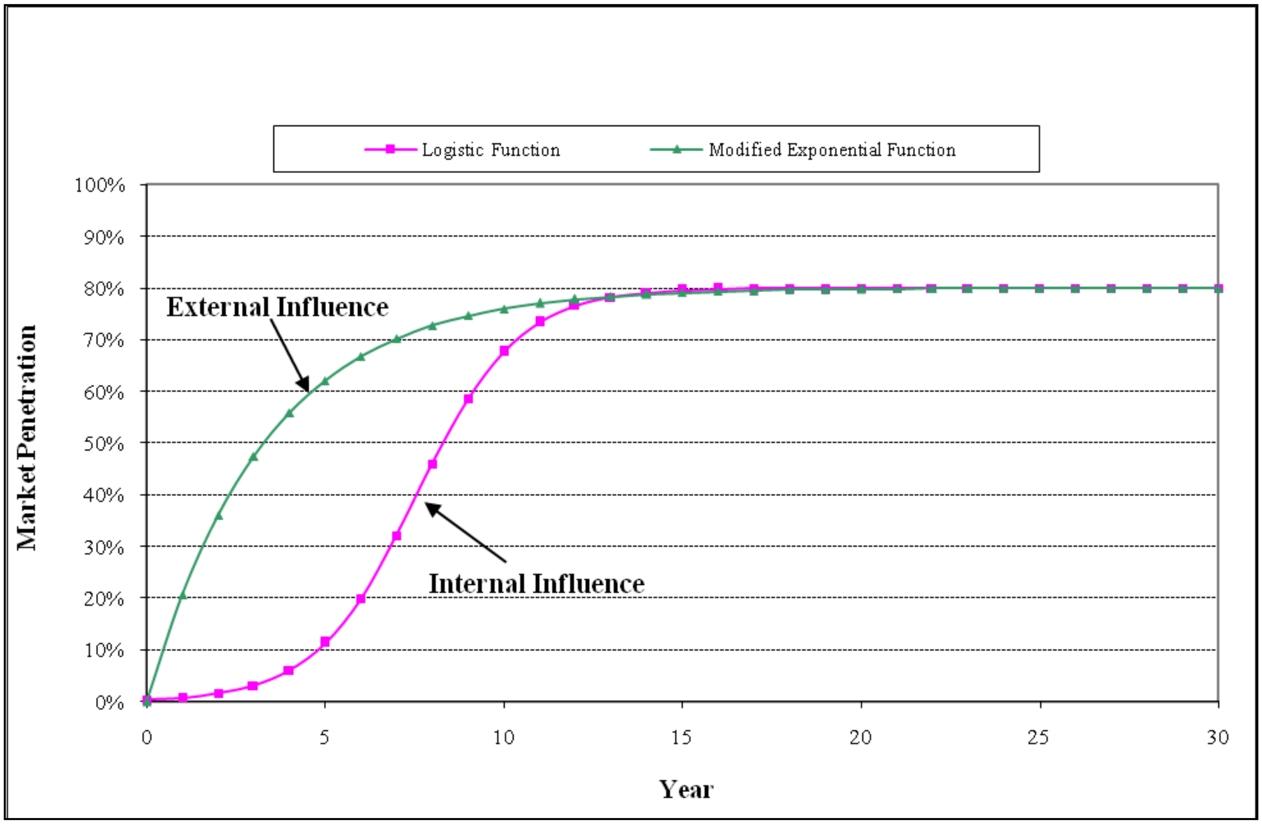

Figure 17A.4.1 S-Curves Showing Effects of External and Internal Sources on Adoption of New Technologies

17A.4.2 Adjustment of XENERGY Penetration Curves

In consultation with the primary authors of the 2002 XENERGY study who later conducted similar California studies, DOE made some adjustments to XENERGY's original implementation (penetration) curves.[6] The experiences with utility programs since the XENERGY study indicate that incentive programs have difficulty achieving penetration rates as high as 80 percent. Consumer response is limited by barriers created by consumer utility issues and other non-economic factors. DOE therefore adjusted the maximum penetration parameters for some of the curves from 80 percent to the following levels:

Moderate Barriers:	70%
High Barriers:	60%
Extremely High Barriers:	50%

The *low barriers* and *no barriers* curves (the latter used only when a product has a very high base-case-market share) remained, respectively, with 80 percent and 100 percent as their maximum penetration rates. For the interpolated penetration curves (discussed below), DOE set the *no barriers* and *extremely high barriers* curves as the upper and lower bounds, respectively, for any benefit/cost ratio points higher or lower than the curves. It set another constraint such that the policy case market share cannot be great than 100 percent, as might occur for products with high base case market shares of the target-level technology.

17A.4.3 Interpolation of Penetration Curves

As discussed above, the XENERGY penetration (implementation) curves followed a functional form to estimate the market implementation rate caused by energy efficiency measures such as consumer rebates.[c] The XENERGY report presents five reference market implementation curves that vary according to the level of market barriers to technology penetration.[1] Such curves have been used by DOE in the Regulatory Impact Analyses for rulemakings for appliance energy efficiency standards to estimate market share increases in response to rebate programs.[d] They provide a framework for evaluating technology penetration, yet require matching the studied market to the curve that best represents it. This approximate matching can introduce some inaccuracy to the analysis.

Blum et al (2011, appendix A)[7] presents an alternative approach to such evaluation: a method to estimate market implementation rates more accurately by performing interpolations of the reference curves. The referred report describes the market implementation rate function and the reference curves, the method to calibrate the function to a given market, and the limitations of the method.

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[c] Chapter 17 refers to these curves as *penetration curves*. This section, in references to the original source, uses the term *implementation curve*.

[d] DOE has also used this method to estimate market share increases resulting from consumer tax credit and manufacturer tax credit programs, since the effects of tax credits on markets can be considered proportional to the rebate impacts.

17A.5 CONSUMER REBATE PROGRAMS

DOE performed an internet search for rebate programs that offered incentives for NWGFs in July, 2014. Some organizations nationwide, comprising electric utilities and regional agencies, offer rebate programs for this equipment. Table 17A.5.4 provides the organizations' names, states, rebate amounts with corresponding AFUEs, and program websites (as they were available in July, 2014). If there is more than one entry for an organization, it offers different rebates in different states. When an organization offers rebates through several utilities, it is represented only once in each table.

DOE performed statistical analysis to calculate a rebate amount for NWGFs. It relied on the data it gathered from 155 rebates programs offered by 65 organizations (see Table 17A.5.4). Most programs set a target efficiency level based on AFUE.[e] DOE estimated a rebate value per unit of AFUE using the following regression model:

$$reb(AFUE) = \beta_{AFUE} \cdot AFUE + \varepsilon$$

Eq. 17A.1

Where:

$reb(AFUE)$	rebate value (dollars per AFUE) offered towards a unit with efficiency level *AFUE*
$AFUE$	efficiency level (AFUE) targeted by the rebate program
β_{AFUE}	statistical coefficient
ε	statistical error.

Table 17A.5.2 shows the results for the model above. Table 17A.5.3 presents the rebate amounts calculated for each efficiency level covered by this rulemaking.

Table 17A.5.2 Results from regression model*

	Coefficient	Unit	SE	P-Value
β_{AFUE}	3.461	dollars/AFUE	0.132	0.000

* R^2=0.819

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[e] DOE assumed the ENERGY STAR regional AFUE levels (0.90 AFUE for Rest of Country, 0.95 AFUE for North) as the minimum efficiency level for the programs that do not specify an AFUE level for program eligibility.

Table 17A.5.3 Rebate amount by efficiency level

AFUE	Rebate (*2013$*)
0.90	311.53
0.95	328.83
0.92*	**318.45**
0.95*	328.83
0.98	339.22

* Target level.

Table 17A.5.4 Rebates for Residential Non-Weatherized Gas-Fired Furnaces[f]

Organization	State	Rebate	AFUE (%)	Website
Alagasco	AL	$800	90	www.alagasco.com/ways-to-save/rebates---offers/furnace-rebate-885.html
CenterPoint Energy	AR	$400	90	www.centerpointenergy.com/services/naturalgas/residential/efficiencyrebatesandprograms/heatingsystemrebates/AR/
CenterPoint Energy	AR	$600	95	www.centerpointenergy.com/services/naturalgas/residential/efficiencyrebatesandprograms/heatingsystemrebates/AR/
CenterPoint Energy	AR	$125	80	www.centerpointenergy.com/services/naturalgas/residential/efficiencyrebatesandprograms/heatingsystemrebates/AR/
CenterPoint Energy	AR	$175	90	www.centerpointenergy.com/services/naturalgas/residential/efficiencyrebatesandprograms/heatingsystemrebates/AR/
SourceGas	AR	$400	90	http://excessisout.com/sourcegas-arkansas/how_we_can_help/residential_reduce_and_rebate/
SourceGas	AR	$600	95	http://excessisout.com/sourcegas-arkansas/how_we_can_help/residential_reduce_and_rebate/
Southern California Gas Company	CA	$250	95	http://socalgas.com/for-your-home/rebates/multifamily/
Energy Smart	CO	$300	92	www.energysmartyes.com/rebates/for-homes.html
SourceGas	CO	$300	94	www.energysmartcolorado.com/rebates-2/
Atoms Energy	CO	$200	92	www.energysmartcolorado.com/rebates-2/
Atoms Energy	CO	$300	94	www.energysmartcolorado.com/rebates-2/
Xcel Energy	CO	$120	94	www.energysmartcolorado.com/rebates-2/
City of Fort Collins	CO	$300	90	www.fcgov.com/utilities/residential/conserve/energy-efficiency/home-efficiency-program/rebates#furnace
City of Fort Collins	CO	$500	92	www.fcgov.com/utilities/residential/conserve/energy-efficiency/home-efficiency-program/rebates#furnace

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[f] This table is based on rebate programs DOE found to be available through an extensive internet search in July, 2014.

Organization	**State**	**Rebate**	**AFUE (%)**	**Website**
Connecticut Light & Power	CT	$600	95	www.cl-p.com/Home/SaveEnergy/High_Efficiency_Furnace_and_Natural_Gas_Boiler_Rebate/?MenuID=4294986191
UI	CT	$600	95	www.uinet.com/wps/portal/uinet/residential/!ut/p/c5
CNG	CT	$600	95	www.cngcorp.com/wps/portal/cng/yourhome/!ut/p/c5
Southern Connecticut Gas	CT	$600	95	www.soconngas.com/wps/portal/scg/yourhome/!ut/p/c5
Yankee Gas	CT	$600	95	www.yankeegas.com/For_your_Home/SaveEnergyAndMoney/High_Efficiency_Furnace_and_Natural_Gas_Boiler_Rebate/
Norwich Public Utilities	CT	$400	95	http://norwichpublicutilities.com/index.php/my-home/efficiency-home
Energize Delaware	DE	$200	90	www.energizedelaware.org/Incentives/
Energize Delaware	DE	$350	94	www.energizedelaware.org/Incentives/
City of Tallahassee	FL	$700	90	www.talgov.com/you/you-products-home-gas-rebates.aspx
City of Tallahassee	FL	$350	90	www.talgov.com/you/you-products-home-gas-rebates.aspx
Florida Public Utilities	FL	$725	90	www.fpuc.com/naturalgas/rebates-conservation/rebates/
Florida Public Utilities	FL	$500	90	www.fpuc.com/naturalgas/rebates-conservation/rebates/
Florida Public Utilities	FL	$500	90	www.fpuc.com/naturalgas/rebates-conservation/rebates/
North Shore Gas	IL	$350	95	www.northshoregasdelivery.com/home/rebates_residential.aspx
Citizens Energy Savers	IN	$150	92	https://citizens-residential-rebates.clearesult.com/#rebateintakewelcome
Citizens Energy Savers	IN	$250	95	https://citizens-residential-rebates.clearesult.com/#rebateintakewelcome
NIPSCO	IN	$250	95	www.nipsco.com/save-energy/residential/energy-efficiency-rebates/equipment-rebates
NIPSCO	IN	$200	95	www.nipsco.com/save-energy/residential/energy-efficiency-rebates/equipment-rebates
NIPSCO	IN	$150	92	www.nipsco.com/save-energy/residential/energy-efficiency-rebates/equipment-rebates
Vectren	IN	$150	*92*	www.vectren.com/Save_Energy/Residential_Rebates_&_Incentives/Residential_Rebates.jsp
Vectren	IN	$250	*95*	www.vectren.com/Save_Energy/Residential_Rebates_&_Incentives/Residential_Rebates.jsp
Alliant Energy	IA	$500	94	www.alliantenergy.com/SaveEnergyAndMoney/Rebates/HomeIA/030030
Alliant Energy	IA	$700	96	www.alliantenergy.com/SaveEnergyAndMoney/Rebates/HomeIA/030030
Liberty Utilities	IA	$250	92	www.libertyutilities.com/central/saving/ee_iowa_heer.html
Liberty Utilities	IA	$325	94	www.libertyutilities.com/central/saving/ee_iowa_heer.html
Liberty Utilities	IA	$400	96	www.libertyutilities.com/central/saving/ee_iowa_heer.html
Cedar Falls Utilities	IA	$400	95	www.cfu.net/save-energy/residential-rebates.aspx

Organization	State	Rebate	AFUE (%)	Website
Atmos Energy	KY	$250	90	http://atmosenergy.com/home/efficiency/ky_rebate.html
Atmos Energy	KY	$325	94	http://atmosenergy.com/home/efficiency/ky_rebate.html
Atmos Energy	KY	$400	96	http://atmosenergy.com/home/efficiency/ky_rebate.html
Baltimore Gas & Electric	MD	$300	92	www.bgesmartenergy.com/residential/heating-cooling/equipment
Baltimore Gas & Electric	MD	$400	92	www.bgesmartenergy.com/residential/heating-cooling/equipment
Maryland Be SMART Home Efficiency Rebate Program	MD	$500	95	www.mdhousing.org/website/programs/BeSmart/rebate.aspx
Berkshire Gas	MA	$300	95	www.berkshiregas.com/wps/portal/bgc/usageandsafety/!ut/p/c5
Berkshire Gas	MA	$600	97	www.berkshiregas.com/wps/portal/bgc/usageandsafety/!ut/p/c5
Columbia Gas of Massachusetts	MA	$300	95	www.columbiagasma.com/en/ways-to-save/natural-gas-equipment-rebate-program
Columbia Gas of Massachusetts	MA	$600	97	www.columbiagasma.com/en/ways-to-save/natural-gas-equipment-rebate-program
GasNetworks	MA	$300	95	www.gasnetworks.com/efficiency/applications.asp
GasNetworks	MA	$450	97	www.gasnetworks.com/efficiency/applications.asp
Consumers Energy	MI	$200	95	www.consumersenergy.com/eeprograms/RRebateChart.aspx?id=4123
Consumers Energy	MI	$250	96	www.consumersenergy.com/eeprograms/RRebateChart.aspx?id=4123
Consumers Energy	MI	$300	97	www.consumersenergy.com/eeprograms/RRebateChart.aspx?id=4123
DTE Energy	MI	$200	95	https://www2.dteenergy.com/wps/portal/dte/residential/saveEnergy/details/Rebates%20and%20Offers/Heating%20Equipment/!ut/p/b1/
DTE Energy	MI	$250	96	https://www2.dteenergy.com/wps/portal/dte/residential/saveEnergy/details/Rebates%20and%20Offers/Heating%20Equipment/!ut/p/b1
DTE Energy	MI	$300	97	https://www2.dteenergy.com/wps/portal/dte/residential/saveEnergy/details/Rebates%20and%20Offers/Heating%20Equipment/!ut/p/b1
Energy Smart (20 Municipalities)	MI	$150	95	www.mienergysmart.com/
Lansing Board of Water & Light	MI	$150	95	www.lbwl.com/energysavers.aspx
Center Point Energy	MN	$150	92	www.centerpointenergy.com/services/naturalgas/residential/efficiencyrebatesandprograms/heatingsystemrebates/587c4f5b7a1c3110VgnVCM10000001a10d0aRCRD/MN/
Center Point Energy	MN	$300	94	www.centerpointenergy.com/services/naturalgas/residential/efficiencyrebatesandprograms/heatingsystemrebates/587c4f5b7a1c3110VgnVCM10000001a10d0aRCRD/MN/
Center Point Energy	MN	$400	96	www.centerpointenergy.com/services/naturalgas/residential/efficiencyrebatesandprograms/heatingsystemrebates/587c4f5b7a1c3110VgnVCM10000001a10d0aRCRD/MN/
Center Point Energy	MN	$50	92	www.centerpointenergy.com/services/naturalgas/residenti

Organization	State	Rebate	AFUE (%)	Website
				al/efficiencyrebatesandprograms/heatingsystemrebates/587c4f5b7a1c3110VgnVCM10000001a10d0aRCRD/MN/
Center Point Energy	MN	$350	95	www.centerpointenergy.com/services/naturalgas/residential/efficiencyrebatesandprograms/heatingsystemrebates/587c4f5b7a1c3110VgnVCM10000001a10d0aRCRD/MN/
Minnesota Energy	MN	$500	92	www.minnesotaenergyresources.com/business/builders_low_income_rebates.aspx
Minnesota Power	MN	$200	95	www.mnpower.com/EnergyConservation/RebatesAndSavings
New Ulm Minnesota	MN	$200	94	www.ci.new-ulm.mn.us/index.asp?SEC=743A5650-3018-4B6E-B7B0-662834287912&DE=C2171BC0-5163-4B5B-A7FA-3CB25AAE5C7A&Type=B_BASIC
New Ulm Minnesota	MN	$100	92	www.ci.new-ulm.mn.us/index.asp?SEC=743A5650-3018-4B6E-B7B0-662834287912&DE=C2171BC0-5163-4B5B-A7FA-3CB25AAE5C7A&Type=B_BASIC
New Ulm Minnesota	MN	$200	94	www.ci.new-ulm.mn.us/index.asp?SEC=743A5650-3018-4B6E-B7B0-662834287912&DE=C2171BC0-5163-4B5B-A7FA-3CB25AAE5C7A&Type=B_BASIC
Northern Municipal Power Agency	MN	$150	95	www.minnkota.com/Conservation/
Owatonna Public Utilities	MN	$100	92	www.owatonnautilities.com/residential-customers/residential-rebates
Owatonna Public Utilities	MN	$200	95	www.owatonnautilities.com/residential-customers/residential-rebates
Owatonna Public Utilities	MN	$300	96	www.owatonnautilities.com/residential-customers/residential-rebates
Ameren	MO	$150	92	www.ameren.com/sites/aue/NaturalGas/Pages/ResidentialNaturalGasPrograms.aspx
Ameren	MO	$200	92	www.ameren.com/sites/aue/NaturalGas/Pages/ResidentialNaturalGasPrograms.aspx
Ameren	MO	$250	94	www.ameren.com/sites/aue/NaturalGas/Pages/ResidentialNaturalGasPrograms.aspx
Ameren	MO	$300	94	www.ameren.com/sites/aue/NaturalGas/Pages/ResidentialNaturalGasPrograms.aspx
Liberty Utilities	MO	$200	92	www.libertyutilities.com/central/saving/ee_missouri_heer.html
Liberty Utilities	MO	$250	94	www.libertyutilities.com/central/saving/ee_missouri_heer.html
Liberty Utilities	MO	$300	96	www.libertyutilities.com/central/saving/ee_missouri_heer.html
City Utilities of Springfield	MO	$400	95	www.cityutilities.net/conserve/pgm-hvac.htm
Laclede Gas Company	MO	$150	92	www.originalgreenenergy.com/rebatesandsavings/residentialhighefficiencyheating/
Laclede Gas Company	MO	$200	96	www.originalgreenenergy.com/rebatesandsavings/residentialhighefficiencyheating/
Energy Sense	MO	$200	90	www.betterheatingnow.com/central-heating.html
Energy Sense	MO	$300	96	www.betterheatingnow.com/central-heating.html
Alliant Energy	MN	$250	92	www.alliantenergy.com/SaveEnergyAndMoney/Rebates/HomeMN/030052

Organization	State	Rebate	AFUE (%)	Website
Alliant Energy	MN	$325	94	www.alliantenergy.com/SaveEnergyAndMoney/Rebates/HomeMN/030052
Alliant Energy	MN	$400	96	www.alliantenergy.com/SaveEnergyAndMoney/Rebates/HomeMN/030052
MidAmerican Energy	NE	$250	92	www.midamericanenergy.com/ee/ne_res_rebates.aspx
MidAmerican Energy	NE	$325	94	www.midamericanenergy.com/ee/ne_res_rebates.aspx
MidAmerican Energy	NE	$400	96	www.midamericanenergy.com/ee/ne_res_rebates.aspx
Southwest Gas Corporation	NV	$300	92	www.swgasliving.com/rebates/nevada/nevada-northern-nv-only-furnace-homeownerrenter
Southwest Gas Corporation	NV	$400	95	www.swgasliving.com/rebates/nevada/nevada-northern-nv-only-furnace-homeownerrenter
Southwest Gas Corporation	NV	$500	97	www.swgasliving.com/rebates/nevada/nevada-northern-nv-only-furnace-homeownerrenter
New Jersey's Clean Energy Program	NJ	$250	92	www.njcleanenergy.com/residential/programs/warmadvantage/furnaces-and-boilers
New Jersey's Clean Energy Program	NJ	$250	85	www.njcleanenergy.com/residential/programs/warmadvantage/furnaces-and-boilers
New Mexico Gas Company	NN	$200	90	www.nmgcgetrebates.com/furnace
New Mexico Gas Company	NN	$250	92	www.nmgcgetrebates.com/furnace
New Mexico Gas Company	NN	$300	95	www.nmgcgetrebates.com/furnace
New Mexico Gas Company	NN	$275	90	www.nmgcgetrebates.com/furnace
New Mexico Gas Company	NN	$325	92	www.nmgcgetrebates.com/furnace
New Mexico Gas Company	NN	$375	95	www.nmgcgetrebates.com/furnace
National Fuel	NY	$300	90	www.nationalfuelforthought.com/rebate-conditions7.html
National Fuel	NY	$400	90	www.nationalfuelforthought.com/rebate-conditions7.html
National Grid: New York - Long Island	NY	$450	94	https://www1.nationalgridus.com/EnergyEfficiencyPrograms
National Grid: New York - Long Island	NY	$300	92	https://www1.nationalgridus.com/EnergyEfficiencyPrograms
National Grid: New York - Long Island	NY	$140	90	https://www1.nationalgridus.com/EnergyEfficiencyPrograms
National Grid: New York - Metro	NY	$600	94	https://www1.nationalgridus.com/EnergyEfficiencyPrograms-NYM-RES
National Grid: New York - Metro	NY	$400	92	https://www1.nationalgridus.com/EnergyEfficiencyPrograms-NYM-RES
National Grid: New York - Metro	NY	$200	90	https://www1.nationalgridus.com/EnergyEfficiencyPrograms-NYM-RES
National Grid: New York - Upstate	NY	$420	94	https://www1.nationalgridus.com/EnergyEfficiencyPrograms
National Grid: New York - Upstate	NY	$280	92	https://www1.nationalgridus.com/EnergyEfficiencyPrograms
National Grid: New York - Upstate	NY	$140	90	https://www1.nationalgridus.com/EnergyEfficiencyPrograms

Organization	**State**	**Rebate**	**AFUE (%)**	**Website**
NYSEG	NY	$115	90	www.nyseg.com/UsageAndSafety/usingenergywisely/eeps/default.html
NYSEG	NY	$225	92	www.nyseg.com/UsageAndSafety/usingenergywisely/eeps/default.html
NYSEG	NY	$340	94	www.nyseg.com/UsageAndSafety/usingenergywisely/eeps/default.html
NYSEG	NY	$340	95	www.nyseg.com/UsageAndSafety/usingenergywisely/eeps/default.html
RG&E	NY	$115	90	www.rge.com/UsageAndSafety/usingenergywisely/eeps/default.html
RG&E	NY	$225	92	www.rge.com/UsageAndSafety/usingenergywisely/eeps/default.html
RG&E	NY	$340	94	www.rge.com/UsageAndSafety/usingenergywisely/eeps/default.html
RG&E	NY	$340	95	www.rge.com/UsageAndSafety/usingenergywisely/eeps/default.html
PSNC Energy	NC	$100	90	www.psncenergy.com/en/save-energy-and-money/appliance-rebates/default.htm
Bright Energy Solutions (offered by 5 utilities)	ND	$150	95	www.brightenergysolutions.com/municipalities/?category=home&state=nd
Columbia Gas of Ohio	OH	$300	96	www.columbiagasohio.com/ways-to-save/save-energy-money/furnace-rebates
Vectren	OH	$150	92	www.vectren.com/Save_Energy/Residential_Rebates_&_Incentives/Residential_Rebates.jsp
Vectren	OH	$250	95	www.vectren.com/Save_Energy/Residential_Rebates_&_Incentives/Residential_Rebates.jsp
CenterPoint Energy	OK	$300	90	www.centerpointenergy.com/services/naturalgas/residential/efficiencyrebatesandprograms/heatingsystemrebates/OK/
CenterPoint Energy	OK	$400	95	www.centerpointenergy.com/services/naturalgas/residential/efficiencyrebatesandprograms/heatingsystemrebates/OK/
Oklahoma Natural Gas	OK	$150	92	www.oklahomanaturalgas.com/en/SaveEnergyAndMoney/EnergyEfficiencyProgram/HeatingSystemReplacementProgram.aspx
Oklahoma Natural Gas	OK	$550	95	www.oklahomanaturalgas.com/en/SaveEnergyAndMoney/EnergyEfficiencyProgram/HeatingSystemReplacementProgram.aspx
Avista	OR	$200	90	www.avistautilities.com/savings/rebates/Pages/ORResidentialRebateInfo.aspx
Energy Trust of Oregon	OR	$100	90	http://energytrust.org/residential/incentives/heating-and-cooling/GasFurnaces1
PECO	PA	$300	95	www.peco.com/Savings/ProgramsandRebates/Residential/PECOSmartGasEfficiencyUpgrade/Pages/Overview.aspx
PGW	PA	$500	94	www.rebate-zone.com/pgworks/CurrentRebatesPGWRes.asp
National Grid: Rhode Island	RI	$600	97	https://www1.nationalgridus.com/EnergyEfficiencyPrograms
National Grid: Rhode	RI	$300	95	https://www1.nationalgridus.com/EnergyEfficiencyProgra

Organization	State	Rebate	AFUE (%)	Website
Island				ms
Bright Energy Solutions (offered by 10 utilities)	SD	$150	95	www.brightenergysolutions.com/municipalities/?category=home&state=sd
Bright Energy Solutions - City of Faith	SD	$200	90	www.brightenergysolutions.com/municipalities/?category=home&state=sd&municipality=68
Bright Energy Solutions - City of Faith	SD	$325	94	www.brightenergysolutions.com/municipalities/?category=home&state=sd&municipality=68
Bright Energy Solutions - City of Faith	SD	$400	96	www.brightenergysolutions.com/municipalities/?category=home&state=sd&municipality=68
MidAmerican Energy	SD	$600	95	www.midamericanenergy.com/ee/sd_res_rebates.aspx
Texas Gas Service	TX	$75	90	www.texasgasservice.com/en/SaveEnergyAndMoney/ConservationPrograms/AustinConservation/ResidentialPrograms/HeatingPrograms/Furnace.aspx
Vermont Gas	VT	$400	94	www.vermontgas.com/efficiency_programs/res_programs.html
Columbia Gas of Virginia	VA	$300	90	www.columbiagasva.com/ways-to-save/residential-customers/qualifying-equipment
Focus on Energy	WI	$100	90	https://focusonenergy.com/residential/programupdates
Focus on Energy	WI	$700	90	https://focusonenergy.com/residential/programupdates
Focus on Energy	WI	$475	95	https://focusonenergy.com/residential/programupdates
Questar Gas	WY	$200	92	www.thermwise.com/home/ApplianceRebates.php
Questar Gas	WY	$350	95	www.thermwise.com/home/ApplianceRebates.php
Questar Gas	WY	$400	95	www.thermwise.com/home/ApplianceRebates.php
Questar Gas	WY	$450	98	www.thermwise.com/home/ApplianceRebates.php

17A.6 FEDERAL AND STATE TAX CREDITS

This section summarizes the Federal and State tax credits available to consumers who purchase energy efficient appliances. This section also describes tax credits available to manufacturers who produce certain energy efficient appliances.

17A.6.1 Federal Tax Credits for Consumers

EPACT 2005 included Federal tax credits for consumers who installed efficient air conditioners or heat pumps; gas, oil and propane furnaces and boilers; furnace fans; and/or gas, oil, or electric heat pump water heaters in new or existing homes.[8, 9] These tax credits were in effect in 2006 and 2007, expired in 2008, and were reinstated for 2009–2010 by the American Recovery and Reinvestment Act (ARRA).[10] There was a $1,500 cap on the credit per home, including the amount received for insulation, windows, and air and duct sealing. Congress extended this provision for 2011, with some modifications to eligibility requirements, and reductions in the cap to $500 per home. The American Taxpayer Relief Act of 2012 extended,

with some modifications, residential tax credits for air conditioners, heat pumps, furnaces, and water heaters placed in service between January 1, 2012 and December 31, 2013.[8, 11]
The tax credit for furnace fans was $50 in 2011, after which it expired.

The importance of the Federal tax credits has been emphasized in research in the residential heating industry on the impacts of the relatively large credits that were available for HVAC (heating, ventilating, and air conditioning) equipment. In a survey of HVAC distributors conducted by Vermont Energy Investment Corporation, respondents indicated that the ample credit had had a notable impact on sales of higher-efficiency heating and cooling equipment. Some distributors combined the Federal tax credits with manufacturer rebates and utility program rebates for a greater consumer incentive. However, when the amount of the Federal tax credit was reduced, smaller utility rebate incentives had not induced the same levels of equipment sales increases. The decrease in incentive size from a $1,500 cap in 2009-2010 to a $500 cap in 2011, during a period when the economy continued to be sluggish, resulted in a decline in total sales of residential HVAC products. Distributors stated that an incentive needed to cover 25 to 75 percent of the incremental cost of the efficient equipment to influence consumer choice. The industry publication "2011 HVAC Review and Outlook" noted a decline in sales of air conditioning units with >14 SEER in 2011 and a return in sales of units with >16 SEER to 2009 levels (after an increase in 2010). The large majority of distributor observed no impacts from the utility programs with their lower rebate amounts available in 2011. Distributors also commented on the advantages of the Federal tax credit being nationwide in contrast to utility rebate programs that target regional markets.[12, 13]

In an effort to evaluate the potential impact of a Federal appliance tax credit program, DOE reviewed Internal Revenue Service (IRS) data on the numbers of taxpayers who claimed the tax credits during tax years 2006 and 2007. It estimated the percentage of taxpayers who filed Form 5695, *Residential Energy Credits.*[14] It also estimated the percentage of taxpayers with entries under Form 5695's section 3, *Residential energy property costs*, line 3b, *qualified natural gas, propane, or oil furnace or hot water boiler*. DOE reasoned that the percentage of taxpayers with an entry on Line 3b could serve as a rough indication of the potential of taxpayer participation in a Federal tax credit program for furnaces during the initial program years. DOE found that of all residential taxpayers filing tax returns, 0.8 percent in 2006 and 0.6 percent in 2007, claimed a credit for a furnace or boiler. DOE further found that the percentages of those filing Form 5695 for <u>any</u> qualifying energy property expenditure (which also included installation of efficient windows, doors and roofs) were 3.1 and 3.2 percent in 2006 and 2007 respectively.

DOE also reviewed data from an earlier Federal energy conservation tax credit program in place in the 1980s. While this tax credit was available from 1979 through 1985, DOE located data for only the first three years of the program.[15, 16, 17] For those three years - 1979, 1980, and 1981 - the percentages of taxpayers filing Form 5695 were 6.4 percent, 5.2 percent, and 4.9 percent. Given that the data from this earlier tax credit program were not disaggregated by type of energy property, this data series served only to indicate a possible trend of greater participation in the initial program year, followed by slightly smaller participation in subsequent years. However, DOE did not find detailed analysis of this program to indicate the possible reasons for such a trend. Also, this trend varies from the more stable trend shown in the EPAct 2005 energy tax credit program data for its first two program years.

As discussed in chapter 17, DOE analyzed the percentage of participation in consumer tax credit programs using its estimates of consumer participation in rebate programs that was based on benefit/cost data specific to each product class. Hence it was difficult to compare these detailed estimates to the more general data analysis described above from the existing Federal tax credit program, or to use the IRS data analysis in its consumer tax credit analysis.

17A.6.2 Federal Tax Credits for Manufacturers

EPACT 2005 provided Federal Energy Efficient Appliance Credits to manufacturers that produced high-efficiency refrigerators, clothes washers, and dishwashers in 2006 and 2007.[18] The Emergency Economic Stabilization Act of 2008[19] amended the credits and extended them through 2010. The credits were extended again to 2011 with modifications in the eligibility requirements. Manufacturer tax credits were extended again, by the American Taxpayer Relief Act of 2012, for clothes washers, refrigerators, and dishwashers manufactured between January 1, 2012 and December 31, 2013.

Manufacturers who produce these appliances receive the credits for increasing their production of qualifying appliances. These credits had several efficiency tiers in 2011. For 2012-2013, credits for the higher tiers remain but were eliminated for the lowest (least efficient) tiers for clothes washers and dishwashers.[11] The credit amounts applied to each unit manufactured. The credit to manufacturers of qualifying clothes washers, refrigerators and dishwashers was capped at $75 million for the period of 2008-2010. However, the most efficient refrigerator (30%) and clothes washer (2.2 MEF/4.5 wcf) models was not subject to the cap. The credit to manufacturers was capped at $25 million for 2011, with the most efficient refrigerators (35%) and clothes washers (2.8 MEF/3.5 WCF) exempted from this cap.[20]

17A.6.3 State Tax Credits

The States of Oregon and Montana have offered consumer tax credits for efficient appliances for several years, and the States of Kentucky, Michigan and Indiana began offering such credits in 2009. The Oregon Department of Energy (ODOE) has disaggregated data on taxpayer participation in credits for eligible products. (See the discussion in chapter 17, section 17.3.3, on tax credit data for clothes washers.) Montana’s Department of Revenue does not disaggregate participation data by appliance, although DOE reviewed Montana's overall participation trends and found them congruent with its analysis of Oregon's clothes washer tax credits.

Oregon’s Residential Energy Tax Credit (RETC) was created in 1977. The Oregon legislature expanded the RETC program in 1997 to include residential refrigerators, clothes washers, and dishwashers, which significantly increased participation in the program. The program subsequently added credits for high-efficiency heat pump systems, air conditioners, and water heaters (2001); furnaces and boilers (2002); and duct/air sealing, fuel cells, heat recovery, and renewable energy equipment. Beginning in 2012 a Tax Credit Extension Bill (HB3672) eliminated refrigerators, clothes washers, dishwashers, air conditioners, and boilers from the RETC program, leaving credits for water heaters, furnaces, heat pumps, tankless water heaters, and heat pump water heaters.[21, 22] Those technologies recognized by the Oregon Department of Energy as "premium efficiency" are eligible for tax credit of $0.60 per kWh saved in the first year (up to $1,500).[21, 23]

Montana has had an Energy Conservation Tax Credit for residential measures since 1998.[24] The tax credit covers various residential energy and water efficient products, including split system central air conditioning; package system central air conditioning; split system air source heat pumps; package system heat pumps; natural gas, propane, or oil furnaces; hot water boilers; advanced main air circulating fans; heat recovery ventilators; gas, oil, or propane water heaters; electric heat pump water heaters; low-flow showerheads and faucets; light fixtures; and controls. In 2002 the amount of the credit was increased from 5 percent of product costs (up to $150) to 25 percent (up to $500) per taxpayer. The credit can be used for products installed in new construction or remodeling projects. The tax credit covers only that part of the cost and materials that exceed established standards of construction.

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