CHAPTER 5. ENGINEERING ANALYSIS

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CHAPTER 5. ENGINEERING ANALYSIS

5.1 INTRODUCTION

The U.S. Department of Energy (DOE) performed an engineering analysis to establish the relationship between the manufacturer production cost (MPC) and the energy efficiency of residential heating products, which include residential water heaters, direct heating equipment (DHE), and pool heaters. The relationship between the MPC and energy efficiency, or cost-efficiency relationship, serves as the basis for cost-benefit calculations for individual consumers, manufacturers, and the Nation. This section provides an overview of the engineering analysis (section 5.5), discusses the product classes (section 5.3), establishes baseline unit specifications (section 5.4.1), discusses incremental efficiency levels (section 5.4.2), explains the methodology used for data gathering (section 5.8), and presents the analysis and results (section 5.10). DOE completed a separate engineering analysis for each of the product types: residential water heaters, direct heating equipment, and pool heaters.

The primary inputs of the engineering analysis are baseline information from the market and technology assessment (chapter 3) and the technologies from the screening analysis (chapter 4). Additional inputs include cost and efficiency data derived from the physical teardown analysis and engineering interviews with manufacturers. The primary output of the engineering analysis is a set of cost-efficiency curves.

DOE typically structures its engineering analysis around one of three methodologies: (1) the design-option approach, which calculates the incremental cost of adding specific design options to the baseline model; (2) the efficiency-level approach, which calculates the relative costs of achieving increases in energy efficiency levels without regard to the particular design options used to achieve such increases; and/or (3) the reverse engineering cost-assessment approach, which involves a “bottom-up” manufacturing cost assessment based on a detailed bill of materials (BOM) derived from product teardowns. Which methodology to use for the engineering analysis depends on the product, the technologies under study, and historical data.

To establish the industry cost-efficiency curves for residential heating products, DOE used the efficiency-level approach to identify incremental improvements in efficiency for each product and the cost-assessment approach to develop a cost for each efficiency level. DOE identified the most common residential heating products on the market and determined their corresponding efficiency levels, the component specifications, and the distinguishing technology features associated with those levels. After identifying the most common products that represent a cross section of the market, DOE gathered additional information through reverse engineering, product information from manufacturer catalogs, and discussions with experts and manufacturers of water heaters, direct heating equipment, and pool heaters. This approach provided useful information, including identification of potential technology paths manufacturers might use to increase energy efficiency. DOE generated bills of materials by disassembling multiple manufacturers' products that span a range of efficiency levels for each of the three product categories. The BOMs describe the product in detail, including all manufacturing steps required to make and/or assemble each part. Subsequently, DOE developed a cost model that converted the BOMs and efficiency levels into MPCs. By applying derived manufacturer markups to the MPCs, DOE calculated the manufacturer selling prices (MSPs) and constructed industry cost-efficiency curves.

In a subsequent life-cycle cost analysis (chapter 8), DOE used the industry cost-efficiency curves to determine consumer prices for each of the covered residential heating products by applying the appropriate distribution channel markups.

5.2 PRODUCT CLASSES

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

Table 5.2.1, Table 5.2.2, and Table 5.2.3 show the product classes adopted in the final rule for the residential water heaters, DHE, and pool heaters that are subject to these standards. Table 5.2.2 shows the proposed revisions to the direct heating equipment product class descriptions. DOE is considering these revisions to include vented gas hearth products (see chapter 3 for more information).

Table 5.2.1 Residential Water Heater Product Classes

Residential Water Heater Type	**Characteristics**	
	Nominal Input	**Rated Storage Volume**
Gas-Fired Storage	75,000 Btu/h or less	20 to 100 gallons
Oil-Fired Storage	105,000 Btu/h or less	50 gallons or less
Electric Storage	12 kilowatts (40,956 Btu/h) or less	20 to 120 gallons
Gas-Fired Instantaneous	Over 50,000 Btu/h up to 200,000 Btu/h	2 gallons or less

Table 5.2.2 Residential Direct Heating Equipment Product Classes (with Revised Descriptions)

Direct Heating Equipment Design Type	Product Class, by Input Rating *Btu/h*
Gas Wall Fan	Up to 42,000
	Over 42,000
Gas Wall Gravity	Up to 27,000
	Over 27,000 up to 46,000
	Over 46,000
Gas Floor	Up to 37,000
	Over 37,000
Gas Room	Up to 20,000
	Over 20,000 up to 27,000
	Over 27,000 up to 46,000
	Over 46,000
Gas Hearth	Up to 20,000
	Over 20,000 up to 27,000
	Over 27,000 up to 46,000
	Over 46,000

Table 5.2.3 Residential Pool Heaters Product Classes

Pool Heater Type
Residential Gas-Fired

5.3 PRODUCT CLASSES ANALYZED

DOE reviewed all of the product classes of residential water heaters (storage-type and instantaneous), DHE, and pool heaters for the engineering analysis. Because the storage volume and input capacity affect the energy efficiency of the products, DOE examined each product type separately. DOE analyzed water heaters, direct heating equipment, and pool heaters that represent a cross section of the residential heating products market. The analysis of these representative products and product classes allowed DOE to analyze specific characteristics common to the products in a range of storage and input capacities, where appropriate. DOE then expanded the analysis to include all covered products in each product class

For residential storage-type water heaters, the tank volume significantly affects the energy consumed. That is, it takes more energy to heat a larger volume of water from a given temperature to a higher temperature. Additionally, the tank surface area increases as tank volume increases. Among other factors, the heat transfer rate is a function of surface area. Therefore, increased surface area increases the rate of heat transfer to the ambient air, which increases standby losses. This is reflected in the existing Federal energy conservation standards as the energy factor is a function of the tank storage volume for gas-fired, oil-fired, and electric storage water heaters.

DOE examined specific storage volumes (referred to as representative storage volumes) for gas-fired, oil-fired, and electric storage water heaters because EPCA established the energy efficiency equations for residential water heaters as a function of storage volume. DOE reviewed shipment data from AHRI, and identified the storage volumes corresponding to the highest number of shipments for gas-fired, oil-fired, and electric storage water heaters. Storage volume typically does not vary for gas-fired instantaneous water heaters, so DOE conducted a similar review of shipment data to determine the input rating corresponding to the highest number of shipments. See chapter 9 of the final rule TSD for more details on the shipment data. Table 5.3.1 presents the representative rated storage volumes for residential water heaters.

Table 5.3.1 Representative Residential Water Heaters as Described by Storage Capacity and Defined by Gallons

Residential Water Heater Product Class	Representative Rated Storage Volume *gallons*
Gas-Fired Storage	40
Oil-Fired Storage	32
Electric Storage	50
Gas-Fired Instantaneous	0 (199 kBtu/h input capacity)

After conducting the primary analysis on the representative rated storage volumes for each product class, DOE extended the analysis to other rated storage volumes for gas-fired, electric, and oil-fired storage water heaters using the energy efficiency equations and the cost model. See section 5.8.6 for a description of how the MPCs were scaled to other rated storage volumes and section 5.14 for additional details on DOE's methodology for extending the analysis beyond the representative rated capacities. For gas-fired instantaneous water heaters, the analysis of the 199 kBtu/h input capacity was applied to all products within the product class.

Unlike water heaters, DHE conservation standards are not defined by an equation, but instead are defined based on input capacity ranges. DOE examined one specific input capacity range, referred to as representative input rating ranges, for each DHE product class (*i.e.*, gas wall fan, gas wall gravity, gas floor, gas room, and gas hearth). DOE reviewed DHE shipment data from AHRI, data from California Energy Commission (CEC) appliance directory, data from the Federal Trade Commission (FTC), and the Hearth, Patio, and Barbeque Association (HPBA) shipment data. DOE found the input rating range corresponding to the highest number of shipments for each product class, or (for product classes where shipments data were not available) the highest number of models available. Table 5.3.2 presents the representative input rating ranges for residential DHE.

Table 5.3.2 Representative Residential Direct Heating Equipment Product Class as Described by Input Capacity

Direct Heating Equipment Type	Representative Input Rating Range *Btu/h*
Gas Wall Fan	Over 42,000
Gas Wall Gravity	Over 27,000 up to 46,000
Gas Floor	Over 37,000
Gas Room	Over 27,000 up to 46,000
Gas Hearth	Over 27,000 up to 46,000

After analyzing each of the representative product input capacities, DOE extended the analysis to the remaining input capacity ranges for each residential DHE product class. DOE maintained the difference in Annual Fuel Utilization Efficiency (AFUE) values for each input rating range established by EPCA. For example, if the conservation standard increases by two AFUE percentage points for the representative product class, the conservation standards for the other input capacities in the same product type also increase by two AFUE percentage points. The stringency resulting from an amended standard will be constant across the range of inputs for a given product type.

There is only one product class for residential gas-fired pool heaters. However, this product class covers a range of input ratings wide enough to create variations in pool heater design (*e.g.*, large variations in input will change material usage and MPC). Therefore, DOE reviewed the CEC and FTC directories of gas-fired pool heaters and identified 250,000 Btu/h as the representative capacity based on the number of models in the directory at each capacity.

5.4 EFFICIENCY LEVELS

DOE analyzed multiple efficiency levels for each product class presented in section 5.3 and estimated the manufacturer production costs at those levels. The following subsections provide the full efficiency range from the baseline to maximum technologically feasible ("max-tech") efficiency for each product class. In some cases, DOE identified the highest efficiency level by reviewing product literature for commercially available products.

5.4.1 Baseline Unit

DOE selected baseline units as reference points for each product class, 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 equipment in that class. Typically, baseline units just meet and do not exceed current Federal energy conservation standards and provide basic consumer utility.

DOE uses baseline units for comparison in several phases of the 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 compares energy use at each of the higher energy efficiency levels to the energy consumption of the baseline unit for each product class. Similarly, to determine the changes in price to the consumer that result from amended energy conservation standards, DOE compares 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. DOE defines baseline units as units with efficiencies equal to the current Federal energy conservation standards.

The Federal energy conservation standards for residential water heaters, as measured by the EF, were applicable on January 20, 2004. (10 CFR Part 430.32(d), Subpart C). For water heaters, DOE applied the representative storage capacity to the energy efficiency equations in 10 CFR Part 430.32(d) to calculate the baseline unit EFs. Table 5.4.1 presents the baseline unit's EF for each product class of residential water heaters at the representative storage volume.

Table 5.4.1 Baseline Unit EF for Water Heaters

Water Heater Product Class	**Representative Storage Volume** ***gallons***	**Federal Energy Conservation Standards** ***Energy Factor***
Gas-Fired Storage	40	0.59
Oil-Fired Storage	30	0.53
Electric Storage	50	0.90
Gas-Fired Instantaneous	0*	0.62

*Gas-fired instantaneous water heaters have a representative rated input capacity of 199,000 Btu/h.

The Federal energy conservation standards for residential DHE, as measured by the AFUE, were applicable on January 1, 1990. (10 CFR part 430.32(i), subpart C) For direct heating equipment, DOE assigned the baseline unit efficiencies for each product class as the AFUE requirements corresponding to the representative input ratings in 10 CFR part 430.32(i). Table 5.4.2 shows the baseline unit's AFUE for each product class of residential DHE at the representative input rating.

Table 5.4.2 Baseline Unit AFUE for Direct Heating Equipment

Product Class	Representative Input Capacity Range *Btu/h*	Federal Energy Conservation Standards *AFUE*
Gas Wall Fan	Over 42,000	74%
Gas Wall Gravity	Over 27,000 up to 46,000	64%
Gas Floor	Over 37,000	57%
Gas Room	Over 27,000 up to 46,000	64%
Gas Hearth	Over 27,000 up to 46,000	64%

The Federal energy conservation standard for residential pool heaters, as measured by thermal efficiency, became effective on January 1, 1990. (10 CFR part 430.32(k), subpart C) For pool heaters, the baseline unit thermal efficiency of 78 percent corresponds to the energy conservation standard established in 10 CFR part 430.32(k).

See section 5.6.2 for more information on the characteristics of each baseline unit. The market baseline units represent the products on the market that typically have the lowest cost and simplest technologies.

5.4.2 Intermediate Energy Efficiency Levels

DOE conducted a survey of the residential heating products market to determine the designs and efficiencies of products that are currently available to consumers. For each representative product, DOE surveyed various manufacturers' product offerings to identify the efficiency levels that correspond to the highest number of models. By identifying the most prevalent energy efficiencies in the range of available products and examining the designs used at those efficiencies, DOE was able to establish a technology path that manufacturers would typically use to increase the energy efficiency of residential heating products.

DOE established intermediate energy efficiency levels for each product class. The intermediate efficiency levels are representative of the most commonly available efficiency levels, and generally follow technology paths that manufacturers of residential heating products commonly use to maintain cost-effective designs while increasing energy efficiency. DOE reviewed AHRI's product certification directory,[1] manufacturer catalogs, and other publicly available literature to determine which efficiency levels are the most prevalent for each representative product class. Additionally, DOE associated each efficiency level with a particular technology or combination of technologies to make the engineering analysis more transparent. Table 5.4.3 through Table 5.4.11 show the product classes and the respective intermediate energy efficiency levels. For information on the technology associated with each efficiency level, see section 5.7.

For gas-fired storage water heaters, DOE analyzed five efficiency levels between the baseline and the max-tech. The energy factors correspond to the EFs most commonly shipped and having the most commonly used efficiency-related 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 gas-fired water heaters, manufacturers use natural draft and increased insulation to reach the lower intermediate efficiency levels. Manufacturers achieve efficiency levels three and above by using electronic ignition and power venting.

Table 5.4.3 Intermediate Efficiency Levels for 40-Gallon Gas-Fired Storage Water Heaters

Efficiency Level	Energy Factor
1	0.62
2	0.63
3	0.64
4	0.65
5	0.67

For oil-fired storage water heaters, DOE analyzed six efficiency levels between the baseline and max-tech efficiency levels. The energy factors correspond to efficiency levels shipped with technologies commonly used by manufacturers to improve energy efficiency. For example, manufacturers achieve the incremental increases for lower efficiency levels by adding half an inch of insulation for each efficiency level to the baseline product. To achieve even higher efficiency levels, manufacturers switch from fiberglass to foam insulation and usually improve the flue baffling. At the highest intermediate efficiency level (efficiency level 6), manufacturers may use a multi-flue design to increase heat transfer.

Table 5.4.4 Intermediate Efficiency Levels for 32-Gallon Oil-Fired Storage Water Heaters

Efficiency Level	Energy Factor
1	0.54
2	0.56
3	0.58
4	0.60
5	0.62
6	0.66

For electric storage water heaters, DOE selected six efficiency levels between the baseline and max-tech levels. For water heaters using electric resistance heating, manufacturers usually increase EF by adding insulation. Each efficiency level shown corresponds to insulation thicknesses commonly used by manufacturers, except for efficiency level 6. At efficiency level 6, manufacturers switch from a traditional electric resistance heating design to an integrated heat pump design.

Table 5.4.5 Intermediate Efficiency Levels for 50-Gallon Electric Storage Water Heaters

Efficiency Level	Energy Factor
1	0.91
2	0.92
3	0.93
4	0.94
5	0.95
6	2.00

For gas-fired instantaneous water heaters, DOE analyzed seven efficiency levels between the baseline and max-tech. Manufacturers commonly produce units at efficiency level 2 or higher. Manufacturers increase energy efficiency primarily by improving the heat exchanger design and incorporating electronic ignition and power venting. Power venting is usually used in units at efficiency level 3 and higher. Manufacturers reach efficiency level 7 by using a condensing design. Efficiency levels 5 and 6 are considered "near condensing," meaning that the exhaust combustion gases may begin to condense in certain conditions, leading to the formation of acidic condensate. Because of this, manufacturers usually design equipment at these efficiencies to be able to handle condensation for safety purposes. DOE considered this when developing the MPCs for gas-fired instantaneous water heaters.

Table 5.4.6 Intermediate Efficiency Levels for Gas-Fired instantaneous Water Heaters

Efficiency Level	Energy Factor
1	0.69
2	0.78
3	0.80
4	0.82
5	0.84
6	0.85
7	0.92

For gas wall fan DHE, DOE identified three efficiency levels between the baseline and max-tech for analysis. DOE found products produced by manufacturers at every AFUE level between the baseline and max-tech. Manufactures commonly incorporate intermittent ignition, two speed blowers, and improve the heater exchanger design to increase energy efficiency. Manufacturers incorporate these three technologies in combination to obtain efficiency level 3.

Table 5.4.7 Intermediate Efficiency Levels for Gas Wall Fan DHE, Over 42,000 Btu/h

Efficiency Level	AFUE
1	75
2	76
3	77

For gas wall gravity DHE, DOE analyzed three efficiency levels between the baseline and max-tech. These efficiency levels correspond to gas wall gravity DHE in this product class with the most shipments. The one- to two-point increases in AFUE between each level reflect improvements in the heat exchanger design.

Table 5.4.8 Intermediate Efficiency Levels for Gas Wall Gravity DHE, Over 27,000 Btu/h and up to 46,000 Btu/h

Efficiency Level	AFUE
1	66
2	68
3	69

DOE did not select any gas floor DHE intermediate efficiency levels to analyze, as manufacturers offer products only at baseline and max-tech efficiency levels. Manufacturers commonly increase the AFUE of gas floor DHE by improving the heat exchanger design.

DOE analyzed four intermediate efficiency levels for gas room DHE. Manufacturers typically improve heat the heat exchanger design to achieve incremental increases in AFUE.

Table 5.4.9 Intermediate Efficiency Levels for Gas Room DHE Over 27,000 Btu/h and up to 46,000 Btu/h

Efficiency Level	AFUE
1	65
2	66
3	67
4	68

DOE selected two intermediate efficiency levels for gas hearth DHE. Manufacturers commonly employ an electronic ignition and ceramic glass to achieve these efficiency levels. Manufacturers also commonly use air-circulating blowers at efficiency level 2.

Table 5.4.10 Intermediate Efficiency Levels for Gas Hearth DHE, Over 27,000 Btu/h and up to 46,000 Btu/h

Efficiency Level	AFUE
1	67
2	72

DOE selected seven pool heater intermediate efficiency levels to analyze. DOE found that manufacturers usually achieve efficiency levels 1 and 2 by improving the heat exchanger design, and reach efficiency level 3 by also improving the combustion chamber insulation. Manufacturers use power venting for efficiency levels 4, 5, and 6, and condensing operation to achieve efficiency level 7.

In addition, DOE distinguished between the standing pilot and electronic ignition systems for residential pool heaters because of the difference in energy use of the two ignition systems. The DOE test procedure to measure the thermal efficiency of residential pool heaters does not account for the energy use differences between the two ignition systems. After surveying the pool heater market, DOE determined that electronic ignition is offered in products spanning the whole range of efficiencies, while standing pilot ignition systems are only offered in products with efficiencies at the first three intermediate efficiency levels. Consequently, DOE developed two baseline products and two efficiency pathways for efficiency levels 1 through 3.

Table 5.4.11 Intermediate Efficiency Levels for Gas-Fired Pool Heaters, 250,000 Btu/h

Efficiency Level	Thermal Efficiency *%*
1*	79
2*	81
3*	82
4**	83
5**	84
6**	86
7**	90

* Models having pilot or electronic ignition.
** Models having electronic ignition only.

5.4.3 Max-Tech Efficiency Levels

As part of the engineering analysis, DOE determined the maximum technologically feasible improvement in energy efficiency for water heaters, direct heating equipment, and pool heaters, as required by section 325(o) of EPCA. (42 U.S.C. 6295(o)) DOE conducted a survey of the residential heating products market and the research fields that support the market. For the representative product within a given product class, no working products or prototypes at efficiency levels above the max-tech level are currently available that could be manufactured using technologies considered from the screening analysis. Table 5.4.12 and Table 5.4.13 list the max-tech levels DOE determined for the various product classes of residential water heaters direct heating equipment. The max-tech level for the single pool heater product class is also described below.

For gas-fired storage water heaters, DOE determined that condensing technology could enable manufacturers to achieve efficiencies as high as 0.77 EF. DOE determined that electric storage water heaters using integrated heat pump heating technology could obtain EFs of 2.35. For oil-fired storage water heaters, DOE identified 0.68 EF as the max-tech efficiency level, which can be achieved using a combination of electronic ignition, foam insulation, and enhanced flue baffling (*i.e.*, a multiple flue design). DOE identified 0.95 EF as the max-tech for gas-fired instantaneous water heaters that use condensing technology. Table 5.4.12 summarizes the max-tech efficiency levels identified for water heaters.

Table 5.4.12 Max-Tech Efficiency Levels for Water Heaters

Water Heater Product Class	**Storage Volume** ***gallons***	**Max-Tech Efficiency Level** ***Energy Factor***
Gas-Fired Storage	40	0.77
Oil-Fired Storage	32	0.68
Electric Storage	50	2.35
Gas-Fired Instantaneous	0	0.95

For gas wall fan DHE, DOE identified a max-tech efficiency level design with induced draft combustion, resulting in an AFUE of 80 percent. For gas wall gravity DHE, DOE identified 70 percent AFUE as the max-tech level, which is achievable with an improved heat exchanger design and electronic ignition. For gas floor DHE, DOE identified the max-tech efficiency level as 58 percent AFUE, which can be reached using an improved heat exchanger design. For gas room DHE, DOE identified the max-tech efficiency level as 83 percent AFUE, which manufacturers can achieve using an electronic ignition and improved heat exchanger. For gas hearth DHE, DOE identified a max-tech level of 93 percent AFUE, which requires condensing operation. Table 5.4.13 summarizes the max-tech efficiency levels DOE analyzed for the NOPR analysis.

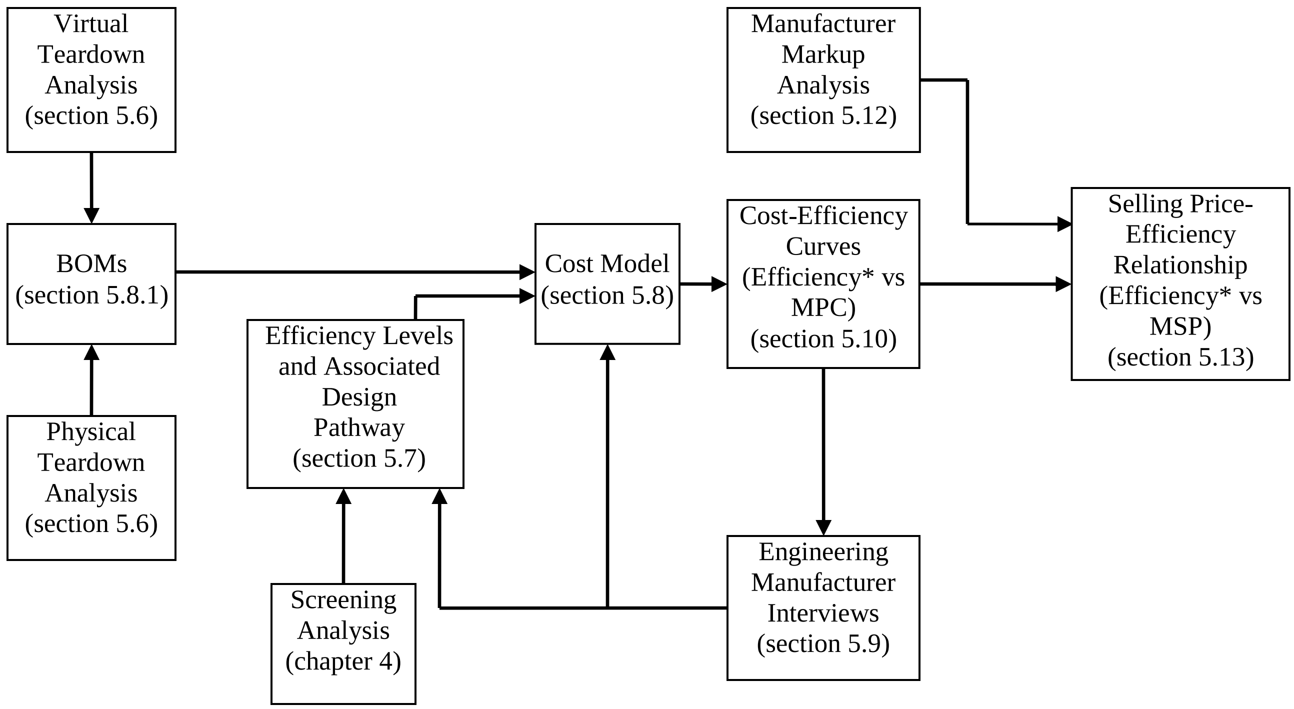
Table 5.4.13 Max-Tech Efficiency Levels for Direct Heating Equipment

Product Class	**Input Capacity** ***Btu/h***	**Max-Tech Efficiency Level** ***AFUE***
Gas Wall Fan	Over 42,000	80
Gas Wall Gravity	Over 27,000 up to 46,000	70
Gas Floor	Over 37,000	58
Gas Room	Over 27,000 up to 46,000	83
Gas Hearth	Over 27, 000 up to 46,000	93

For residential pool heaters, DOE identified products capable thermal efficiencies of 95 percent as the max-tech, which are achieved with condensing operation.

5.5 METHODOLOGY OVERVIEW

This section describes the analytical methodology used in the engineering analysis. Figure 5.5.1 shows a flow diagram of this methodology and the corresponding sections in this chapter. The results of the engineering analysis are cost-efficiency curves for each representative product class.



*Efficiency is defined as energy factor (EF), annual fuel utilization efficiency (AFUE), or thermal efficiency for water heaters, direct heating equipment, and pool heaters, respectively.

Figure 5.5.1 Flow Diagram of Engineering Analysis Methodology

DOE started by identifying residential heating products available on the market and the energy efficiency level associated with each. DOE also identified the technologies and features typically incorporated into products at the baseline level and various energy efficiency levels above the baseline. Next, DOE selected products at the representative rated storage volumes and input capacities for the physical teardown analysis. DOE gathered the information from the physical teardown analysis to create bills of materials for each product using reverse engineering methods (see section 5.6). DOE then used the physical teardown analysis to identify the design pathways manufacturers use to increase the EF of residential water heaters, the AFUE of residential direct heating equipment, and the thermal efficiency of residential pool heaters. DOE converted the information recorded in the BOMs to dollar values to calculate the MPC for products spanning the full range of efficiencies from the baseline to the maximum technology available. DOE also identified the technology or combination of technologies mainly responsible for improving the energy efficiency of each product. Comparing the increase in MPC to the increase in energy efficiency determined the cost-effectiveness of each technology. Finally, DOE conducted a sensitivity analysis on material prices to examine the effect of the spikes in metal prices that the heating products industries have experienced over the past few years.

During the preparation of the cost-efficiency comparison and MPCs, DOE interviewed manufacturers to gain insight into the water heating, direct heating, and pool heating industries and requested comments on the engineering approach DOE used for the analysis (section 5.9). DOE used the information gathered from these interviews to refine efficiency levels and potential technology pathways as well as assumptions in the cost model. Next, DOE converted the MPCs into MSPs (section 5.12) using publicly available water heating, direct heating, and pool heating industry financial data, along with manufacturer feedback.

5.6 TEARDOWN ANALYSIS

To assemble BOMs and calculate the manufacturing costs of the different components in residential heating products, DOE disassembled multiple units into their components and estimated the material and labor cost of each component. This process is referred to as a "physical teardown." A supplementary method, called a "virtual teardown," uses published manufacturer catalogs and supplementary component data to estimate the major physical differences between a product that was physically disassembled and a similar product that was not. The teardown analysis for the preliminary engineering analysis included more than 40 physical and virtual teardowns of water heaters, direct heating equipment, and pool heaters. For the NOPR analysis, DOE performed more than 20 additional physical teardowns to further supplement the analysis. Additionally, for the final rule analysis, DOE performed two additional physical teardowns for heat pump water heaters.

5.6.1 Selection of Units

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

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

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

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

DOE surveyed the residential heating products industry and identified products available to consumers as well as prototypes developed by manufacturers' research efforts. DOE then applied the aforementioned criteria and selected baseline, intermediate, and max-tech units that met the energy efficiency levels and included the technologies identified in the market surveys (sections 5.3, 5.4, 5.7). In several cases, DOE substituted a virtual teardown in the place of a physical teardown. For example, if two water heaters differed only by insulation thickness, one was physically torn down and the additional material and cost (*i.e.*, additional insulation, extra sheet metal, longer temperature and pressure relief valve, etc.) were added to the first to determine the MPC of the second.

Using the data gathered from the physical teardowns, DOE characterized each component according to its weight, dimensions, material, quantity, and the manufacturing processes used to fabricate and assemble it. For supplementary virtual teardowns, DOE gathered product data such as dimensions, weight, and design features from publicly available manufacturer catalogs. DOE obtained information and data not typically found in catalogs and brochures, such as fan motor details, gas manifold specifications, and assembly details, from the physical teardowns of similar products or by estimations based on industry knowledge. DOE collected additional component information during the manufacturer interviews.

DOE selected more than 5 s0 examples of water heaters, direct heating equipment, and pool heaters to represent the market, and used these for physical teardowns in the engineering analysis. 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.

5.6.2 Baseline Units

DOE selected baseline units for the teardown analysis to determine the technologies manufacturers typically incorporate into products at energy efficiencies equal to the current Federal energy conservation standards. Typically, the baseline units are representative of the minimum technology and lowest cost product that manufacturers can produce. DOE compared cost of products at the baseline and technologies used in those products to those at higher energy efficiency levels. The efficiencies of the baseline units are presented in section 5.4.1.

5.6.2.1 Water Heater Baseline Unit Features

DOE gathered information from the physical and virtual teardowns and from published information and data to determine which features manufacturers typically incorporate into units at the baseline efficiency levels. DOE also identified the general characteristics common to product types. For example, all storage tank designs include a dip tube, a hot water outlet, and a sacrificial anode. DOE also identified the operating features of the baseline units. For example, baseline gas-fired storage and instantaneous products use standing pilots, require no electricity, and use a natural draft to ventilate. Table 5.6.1 shows the characteristics of baseline water heaters.

Table 5.6.1 Market Baseline Unit Characteristics for Water Heaters

	Water Heater Product Class			
Characteristics	Gas-Fired Storage	Oil-Fired Storage	Electric Storage	Gas-Fired Instantaneous
Storage Tank	X	X	X	
Foam Insulation	X (1”)		X (1.5”)	
Fiberglass Insulation		X (1”)		
Dip Tube	X	X	X	
Cold Water Inlet				X
Hot Water Outlet	X	X	X	X
Combustion Chamber	X	X		X
Burner	X			X
Oil-Fired Power Burner System		X		
Sacrificial Anode	X	X	X	
Flue/Flue Baffle (CRS)	X	X		
Heat Exchanger (Copper)				X
Vent				X
Temperature/Pressure Relief Valve	X	X	X	
Standing Pilot Ignition System	X			X
Burner Control Thermostat	X	X		X
Gas Valve	X			X
Electric Resistive Heating Elements			X	
Thermostat/Wire Harness			X	
Flow Detector				X
Outer Case	X	X	X	X
Heat Trap	X		X	
Packaging	X	X	X	X

5.6.2.2 Direct Heating Equipment Baseline Unit Features

DOE gathered information from the physical and virtual teardowns and from published information and data to determine which features manufacturers incorporate into direct heating equipment at the baseline efficiency levels. Generally, baseline direct heating equipment units require no electricity (except where a wall fan needs power for the fan motor), use standing pilot ignition systems, and use a natural draft to ventilate. With the exception of the air circulation fan of a wall fan unit, direct heating equipment baseline products differ primarily by the outer casing design, while the method of operation is similar for all product types. Table 5.6.2 shows the characteristics of baseline direct heating equipment.

Table 5.6.2 Market Baseline Unit Characteristics for Direct Heating Equipment

	Gas DHE Product Class				
Characteristics	**Wall Fan**	**Wall Gravity**	**Floor**	**Room**	**Hearth**
Heat Exchanger (ACRS)	X	X	X	X	X
Room Circulation Blower	X				
Standing Pilot Ignition System	X	X	X	X	X
Burner	X	X	X	X	X
Pilot Light Sensing Control Valve	X	X	X	X	X
Combustion Chamber	X	X	X	X	X
Flue	X	X	X	X	X
Air Intake	X	X	X	X	X
Burner Control Thermostat	X	X	X	X	X
Floor Grate			X		
Outer Case	X	X	X	X	X
Packaging	X	X	X	X	X

5.6.2.3 Pool Heater Baseline Unit Features

DOE identified the characteristics of a baseline efficiency residential pool heater by examining pool heaters during the physical teardown analysis and reviewing available literature and data for pool heaters during virtual teardowns. For most units, a copper tube heat exchanger is located above a burner assembly, and units are naturally drafted. DOE did not specify a particular ignition system at the baseline efficiency level because both electronic ignitions and standing pilot systems exist, and during the technology assessment DOE determined that the ignition type had no effect on energy efficiency as measured by thermal efficiency (chapter 3).

However, as noted previously, DOE distinguished between the two ignition systems because of the energy use difference between electronic ignition and standing pilot systems that the DOE test procedure does not account for. DOE's test procedure is a steady-state test procedure, determining thermal efficiency when the burner is on. The thermal efficiency descriptor specified by EPCA and measured by DOE's test procedure does not account for the additional energy consumption of a continuous, standing pilot light when the burner is off, and thus does not account for the energy efficiency benefits from an electronic ignition. Therefore, DOE identified two pathways that could be used to achieve the efficiencies analyzed, with separate baseline products to recognize the differences in energy use associated with standing pilots and electronic ignition. The market baseline unit characteristics for pool heaters are:

- cold water inlet;
- hot water outlet;
- heat exchanger (copper);
- ignition system (standing pilot or electronic)
- burner;
- combustion chamber;
- flue/vent;
- air intake;
- burner control thermostat;
- outer case; and
- packaging.

The residential heating products 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 each baseline unit and the method of operation (*i.e.*, standing pilot, natural draft) to units with higher energy efficiencies to determine the change in manufacturing, installation, and operating costs (chapter 8). Finally, by comparing design features, DOE identified individual technologies and how each affected energy efficiency and the cost-efficiency relationship for each unit.

5.7 TECHNOLOGY OPTIONS

Technology options are technology and design changes manufacturers use to improve product energy efficiency. These technologies provide different ways to increase product energy efficiency from the baseline to the market max-tech efficiency. While manufacturers use many different technologies and approaches to increase the energy efficiency of residential heating products, the technologies and combinations of technologies presented in the following sections, and their ordering is one possible way manufacturers could increase efficiency all the way up to the max-tech levels.

For the engineering analysis, DOE calculated the manufacturing costs for each efficiency level between the baseline and max-tech at each of the levels specified in section 5.4.2. Using the teardown analysis and discussions with manufacturers, DOE identified each technology typically incorporated at each energy efficiency level, and calculated the cost required to achieve each efficiency level. DOE input the components, materials, and labor required for manufacturing units that can achieve each efficiency level (as determined from the teardown analysis) into the cost model to calculate the MPC at each efficiency level analyzed in the final rule analysis. DOE averaged the costs to normalize the data and avoid exposing sensitive information about individual manufacturers' products. After determining the MPC at each efficiency level, DOE created the cost-efficiency curves (section 5.10).

5.7.1 Screened-In Technologies

DOE considered and analyzed various technologies for improving the energy efficiency of residential water heaters, direct heating equipment, and pool heaters. Several of the technologies DOE considered for improving energy efficiency met the criteria of the screening analysis (chapter 4). DOE reduced the list of viable technologies developed from the screening analysis based on products being manufactured at the time of the analysis. DOE used information from the teardown analysis, manufacturer interviews, and publicly available product literature to determine which technologies are used in commercially available products so that DOE could most accurately represent the current market. DOE also determined which technologies manufacturers would be most likely to include in future products based on the cost effectiveness of these technologies. Although several technologies are not included in the engineering analysis, DOE acknowledges that these are viable methods to improve the energy efficiency of residential water heaters, direct heating equipment, and pool heaters. Table 5.7.1 lists the technologies for water heaters that DOE did not eliminate in the screening analysis (chapter 4) and are included in the engineering analysis.

Table 5.7.1 Technologies Considered for the Engineering Analysis for Water Heaters

Technology Considered	**Water Heater Product Class**			
	Gas-Fired Storage	**Electric Storage**	**Oil-Fired Storage**	**Gas-Fired Instantaneous**
Increased Jacket Insulation	X	X	X	
Foam Insulation			X	
Improve/Increased Heat Exchanger Surface Area				X
Enhanced Flue Baffle	X		X	
Direct-Vent (concentric venting)				X
Power Vent	X			X
Electronic (or interrupted) Ignition	X		X	X
Heat Pump Water Heater		X		
Condensing	X			X

For DHE the technologies that DOE included in the engineering analysis are:

- increased heat exchanger surface area;
- direct-vent (concentric venting);
- electronic ignition;
- two stage and modulating operation; and
- condensing operation.

For pool heaters the technologies that DOE included in the engineering analysis are:

- increased heat exchanger surface area;
- more effective insulation (combustion chamber);

- power venting;
- sealed combustion; and
- condensing operation.

The most prevalent technologies to obtain the intermediate and max-tech energy efficiency levels are described below.

5.7.1.1 Technologies for Gas-Fired Storage Water Heaters

To increase the energy efficiency of gas-fired storage water heaters, manufacturers first increase the thickness of the insulation between the storage tank and the outer shell. Manufacturers typically add up to 2 inches of insulation to reduce the amount of heat loss through the sides of the tank. Manufacturers also replace the standing pilot with an electronic ignition and combine this technology with thicker insulation. For even greater improvements, manufacturers add a power vent to replace the natural vent operation. An enhanced flue baffle, which can improve the heat transfer rate, may also be included in a design having power venting. Max-tech gas-fired storage water heaters include heat exchangers that condense the flue gases to extract the greatest amount of heat. Table 5.7.2 shows the technologies associated with each efficiency level for the representative product.

Table 5.7.2 Gas-Fired Storage Water Heater, 40 Gallon, Standard Burner

Efficiency Level	Technology
Baseline (EF = 0.59)	Standing Pilot and 1” Insulation
1 (EF = 0.62)	Standing Pilot and 1.5” Insulation
2 (EF = 0.63)	Standing Pilot and 2” Insulation
3 (EF = 0.64)	Electronic Ignition, Power Vent, and 1” Insulation
4 (EF = 0.65)	Electronic Ignition, Power Vent and 1.5” Insulation
5 (EF = 0.67)	Electronic Ignition, Power Vent, and 2” Insulation
6 – Max-Tech (EF = 0.77)	Condensing, Power Vent, 2” Insulation

To properly characterize the technologies and costs associated with ultra-low NO_X burners, DOE performed a separate analysis specifically for gas-fired storage water heaters using ultra-low NO_X burners. For ultra-low NO_X gas-fired storage water heaters, DOE developed cost-efficiency curves by performing a teardown analysis of ultra-low NO_X products at several efficiency levels from different manufacturers. DOE analyzed ultra-low NO_X gas-fired storage water heaters at a 40-gallon representative storage volume, as was done for gas-fired storage water heaters with a standard burner, and compared the ultra-low NO_X gas storage water heaters to the comparable gas storage water heaters with standard burner technology (*i.e.*, not ultra-low NO_X compliant). The same efficiency levels were used for ultra-low NO_X gas storage water heaters as were used for standard burner gas storage water heaters. However, the technologies for standard burner gas-fired water heaters and ultra-low NO_X gas-fired water heaters vary due to differences in operating characteristics of the burners. Ultra-low NO_X burners typically reduce the pressure in the flue, which can create venting problems if the pressures required to properly vent combustion products are not maintained. To mitigate these problems, manufacturers may reduce the amount of baffling or other airflow restrictions to ensure proper venting, which in turn may decrease efficiency. In order to overcome these issues, manufacturers must use power venting technology to achieve energy factors that are lower than they would achieve with a standard burner gas-fired storage water heater that can contain more baffling. Therefore, the technologies associated with ultra-low NO_X gas-fired water heaters are implemented at lower efficiency levels and yield a lower energy factor than the same technologies associated with gas-fired storage water heaters that use a standard burner.

Table 5.7.3 Gas-Fired Storage Water Heater, 40 Gallon, Ultra-Low NO_X Burner

Efficiency Level	Technology
Baseline (EF = 0.59)	Standing Pilot and 1” Insulation
1 (EF = 0.62)	Standing Pilot and 2” Insulation
2 (EF = 0.63)	Electronic Ignition, Power Vent, and 1” Insulation
3 (EF = 0.64)	Electronic Ignition, Power Vent and 1.5” Insulation
4 (EF = 0.65)	Electronic Ignition, Power Vent, and 1” Insulation
5 (EF = 0.67)	Not Attainable (would go to condensing)
6 – Max-Tech (EF = 0.77)	Condensing, Power Vent, 2” Insulation

5.7.1.2 Technologies for Electric Storage Water Heaters

The majority of electric storage water heaters use resistive heating elements to heat water. Manufacturers usually increase the energy efficiency of electric storage water heaters by increasing the thickness of the foam insulation surrounding the tank. To make significant improvements in energy efficiency, several manufacturers have recent developed products using heat pump water heating technology. Table 5.7.4 shows that heat pump water heaters supplemented by resistive heaters can achieve energy efficiencies up to 2.35 EF at the 50-gallon representative rated storage volume. The increased efficiency of a heat pump water heater at efficiency level 7 (*i.e.*, 2.35 EF at the representative rated storage volume) is typically due to improvements to the heat pump coils and compressor and optimized airflow through the heat pump system as compared to efficiency level 6 (*i.e.*, 2.0 EF at the representative rated storage volume). Heat pump water heaters are the maximum technology available for electric storage water heaters.

Table 5.7.4 Electric Storage Water Heater, 50 Gallon

Efficiency Level	Technology
Baseline (EF = 0.90)	1.5” Foam Insulation
1 (EF = 0.91)	2” Foam Insulation
2 (EF = 0.92)	2.25” Foam Insulation
3 (EF = 0.93)	2.5” Foam Insulation
4 (EF = 0.94)	3” Foam Insulation
5 (EF = 0.95)	4” Foam Insulation
6 (EF = 2.0)	Heat Pump Water Heater
7 – Max-Tech (EF = 2.35)	Heat Pump Water Heater, More Efficient Compressor

5.7.1.3 Technologies for Oil-Fired Storage Water Heaters

Energy efficiency improvements for oil-fired storage water heaters are similar to those for other storage water heaters. By their nature of operation, baseline oil burners feature interrupted ignition and power venting; no oil-fired water heater on the market features a standing pilot or lacks a power vent. Increasing the thickness of insulation surrounding the tank and switching from fiberglass to less conductive foam insulation reduces the amount of heat loss through the tank walls. Enhanced flue baffles or a multiple flue design can increase the rate of heat transfer, which can improve energy efficiency. Table 5.7.5 shows the technologies incorporated into oil-fired storage water heaters.

Table 5.7.5 Oil-Fired Storage Water Heater, 32 Gallon with Burner Assembly

Efficiency Level	Technology
Baseline (EF = 0.53)	1” Fiberglass Insulation
1 (EF = 0.54)	1.5” Fiberglass Insulation
2 (EF = 0.56)	2” Fiberglass Insulation
3 (EF = 0.58)	2.5” Fiberglass Insulation
4 (EF = 0.60)	2” Foam Insulation
5 (EF = 0.62)	2.5” Foam Insulation
6 (EF = 0.66)	1” Fiberglass Insulation and Multi-flue Design
7 – Max-Tech (EF = 0.68)	1” Foam Insulation and Multi-flue Design

5.7.1.4 Technologies for Gas-Fired Instantaneous Water Heaters

Manufacturers of gas-fired instantaneous water heaters increase energy efficiency with technologies similar to those used for gas-fired storage water heaters. EF is increased by improving the heat exchanger area to increase the rate of heat transfer (similar to enhancing flue baffles), replacing the standing pilot with an electronic ignition, and/or adding power vents. Incorporating a direct vent configuration can also improve energy efficiency. The maximum efficiency available for instantaneous water heaters is achieved by using a condensing design. In certain applications (*e.g.*, unusually low return water temperatures), the increased efficiency may cause units at intermediate efficiency levels 5 and 6 (*i.e.*, 0.84 and 0.85 EF, respectively) to operate as condensing water heaters. To manage safety concerns that arise with acidic condensate from condensing flue gases, gas-fired instantaneous water heater manufacturers use heat exchangers and designs capable of managing condensate at these efficiency levels. DOE's MPCs reflect the additional cost of condensate management at efficiency levels 5 and 6. Table 5.7.6 shows the technologies incorporated into gas-fired instantaneous water heaters.

Table 5.7.6 Gas-Fired Instantaneous Water Heater, 0 Gallon, 199,000 Btu/h Input Capacity

Efficiency Level	**Technology**
Baseline (EF = 0.62)	Standing Pilot
1 (EF = 0.69)	Standing Pilot and Improved Heat Exchanger Area
2 (EF = 0.78)	Electronic Ignition And Improved Heat Exchanger
3 (EF = 0.80)	Electronic Ignition and Power Vent
4 (EF = 0.82)	Electronic Ignition, Power Vent, and Improved Heat Exchanger Area
5 (EF = 0.84)	Electronic Ignition, Power Vent, and Improved Heat Exchanger Area
6 (EF = 0.85)	Electronic Ignition, Power Vent, Direct Vent, and Improved Heat Exchanger Area
7 (EF = 0.92)	Electronic Ignition, Power Vent, Direct Vent, Condensing
8 – Max Tech (EF = 0.95)	Electronic Ignition, Power Vent, Direct Vent, Condensing

5.7.1.5 Technologies for Gas Wall Fan Direct Heating Equipment

DOE identified several technologies that manufacturers of wall fan DHE use to improve energy efficiency. Typically, manufacturers replace the standing pilot ignition system with an electronic system and incorporate a two-speed blower to reduce motor power consumption. An improved heat exchanger design increases the rate of heat transfer. Manufacturers reach the maximum technology by including an induced draft combustion system to increase the AFUE to 80. Table 5.7.7 shows the technologies manufacturers typically include in wall fan DHE.

Table 5.7.7 Gas Wall Fan DHE, Over 42,000 Btu/h

Efficiency Level	**Technology**
Baseline (AFUE = 74)	Standing Pilot
1(AFUE = 75)	Intermittent Ignition and Two-Speed Blower
2 (AFUE = 76)	Intermittent Ignition and Improved Heat Exchanger
3 (AFUE = 77)	Intermittent Ignition, Two-Speed Blower, and Improved Heat Exchanger
4 – Max-Tech (AFUE = 80)	Induced Draft and Electronic Ignition

5.7.1.6 Technologies for Gas Wall Gravity Direct Heating Equipment

Technologies incorporated into wall gravity DHE typically do not involve electricity. The baseline units do not use electricity. To enable use during a power outage, manufacturers avoid adding components that would require an electrical connection. Instead, manufacturers improve the heat exchanger to increase the rate of heat transfer and AFUE. When heat exchanger improvements maximize AFUE and even greater energy efficiencies are desired, manufacturers could add an electrical connection for an electronic ignition to achieve the max-tech efficiency level. Table 5.7.8 shows the technologies incorporated into wall gravity DHE.

Table 5.7.8 Gas Wall Gravity DHE, Over 27,000 Btu/h and up to 46,000 Btu/h

Efficiency Level	Technology
Baseline (AFUE = 64)	Standing Pilot
1 (AFUE = 66)	Standing Pilot and Improved Heat Exchanger
2 (AFUE = 68)	Standing Pilot and Improved Heat Exchanger
3 (AFUE = 69)	Standing Pilot and Improved Heat Exchanger
4 – Max Tech (AFUE = 70)	Electronic Ignition

5.7.1.7 Technology for Gas Floor Direct Heating Equipment

Gas floor direct heating equipment is commonly designed to operate without using electricity. Therefore, manufacturers avoid technologies requiring electrical connections, and usually improve efficiency only through using an improved heat exchanger. For gas floor DHE, DOE only analyzed the two efficiency levels currently available on the market, which have been demonstrated to be feasible. Table 5.7.9 shows that manufacturers typically improve AFUE through improving the heat exchanger design.

Table 5.7.9 Gas Floor DHE, Over 37,000 Btu/h

Efficiency Level	Technology
Baseline (AFUE = 57)	Standing Pilot
1 – Max Tech (AFUE = 58)	Standing Pilot and Improved Heat Exchanger

5.7.1.8 Technologies for Gas Room Direct Heating Equipment

Technologies for gas room DHE are similar to those incorporated into gas wall gravity DHE. Manufacturers typically improve the heat exchanger until the achievable AFUE is maximized, then use an electronic ignition to further increase the energy efficiency. Table 5.7.10 shows the technologies commonly used in gas room DHE.

Table 5.7.10 Gas Room DHE, Over 27,000 Btu/h and up to 46,000 Btu/h

Efficiency Level	Technology
Baseline (AFUE = 64)	Standing Pilot
1 (AFUE = 65)	Standing Pilot and Improved Heat Exchanger
2 (AFUE = 66)	Standing Pilot and Improved Heat Exchanger
3 (AFUE = 67)	Standing Pilot and Improved Heat Exchanger
4 (AFUE = 68)	Standing Pilot and Improved Heat Exchanger
5 – Max Tech(AFUE = 83)	Electronic Ignition and Multiple Heat Exchanger Design

5.7.1.9 Technologies for Gas Hearth DHE

Manufacturers of vented gas hearth DHE improve efficiency using several methods. Manufacturers typically implement an air circulating blower to achieve efficiency level 1, and then incorporate an air circulating blower to achieve even greater increases in AFUE. Finally, to reach the max-tech level, manufacturers have developed a vented gas hearth DHE that uses condensing operation.

Table 5.7.11 Gas Hearth DHE, Over 27,000 Btu/h and up to 46,000 Btu/h

Efficiency Level	Technology
Baseline (AFUE = 64)	Standing Pilot
1 (AFUE = 67)	Electronic Ignition
2 (AFUE = 68)	Blower
3 – Max Tech(AFUE = 93)	Condensing

5.7.1.10 Technologies for Pool Heaters

Manufacturers improve the energy efficiency of pool heaters using several different technologies, which DOE initially identified in the market and technology assessment (chapter 3). DOE did not include electronic ignition in this analysis because it does not improve the thermal efficiency as measured by the relevant DOE test procedure. During the market analysis, DOE identified models with both standing pilot and electronic ignition systems at the baseline efficiency level. Consequently, DOE examined two baseline units during the reverse-engineering performed for the engineering analysis—one with a standing pilot and one with an electronic ignition.

Manufacturers typically increase the energy efficiency of a pool heater with a standing pilot ignition system by making improvements to the heat exchanger and the insulation surrounding the combustion chamber. Pool heaters with standing pilot ignition systems can only achieve up to 82 percent thermal efficiency. Table 5.7.12 shows the range of efficiency levels DOE analyzed for pool heaters with standing pilots. The highest thermal efficiency possible for pool heaters with standing pilot ignition is shown at efficiency level 3.

Pool heaters with electronic ignitions are available at all of the efficiency levels DOE analyzed. Since pool heaters with electronic ignitions already require electricity, manufacturers can achieve higher efficiency by using additional technologies that also require electricity. Pool heaters with electronic ignitions can achieve much higher energy efficiency ratings than pool heaters with standing pilot ignitions. Manufacturers typically improve the energy efficiency of pool heaters with electronic ignition by improving the heat exchanger design and adding more effective insulation around the combustion chamber (as is done with standing pilot models). They further improve efficiency by adding power venting and/or sealing the combustion chamber to protect from high winds. The max-tech efficiency level is achieved by including technologies that make the pool heater capable of condensing operation.

Electronic ignitions are usually included in pool heaters at efficiency level 3 and below when local regulations prohibit the use of standing pilots. Electronic ignitions are included in products above efficiency level 3 because an electrical connection (usually present due to the electrical requirements of other components) makes it easier for manufacturers to implement this design. Pool heaters at efficiency level 4 and above employ power vents, which require an electrical power source. Table 5.7.12 shows the technologies commonly incorporated in pool heater designs at each efficiency level from the baseline through max-tech. As noted, models at the baseline through efficiency level 3 can use either standing pilot or electronic ignition systems, while the models at efficiency level 4 and above only use electronic ignition systems.

Table 5.7.12 Gas-Fired Pool Heater, 250,000 Btu/h

Efficiency Level	**Technology**
Baseline (Thermal Efficiency = 78)*	
1 (Thermal Efficiency = 79)*	Improved Heat Exchanger Design
2 (Thermal Efficiency = 81)*	Improved Heat Exchanger Design
3 (Thermal Efficiency = 82)*	Improved Heat Exchanger Design, More Effective Insulation (Combustion Chamber)
4 (Thermal Efficiency = 83)	Power Venting
5 (Thermal Efficiency = 84)	Power Venting, Improved Heat Exchanger Design
6 (Thermal Efficiency = 86)	Sealed Combustion, Improved Heat Exchanger Design
7 (Thermal Efficiency = 90)	Sealed Combustion, Condensing
8 – Max-Tech (Thermal Efficiency = 95)	Sealed Combustion, Condensing, Improved Heat Exchanger Design

*Technologies incorporating either a standing pilot or electronic ignition. Efficiency levels 4 through 8 include electronic ignition.

DOE identified the technologies that manufacturers commonly incorporate into residential heating products, as well as the efficiency levels associated with each technology or combination of technologies. Then DOE determined manufacturing costs at various efficiency levels by incorporating the technologies, along with the materials, labor, and components required for manufacturing (as determined by the teardown analysis and included in the BOMs) into the cost model. This information allowed DOE to develop the relationship between cost and efficiency for each efficiency level.

5.8 COST MODEL

5.8.1 Generation of Bills of Materials

The end result of each teardown is a structured BOM, which describes each product part and its relationship to the other parts in the estimated order in which manufacturers assembled them. The BOMs describe each fabrication and assembly operation in detail, including the type of equipment needed (*e.g.*, presses, drills), process cycle times, and labor associated with each manufacturing step. The result is a thorough and explicit model of the production process, including space, conveyor, and equipment requirements by planned production level. DOE developed structured BOMs for each of the physical and virtual teardowns.

The BOMs incorporate all materials, components, and fasteners classified as either raw materials or purchased parts and assemblies. The designations as raw materials or purchased parts were based on DOE's previous industry experience, recent information in trade publications, and discussions with high- and low-volume original equipment manufacturers (OEMs). DOE also visited manufacturing plants to reinforce its understanding of the industry's current manufacturing practices for each of the three types of residential heating products.

The price of purchased parts is estimated based on volume-variable price quotations and detailed discussions with manufacturers and component suppliers. For fabricated parts, the prices of "raw" materials (*e.g.*, tube, sheet metal) are estimated on the basis of 5-year averages (section 5.8.4.4). The cost of transforming the intermediate materials into finished parts is estimated based on current industry pricing. DOE shared major estimates with manufacturers during manufacturer interviews performed for the preliminary and NOPR analyses phases to gain feedback on its analysis, assumptions, methodology, and results.

5.8.2 Cost Structure of the Spreadsheet Models

DOE uses a detailed, component-focused technique for calculating the manufacturing cost of a product (direct materials, direct labor, and the overhead costs associated with production). The first step in the manufacturing cost assessment was creating a complete and structured BOM by disassembling the units selected for teardown. The units were dismantled, and each part was characterized according to weight, manufacturing processes, dimensions, material, and quantity. The BOM incorporates all materials, components, and fasteners, as well as estimates of raw material and purchased part costs. Assumptions on the sourcing of parts and in-house fabrication were based on industry experience, information in trade publications, and discussions with manufacturers. Interviews with manufacturers and plant visits added industry experience for the methodology and pricing.

After generating the BOMs from the teardown analysis, the final step was to convert this information into dollar values. DOE collected information on labor rates, tooling costs, raw material prices, and other factors. DOE assumed values for these parameters using internal expertise and confidential information available to DOE contractors. Although most of the assumptions are manufacturer-specific and cannot be revealed, section 5.8.4.3 provides a discussion of the values used for each assumption.

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.*, gas manifold assembly, combustion chamber assembly, heat exchanger assembly, controls, etc.) and summarized these costs in a worksheet. During engineering interviews with manufacturers, DOE shared key estimates from the cost model and requested feedback. DOE considered all relevant information manufacturers gave and incorporated it into the analysis, if appropriate.

5.8.3 Cost Model and Definitions

Once DOE disassembled selected units, gathered information from manufacturer catalogs on additional products, and identified technologies, DOE created a manufacturing cost model to translate physical information into MPCs. The cost model is based on production activities and divides factory costs into the following categories:

- Materials: Purchased parts (*e.g.*, gas valves, blower motors, ignition modules), raw materials (*e.g.*, cold rolled steel, copper tube), and indirect materials used for processing and fabrication.
- Labor: Fabrication, assembly, indirect, and supervisor labor. Fabrication and assembly labor cost are burdened with benefits and supervisory costs.
- Overhead: Equipment, tooling, and building depreciation, as well as utilities, equipment and tooling maintenance, insurance, and property taxes.

5.8.3.1 Cost Definitions

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

- Direct material: Purchased parts (outsourced) plus manufactured parts (made in house from raw materials).
- Indirect material: Material used during manufacturing (*e.g.*, welding rods, adhesives).
- Fabrication labor: Labor associated with in-house piece manufacturing.
- Assembly labor: Labor associated with final assembly.
- Indirect labor: Labor costs that scaled with fabrication and assembly labor. This included the cost of technicians, manufacturing engineering support, stocking, etc. that were assigned on a span basis.
- Equipment and plant depreciation: Money allocated to pay for initial equipment installation and replacement as the production equipment wears out.
- Tooling depreciation: Cost for initial tooling (including non-recurring engineering and debugging of the tools) and tooling replacement as it wears out.
- Building depreciation: Money allocated to pay for the building space and the conveyors that feed and/or make up the assembly line.

- Utilities: Electricity, gas, telephones, etc.
- Maintenance: Money spent on maintaining tooling and equipment.
- Insurance: Appropriated as a function of unit cost.
- Property Tax: Appropriated as a function as unit cost.

5.8.4 Cost Model Assumptions Overview

As discussed in the previous section, assumptions about manufacturer practices and cost structure played an important role in estimating the final product cost. Assumptions varied for specific manufacturers, depending on market position, manufacturing practices, and size.

In converting physical information about the product into cost information, DOE reconstructed manufacturing processes for each component using internal expertise and knowledge of the methods used by the industry. DOE used assumptions about manufacturing process parameters (*e.g.*, equipment use, labor rates, tooling depreciation, and cost of purchased raw materials) to determine the value of each component. DOE then summed the values of the components into assembly costs and, finally, the total product cost. The product cost included the material, labor, and overhead costs associated with the manufacturing facility. The material costs included both direct and indirect materials. The labor costs included fabrication, assembly, indirect, direct, and supervisor labor rates, including the associated overhead.

DOE determined labor costs by the type of product (water heaters, direct heating equipment, or pool heaters) manufactured at the factory. Overhead costs include equipment depreciation, tooling depreciation, building depreciation, utilities, equipment, tooling maintenance, insurance, property, and taxes.

DOE presented a draft of the cost-efficiency results to manufacturers during the interviews, and used information from the interview to update the cost model to address manufacturer comments about component and material pricing and production volumes. DOE modified the cost model immediately after an interview so refined data could be presented to the next manufacturer. Positive feedback from manufacturers presented with refined data confirmed the accuracy of the changes.

The next sections discuss assumptions about outsourcing, factory parameters, production volumes, and material prices. When the assumptions are manufacturer-specific, they are presented as industry averages to prevent disclosure of confidential information.

5.8.4.1 Fabrication Estimates

DOE characterized parts based on whether manufacturers purchased them from outside suppliers or fabricated them in house. For purchased parts, DOE estimated the purchase price. For fabricated parts, DOE estimated the price of raw materials and the cost of transforming them into finished parts. Whenever possible, DOE obtained price quotes directly from the manufacturers' suppliers.

DOE based the manufacturing operations assumptions on internal expertise, interviews with manufacturers, and visits to manufacturing facilities. Table 5.8.1 presents the major manufacturer processes identified and developed for the spreadsheet model.

Table 5.8.1 Cost Model In-House Manufacturing Operation Assumptions

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

Fabrication process cycle times were estimated and entered into the BOM. The differences in the manufacturing processes for water heater, direct heating equipment, and pool heater products are reflected in the purchased components. For some of the larger subassemblies, such as burner assemblies, DOE estimated the purchased part costs on a volume-weighted basis from discussions with component suppliers.

5.8.4.2 Production Volumes Assumptions

Manufacturer production volumes vary depending on several factors, including market share, total annual shipments of the product being manufactured (*i.e.*, water heater versus pool heater), and whether the manufacturer produces similar products (*e.g.*, similar commercial equipment, boilers, furnaces, storage tanks). DOE based production volume assumptions for residential heating products on industry knowledge and manufacturer interviews.

According to water heater manufacturers, virtually all new residential constructions use water heaters to heat potable water. Approximately 0.91 million single-family and multi-family home constructions started in 2008, which contributes significantly to total water heater shipments (chapter 3). The replacement market was responsible for a majority of the shipments, however, and brought the total units shipped to approximately 8.2 million in 2008.[2] Three competitors hold the majority of the water heater market share. Gas-fired and electric storage water heaters make up the majority of the market, and large production volumes are necessary for these three companies to service this large demand. Based on the information from manufacturers and shipment information from AHRI, DOE estimated that a factory manufacturing gas-fired and electric storage water heaters produces an average of 1.25 million units per year. Water heater manufacturers have multiple facilities capable of this capacity that collectively meet the overall demand.

The market for oil-fired storage water heaters is smaller, and the factory parameters DOE estimated reflect this. Fewer units are purchased per year so factories do not have large volumes or high rates of output, compared to gas-fired or electric storage water heater production. DOE estimated that a manufacturer of oil-fired storage water heaters produces an average of 15,000 units per year.

Manufacturers of direct heating equipment have significantly smaller production volumes than manufacturers of water heaters because the majority of U.S. homes are heated with ducted central heating systems rather than direct heaters. Additionally, some direct heating equipment is sold primarily in the replacement market (*e.g.*, floor heaters). Considering these factors, DOE estimated that a manufacturer of direct heating equipment products produces an average of 35,000 units per year.

Manufacturers of pool heaters hold a unique position in the residential heating products market because their products serve a small market segment and are considered luxury items. Additionally, shipment levels fluctuate based on the time of year, consumer preferences, economic conditions, and changing regulations from local governments. Four manufacturers supply the majority of pool heaters to the U.S. market. Based on information from manufacturers and shipment information from AHRI, DOE estimated that a manufacturer of pool heaters produces an average of 40,000 units per year.

5.8.4.3 Factory Parameters Assumptions

Manufacturers of water heaters, direct heating equipment, and pool heaters have different factory parameters to meet production volumes. Therefore, DOE used information gathered from publicly available literature, manufacturer interviews, and analysis of common industry practices to formulate factory parameters for each type of manufacturer. DOE first made assumptions about a set of factory parameters before the manufacturer interviews, then revised the assumptions based comments and information gathered during the interviews. Table 5.8.2, Table 5.8.3, Table 5.8.4, and Table 5.8.5 list DOE's assumptions for manufacturers of water heaters, direct heating equipment, and pool heaters. Table 5.8.3 lists assumptions for factory parameters of water heater manufacturers located outside the United States. A portion of units, particularly gas-fired instantaneous water heaters, that are purchased by U.S. consumers are manufactured outside of the United States where factory parameters are different (Table 5.8.2). However, manufacturers with facilities outside the United States typically have some manufacturing, distribution, research and development, and customer service operations in the U.S. The cost model accounts for the impact on MPCs of both domestic and international operations.

Table 5.8.2 Domestic Water Heater Factory Parameter Assumptions

Parameter	Estimate		
	Gas-Fired Manufacturing Facility	**Electric Manufacturing Facility**	**Oil-Fired Manufacturing Facility**
Plant Capacity ***units/year***	1,500,000	1,500,000	50,000
Actual Annual Production Volume ***units/year***	1,250,000	1,250,000	15,000
Fabrication Labor Wages ***$/hr***	16.00	16.00	16.00
Fringe Benefits Ratio ***%***	60	50	60

DOE accounted for the different characteristics of water heater manufacturing facilities outside the United States. International and domestic manufacturing differs from domestic manufacturing by capacity (Table 5.8.3). Because workers in foreign facilities often receive lower wages and fewer benefits, these facilities typically have lower assembly and manufacturing costs and therefore larger capacities and higher product output.

Table 5.8.3 International Water Heater Factory Parameter Assumptions

Parameter	Estimate
Plant Capacity ***units/year***	1,500,000
Actual Annual Production Volume ***units/year***	1,250,000
Labor Wages ***$/hr***	15.50
Fringe Benefits Ratio ***%***	50

The direct heating equipment industry is smaller than the water heater industry, and the manufacturing capacities reflect this (Table 5.8.4). Consumer demand for direct heating equipment typically fluctuates over the year and the majority of shipments occur during the heating season. During the warmer months, plant operations are sometimes suspended entirely, with wage workers taking up to two months' leave. In addition, some products (*e.g.*, floor furnaces) are only sold as replacement units, which reduces production volumes even more, as markets for these particular products do not grow.

Table 5.8.4 Direct Heating Equipment Factory Parameter Assumptions

Parameter	Estimate
Plant Capacity ***units/year***	50,000
Annual Production Volume ***units/year***	35,000
Labor Wages ***$/hr***	16.00
Fringe Benefits Ratio ***%***	50

Pool heater manufacturing capacity falls between the levels for water heaters and direct heating equipment, and factory parameters for pool heater manufacturing are similar to those for direct heating equipment. Production levels are subject to fluctuations over the year as the majority of pool heaters are shipped during the warmer seasons when pools are in use. In addition, pool heaters are considered a luxury item, unlike water heaters, which are considered a household necessity. Therefore pool heater shipment levels are lower and depend on consumers' financial status, weather, and installation and maintenance costs.

Table 5.8.5 Pool Heater Factory Parameter Assumptions

Parameter	Estimate
Plant Capacity ***units/year***	80,000
Annual Production Volume ***units/year***	40,000
Labor Wages ***$/hr***	16.00
Fringe Benefits Ratio ***%***	50

The main differences among the assumptions for the residential heating products are the production volumes and the product output rates. Labor rates for manufacturers of water heaters differ between domestic and international operations. These rates, for both foreign and domestic manufacturers, are based on weighted averages. Certain manufacturers of water heaters, particularly gas-fired instantaneous water heaters, make their products in foreign factories where labor rates are lower than domestic rates. Foreign labor rates are based on information gathered during manufacturer interviews, internal expertise, and industry literature research. DOE assumed that all manufacturers of direct heating equipment and pool heaters are domestic. Domestic labor rates are based on published labor rates for the Heating, Ventilation, and Air Conditioning (HVAC) manufacturing industry from the U.S. Bureau of Labor.[3]

5.8.4.4 Material Prices Assumptions

DOE determined the cost of raw materials using publicly available information such as the American Metals Market,[4] interviews with manufacturers, and discussions with material suppliers. Metals used in the fabrication of residential heating products include plain cold rolled steel (CRS), copper tubing, and aluminum. There have been drastic fluctuations in metal prices over the last few years; to account for these fluctuations, DOE used a 5-year average of metal prices from the Bureau of Labor Statistics Producer Price Indices (PPIs) spanning 2005 to 2005, with an adjustment to 2009$.[5] DOE used the PPIs for copper rolling, drawing, and extruding, and steel mill products, and made the adjustments to 2009$ using the gross domestic product implicit price deflator.[6] Table 5.8.6 shows the 5-year average metal prices DOE used for the analysis.

Table 5.8.6 Five-Year Metal Prices (2005 to 2009)

Metals	**Cost (2009$)** ***$/lb***
Plain Cold Rolled Steel	0.37
Painted CRS	0.63
Galvanized CRS	0.49
Aluminized CRS	0.55
Textured CRS	0.63
CRS Tube	0.68
Stainless Steel	2.10
Fin Aluminum	1.28
Plain Copper	2.17
Copper Tube – Plain	2.82
Brass	1.79

For resins used in the fabrication of these products, DOE used current prices gathered from industry research, publicly available publications such as *Plastics News*,[7] and interviews with manufacturers. Resin prices are contract-specific, determined by quantity and supplier, and therefore have no true fixed market price. For this analysis, DOE used market resin prices current as of December 2009. The prices of resins have been constantly increasing and closely follow petroleum prices. Table 5.8.7 shows the current resin prices DOE used in the analysis.

Table 5.8.7 Most Prevalent Resin Prices as of December 2009

Resins	**Cost (2009$)** ***$/lb***
Polystyrene (PS)	0.756
Polypropylene (PP)	0.800
Polyurethane Foam (non-HCFC blowing agent)	1.391
PVC (Hard)	0.992

5.8.5 Manufacturing Production Cost

Once the cost estimate for each teardown unit was finalized, DOE prepared a detailed summary for relevant components, subassemblies, and processes. The BOM thus details all aspects of unit costs. DOE totaled the cost of materials, labor, and direct overhead used to manufacture a product in order to calculate the MPC.[a]

Figure 5.8.1 shows the general breakdown of costs associated with manufacturing a product.

[a] When viewed from the company-wide perspective, the sum of all material, labor, and overhead costs equals the company's sales cost, also referred to as the cost of goods sold (COGS).

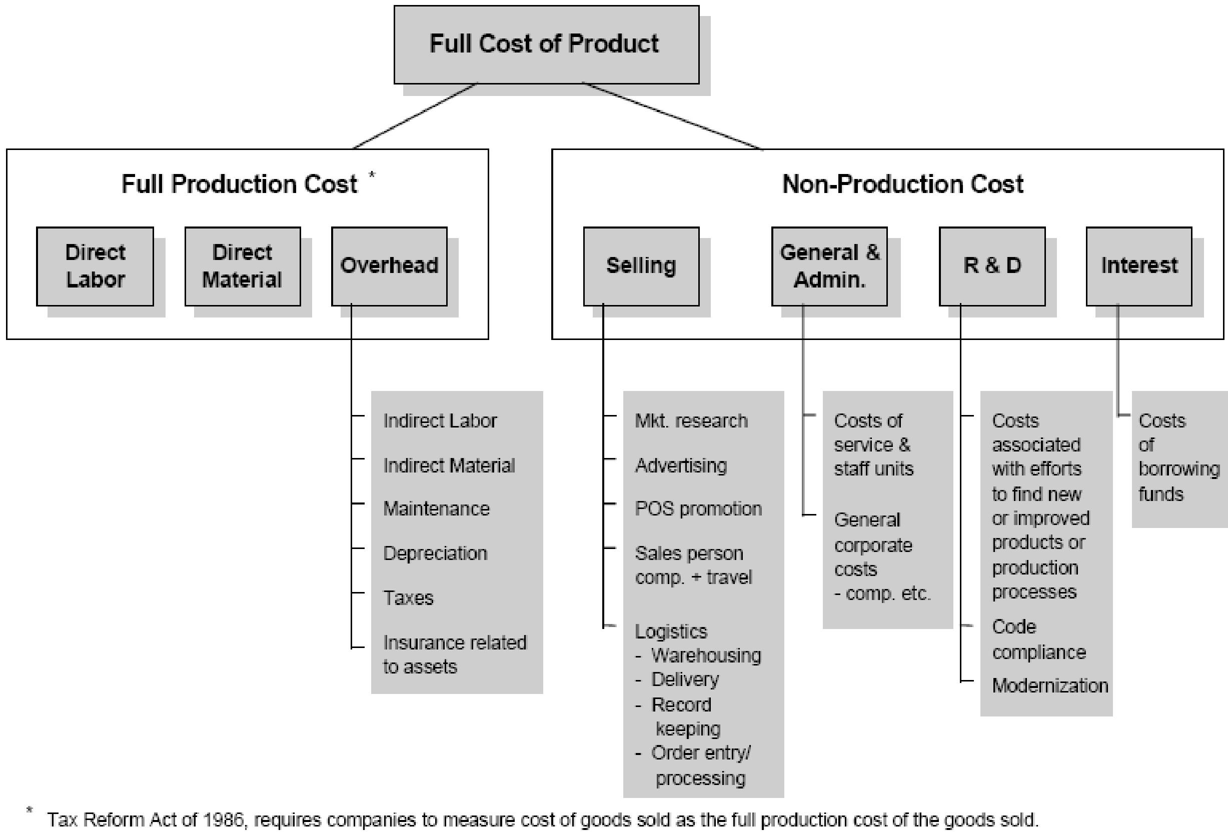


Figure 5.8.1 Full Production Costs

The full cost of product is broken down into two main costs: the full production cost or MPC, and the non-production cost. The non-production cost is equal to the manufacturer markup minus profits.

Following the development of the MPCs, DOE reviewed its major cost estimates during interviews with residential heating products manufacturers, who provided feedback and validation. DOE used a continuous refinement process by incorporating each manufacturer's feedback before the subsequent interview. As a result, DOE developed MPCs for use in the engineering analysis and subsequent analyses.

Technologies used in the units subject to teardown are noted in the summary sheet of each cost model and the costs are estimated individually. Thus, various implementations of technologies can be accommodated, ranging from assemblies that are entirely purchased to units that are entirely made from raw materials. Therefore, hybrid assemblies, consisting of purchased parts and parts made on site, are also accommodated.

5.8.6 MPCs for Rated Storage Volumes Other than the Representative Rated Storage Volume for Water Heaters

Residential storage water heaters display large variations in manufacturing production cost (and as a result, first cost to consumer) across the full range of rated storage volumes. In order to account for these variations in costs at storage volumes larger or smaller than the representative rated storage volume, DOE scaled its MPC estimates and efficiency levels using the energy efficiency equations and manufacturing cost model. DOE analyzes several discrete rated storage volumes higher and lower than the representative storage volume for each water heater product class. DOE developed the MPCs for water heaters at each of the rated storage volumes shown in Table 5.8.8. These storage volumes were determined to be the most prevalent storage volumes available on the market during the market analysis (see chapter 3 of the TSD).

Table 5.8.8 Additional Water Heater Storage Volumes Analyzed

Water Heater Product Class	**Additiona Rated Storage Volumes Analyzed (Gallons, U.S.)**
Gas-fired Storage	30, 50, 65, 75
Electric Storage	30, 40, 66, 80, 119
Oil-fired Storage	50

To develop the MPCs for the additional storage volumes, DOE performed a reverse-engineering analysis (i.e., teardowns analysis) of representative units from a range rated storage volumes and multiple manufacturers. DOE expanded its cost model at the various additional storage volumes based on the data obtained from these teardowns. Whenever possible, DOE maintained the same product line across the full range of rated storage volumes that was identified using the teardowns at the representative storage volumes (see section 5.3). For example, manufacturers often produce lines of products with the same or similar design characteristics across a range of storage volumes. DOE would select models for teardowns at storages volumes outside of the representative rated storage volume that were from the same product line(s) (and thus had similar characteristics) as the models torn down at the representative storage volume. DOE could then attempt to characterize how different components would scale at the different volume sizes. From this information, DOE estimated the corresponding changes in labor and material costs for water heaters with rated storage volumes outside of the representative one.

The cost model accounts for all changes in the size of water heater components that would scale with tank volume. This primarily includes the tank dimensions, wrapper dimensions, tank and wrapper wall thicknesses, insulation thickness, anode rod(s), and flue pipe(s). Components that typically do not change based on tank volume were assumed to remain largely the same across the different storage volume sizes, while accounting for price differences due to changes in insulation thickness. Major components that do not scale with storage volume capacity are gas valves, thermostats, and controls. DOE estimated the changes in material and labor costs that occur at volume sizes higher and lower than the representative capacity based on observations made during teardowns and professional experience. As with the teardowns performed at the representative rated storage volume, performing teardowns of models outside of the representative rated storage volume allowed DOE to accurately model certain characteristics (such as tank wall thickness and wrapper thickness) that are not identifiable in manufacturer literature. Section 5.13.2 summarizes the results of DOE's scaling of manufacturing costs to the additional rated storage volumes for gas-fired, electric, and oil-fired water heaters.

5.9 ENGINEERING MANUFACTURER INTERVIEWS

Throughout the rulemaking process, DOE sought feedback and insight from interested parties to improve the information used in the analyses. For the engineering analysis, DOE discussed the analysis assumptions and estimates, cost model, and cost-efficiency curves with manufacturers of water heaters, direct heating equipment, and pool heaters. When refining the cost model, DOE considered all the information manufacturers provided. DOE incorporated equipment and manufacturing process figures into the analysis in the form of averages to avoid disclosing sensitive information about individual manufacturers' products or manufacturing processes.

Before the interviews, DOE gave manufacturers interview guides (see Appendix 12-A of the NOPR TSD), which included questions and topics to be discussed during the interview, along with assumptions, estimates, and cost-efficiency results. DOE asked manufacturers to provide feedback on the representation of the market and to supply any data that could improve DOE's estimates and assumptions

During the interviews performed in preparation for the NOPR analysis, DOE engaged manufacturers in open discussions so that all issues regarding the heating products rulemaking would be covered. In addition to responding to DOE's specific questions about the engineering analysis and MPCs, manufacturers also commented on a range of other issues affecting the engineering analysis. DOE compiled all of the issues manufacturers discussed and presents those manufacturers consider paramount. Analysis of these key issues allowed DOE to refine the engineering analysis and the manufacturer impact analysis (MIA) (chapter 12). Manufacturers presented two key issues: recent material price increases and the effects on MPC, and cost increases caused by ultra-low NO_X regulations. For a detailed discussion of these issues, see chapter 5 of the NOPR TSD. Manufacturers also provided feedback about other key issues that DOE considered for this rulemaking that do not directly impact the engineering analysis. See chapter 12 of the TSD for more details.

5.10 COST VERSUS EFFICIENCY CURVES

As described in section 5.8.5, DOE first estimated the MPC of the baseline units for each product class. DOE then determined the intermediate efficiency levels, up to max-tech, that represent the residential heating products market, and identified the MPCs for each of these intermediate efficiency levels.

The result of the engineering analysis is 11 cost-efficiency curves representing the product classes examined for the final rule. For storage water heaters, the cost efficiency curves show the representative rated storage volumes, in addition to the other storage volumes analyzed.

Figure 5.10.1 through Figure 5.10.12 show the 11 cost-efficiency curves in the form of energy efficiency (*i.e.*, EF, AFUE, or thermal efficiency) versus MPC. Table 5.10.1 lists the curves and their corresponding figure numbers.

Table 5.10.1 Cost-Efficiency Curves and Corresponding Figures

Product	**Curve Shown in**
Gas-Fired Storage Water Heater, Standard Burner	Figure 5.10.1
Gas-Fired Storage Water Heater, Ultra-Low NOx Burner	Figure 5.10.2
Oil-Fired Storage Water Heater	Figure 5.10.3
Electric Storage Water Heater	Figure 5.10.4
Electric Storage Water Heater Close-Up	Figure 5.10.5
Gas-Fired Instantaneous Water Heater	Figure 5.10.6
Gas Wall Fan DHE	Figure 5.10.7
Gas Wall Gravity DHE	Figure 5.10.8
Gas Floor DHE	Figure 5.10.9
Gas Room DHE	Figure 5.10.10
Gas Hearth DHE	Figure 5.10.11
Gas-Fired Pool Heater	Figure 5.10.12

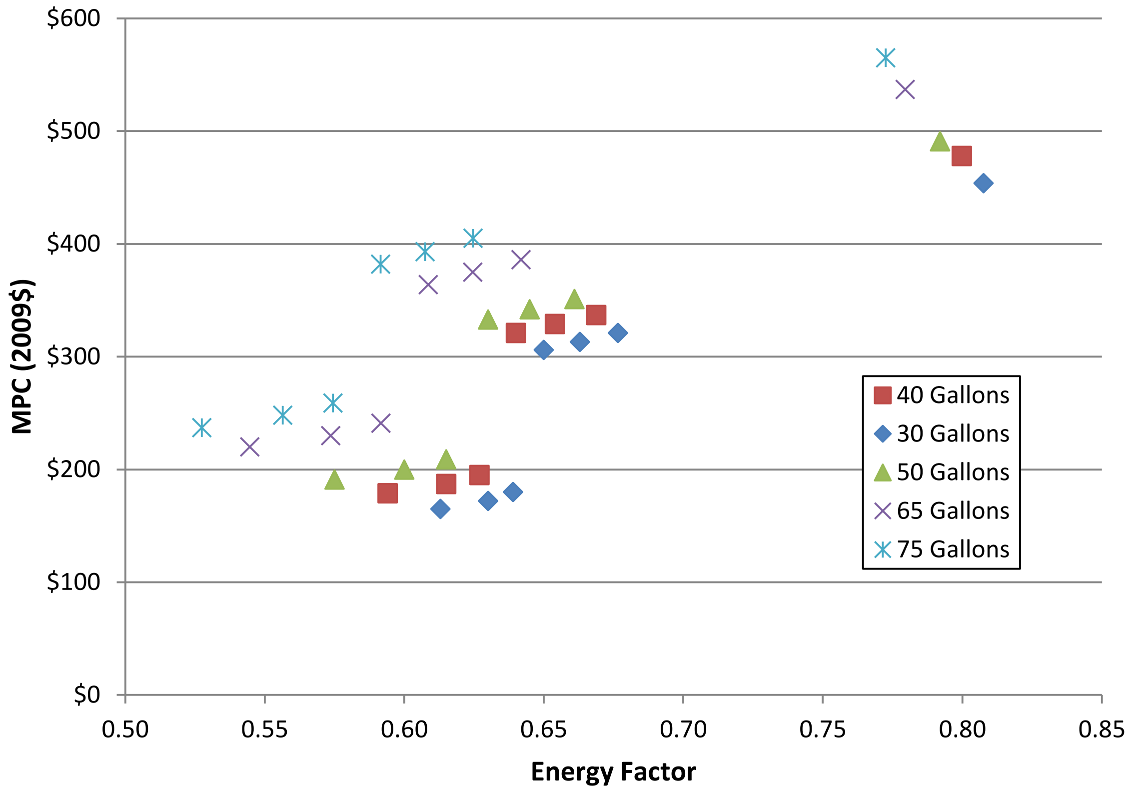


Figure 5.10.1 Manufacturer Production Cost (2009$) versus Energy Factor for Gas-Fired Storage Water Heaters, Standard Burner

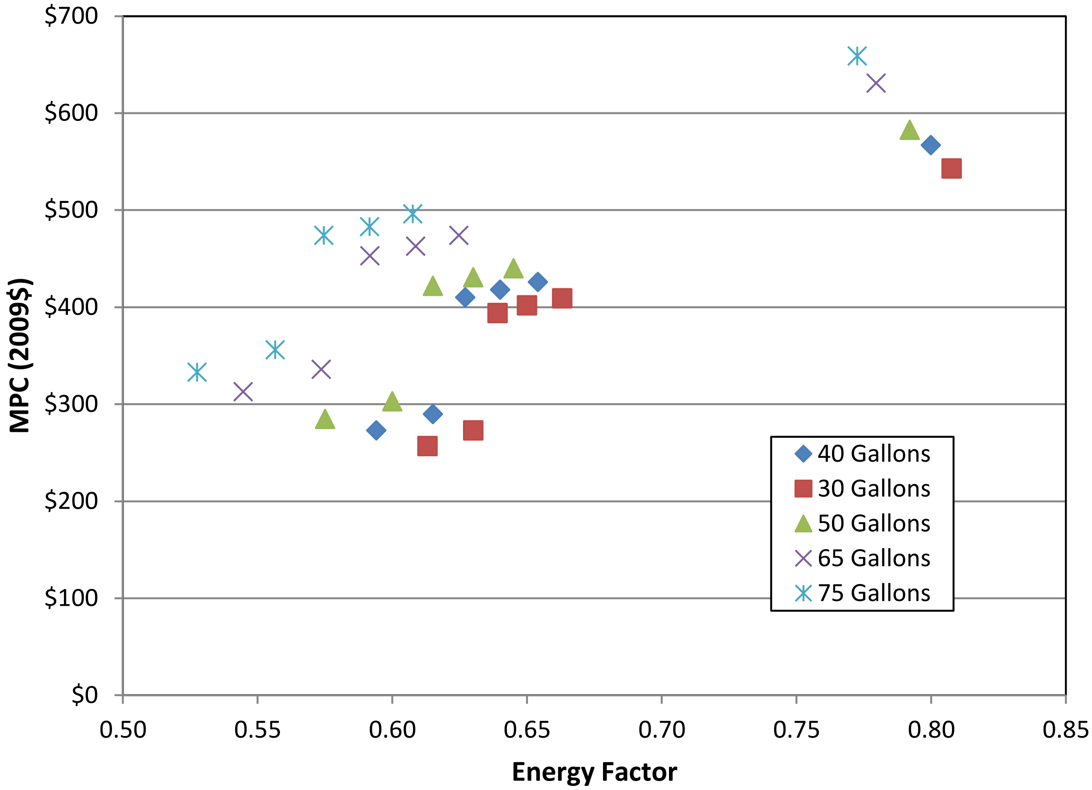


Figure 5.10.2 Manufacturer Production Cost (2009$) versus Energy Factor for Gas-Fired Storage Water Heaters, Ultra-Low NO_X Burner

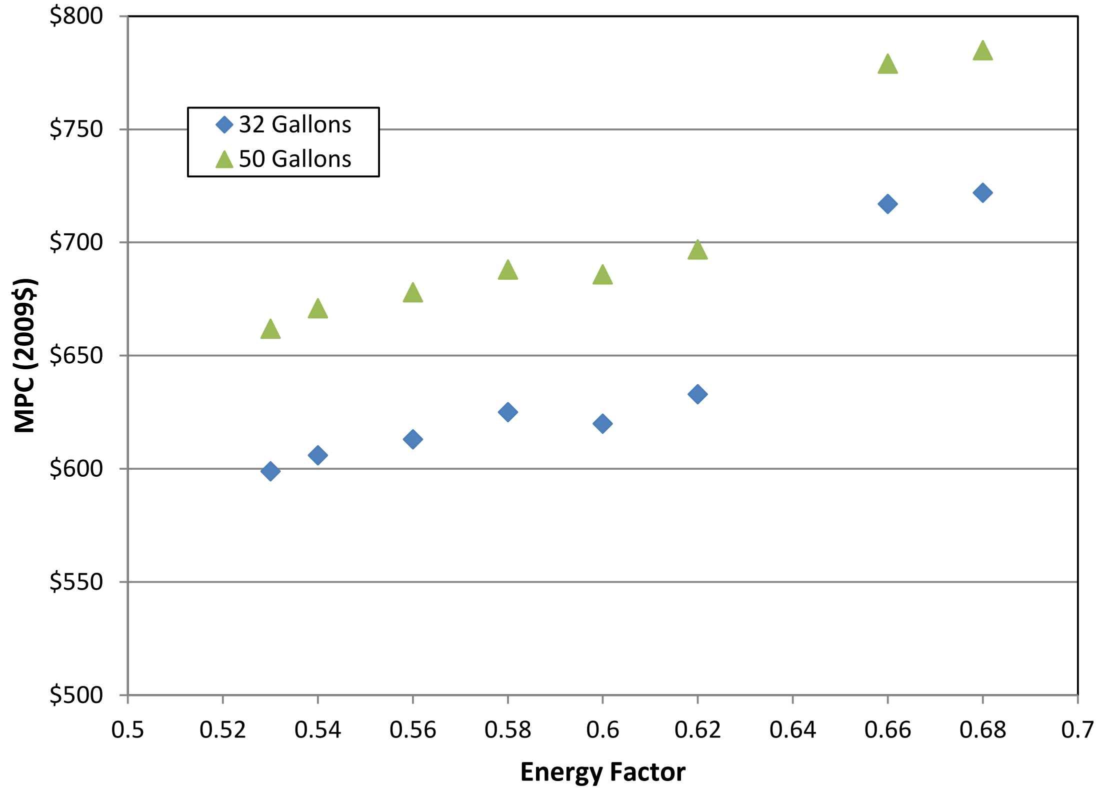


Figure 5.10.3 Manufacturer Production Cost (2009$) versus Energy Factor for Oil-Fired Storage Water Heaters

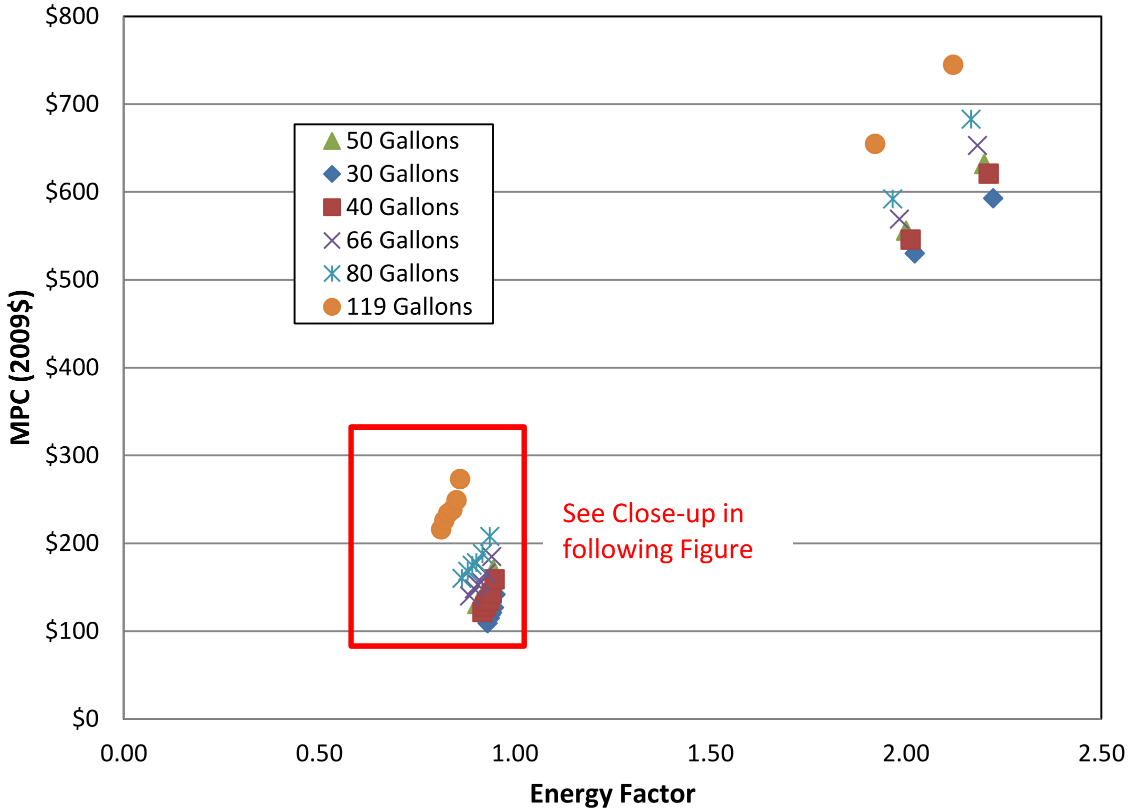


Figure 5.10.4 Manufacturer Production Cost (2009$) versus Energy Factor for Electric Storage Water Heaters

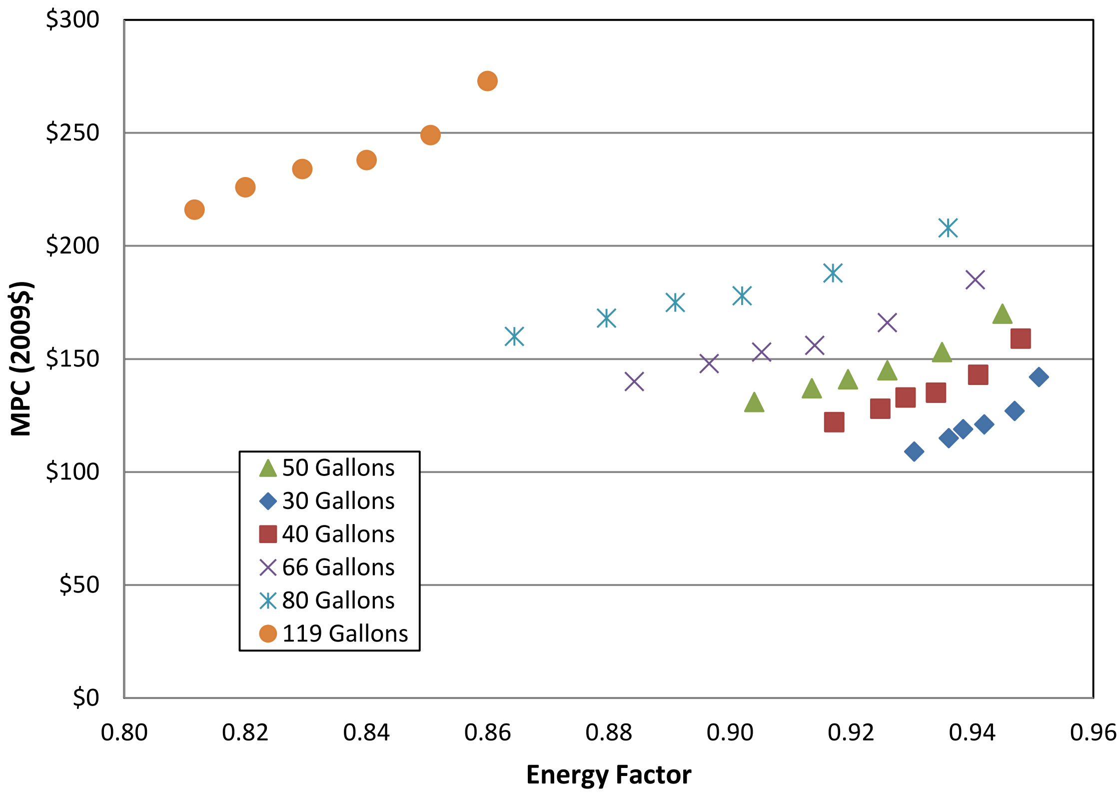


Figure 5.10.5 Close-Up of Resistance Heating Electric Storage Water Heaters

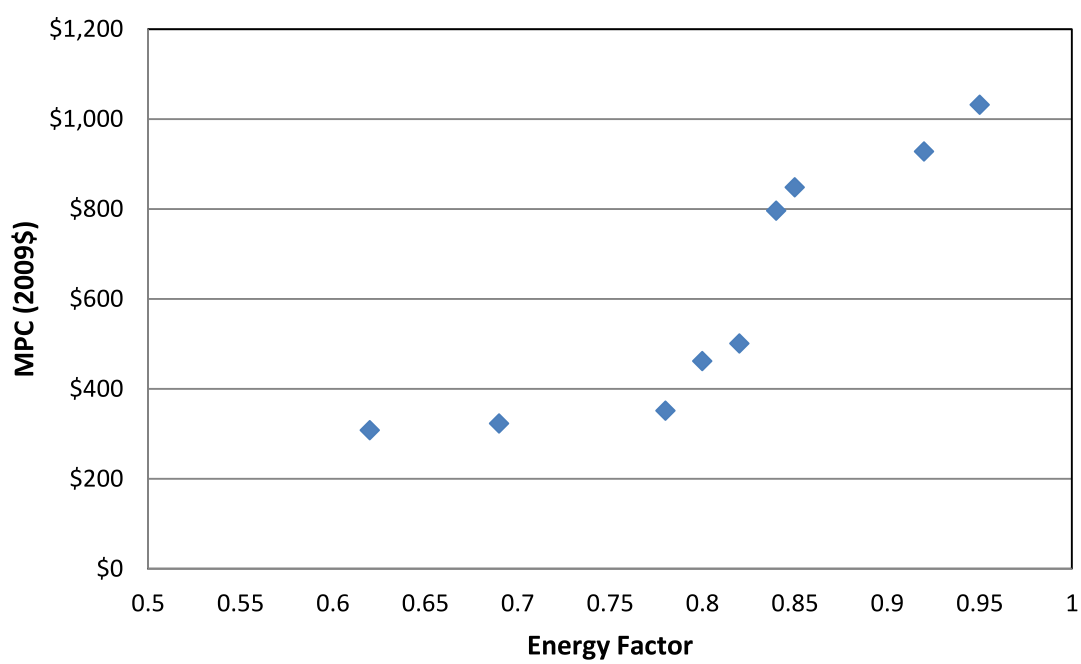


Figure 5.10.6 Manufacturer Production Cost (2009$) versus Energy Factor for Gas-Fired Instantaneous Water Heaters, 0 Gallon, 199,000 Btu/h Input Capacity

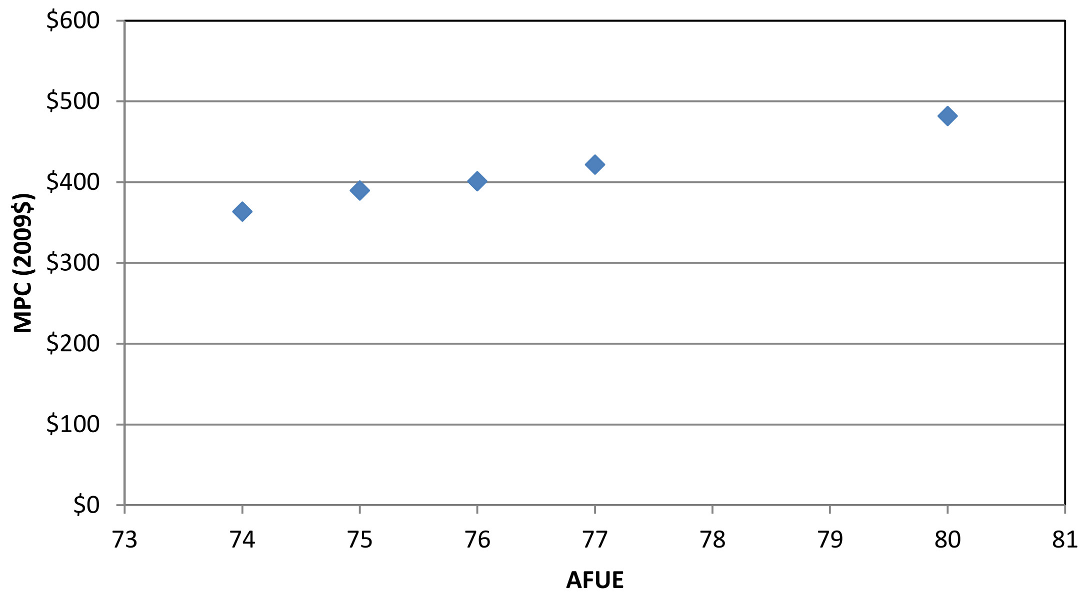


Figure 5.10.7 Manufacturer Production Cost (2009$) versus AFUE for Gas Wall Fan DHE, Over 42,000 Btu/h

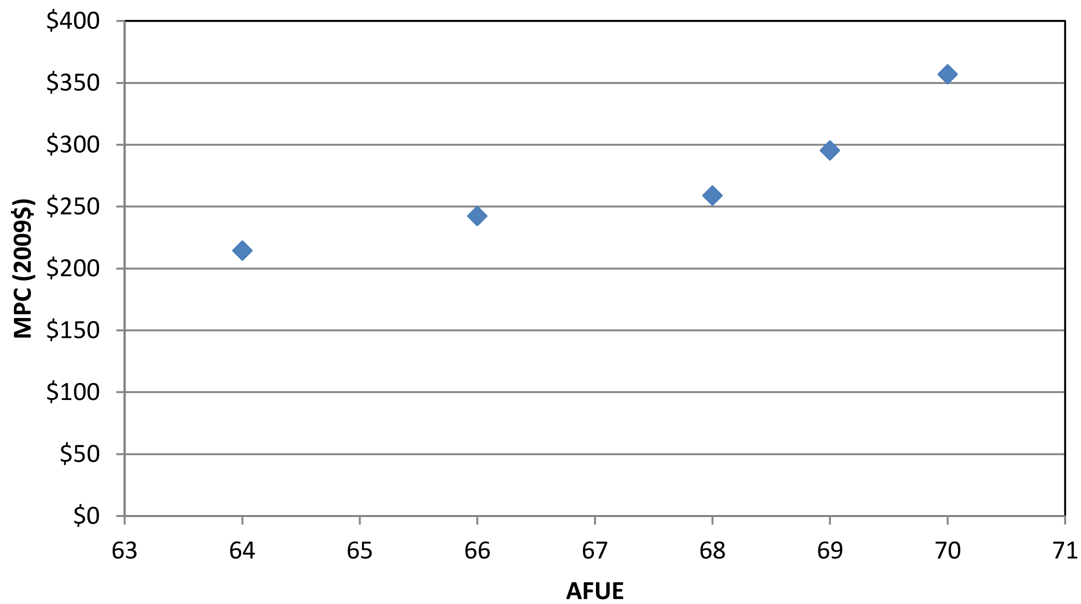


Figure 5.10.8 Manufacturer Production Cost (2009$) versus AFUE for Gas Wall Gravity DHE, Over 27,000 Btu/h and up to 46,000 Btu/h

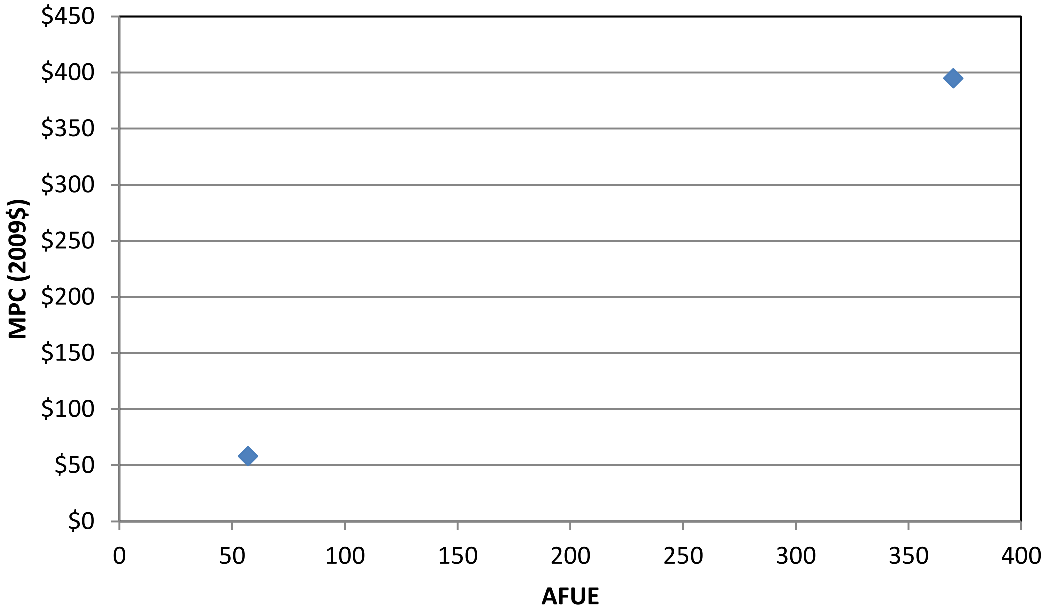


Figure 5.10.9 Manufacturer Production Cost (2009$) versus AFUE for Gas Floor DHE, Over 37,000 Btu/h

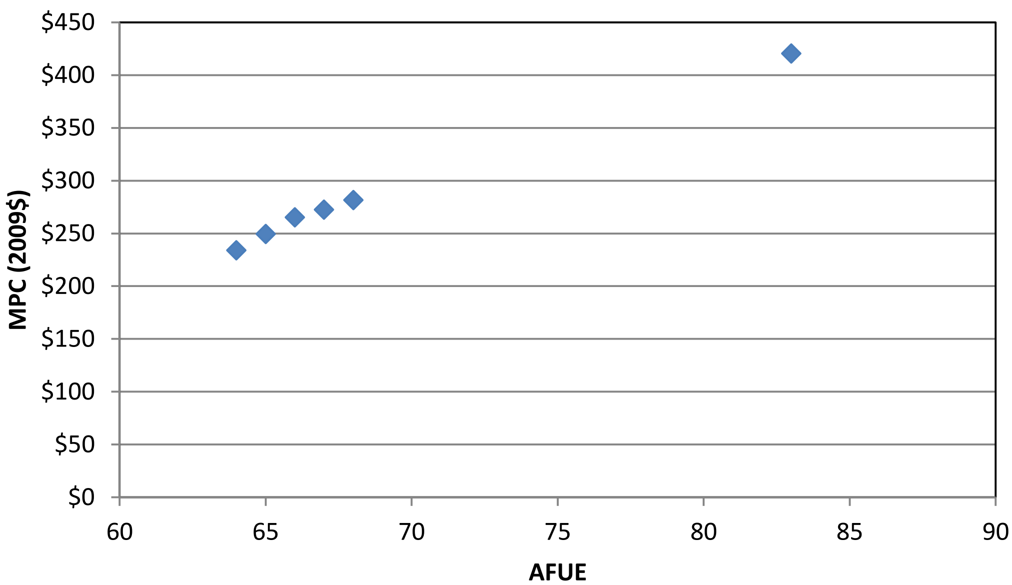


Figure 5.10.10 Manufacturer Production Cost (2009$) versus AFUE for Gas Room DHE, Over 27,000 Btu/h and up to 46,000 Btu/h

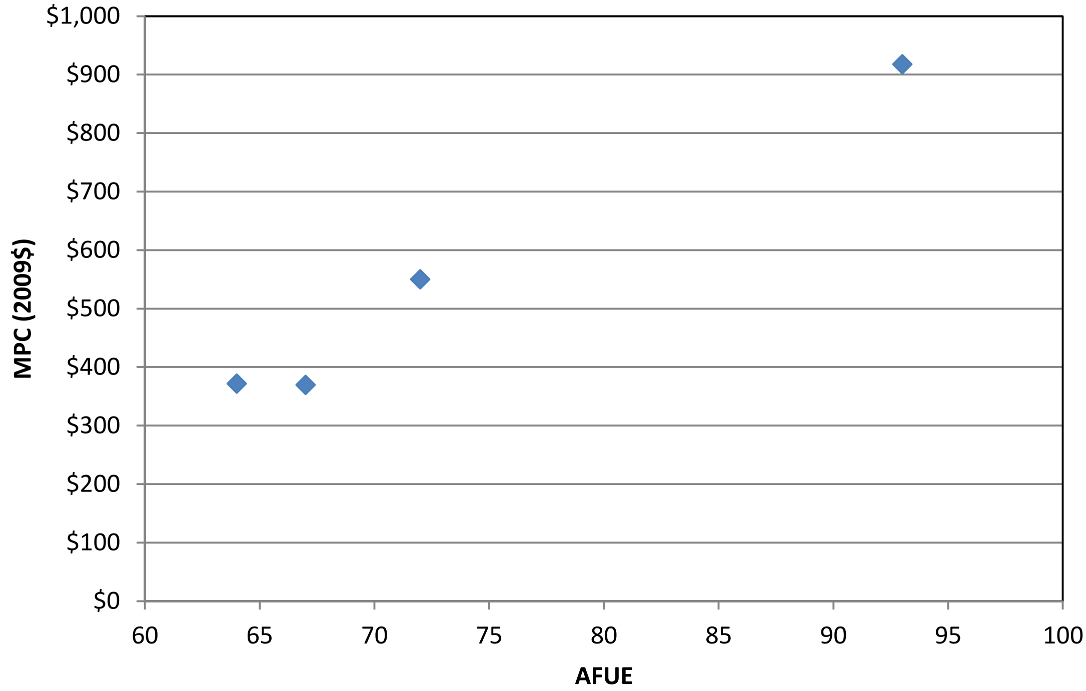


Figure 5.10.11 Manufacturer Production Cost (2009$) versus AFUE for Gas Hearth DHE, Over 27,000 Btu/h and up to 46,000 Btu/h

DOE identified two baselines for residential pool heaters. The first includes pool heaters incorporating a standing pilot ignition system, and the second includes pool heaters incorporating an electronic ignition. DOE did not consider electronic ignition as a technology option because it does not improved thermal efficiency, as defined by DOE test procedures (chapter 3). However, the total energy use of the two ignition types is different and will be used in the consumer economic models (*i.e.*, the LCC and the PBP analysis).

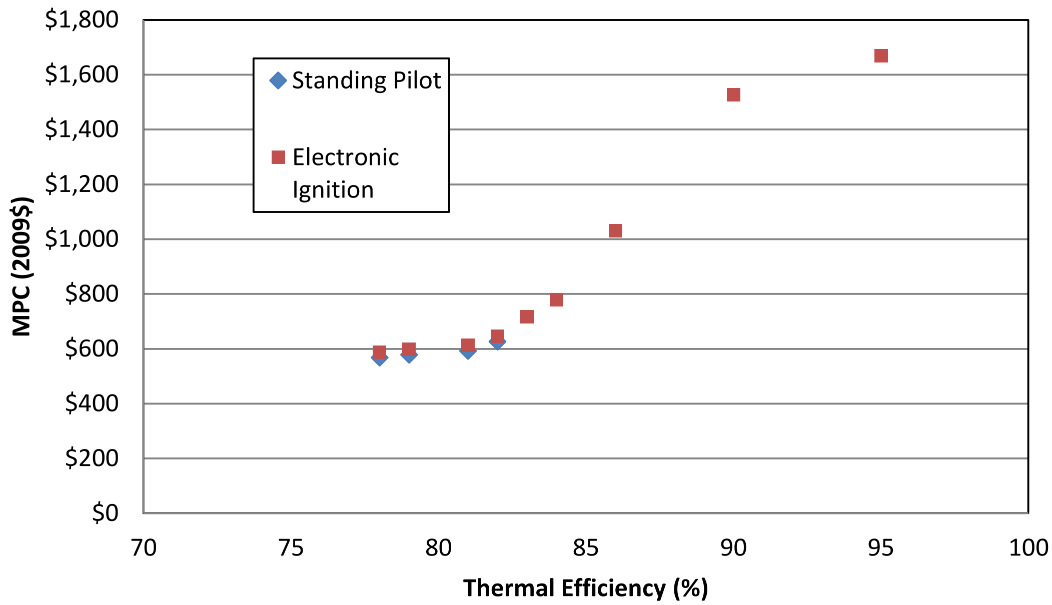


Figure 5.10.12 Manufacturer Production Cost (2009$) versus Thermal Efficiency for Gas-Fired Pool Heater, 250,000 Btu/h

The results show that the cost-efficiency curves are nonlinear. As efficiency increases, manufacturing becomes more difficult and more costly. Large jumps are evident when designs include electronic ignition, blower motors, power vent, and condensing operation designs. Additionally, MPC increases greatly when heat pump technology is used as an alternative to resistive heating for electric storage water heaters.

The non-linear relationship is common to all product types. Products such as DHE and high-efficiency pool heaters see larger increases in MPC due to lower production volumes than water heaters.

5.11 MPC BREAKDOWN

After DOE incorporated all the assumptions into the cost model, it calculated the production cost percentages. The product cost percentages validate the assumptions by comparing them to manufacturers' actual financial data published in annual reports, along with feedback from manufacturers during interviews. DOE also used these figures in the MIA (chapter 12). DOE calculated the average product costs percentages by product type (*i.e.*, water heater, DHE, pool heater) as well as by product class (*e.g.*, gas-fired storage water heater, electric storage water heater) due to the large variations in production volumes, fabrication and assembly costs, and other factors that affect the calculation of the unit's total MPC. Table 5.11.1, Table 5.11.2, and Table 5.11.3 show the different percentages for the production costs that make up the total product MPC.

Table 5.11.1 Total Product MPC Breakdown for Water Heaters

Percentage Cost Breakdown by Water Heater Type *baseline, by %*				
	Gas-Fired, Storage	**Oil-Fired, Storage**	**Electric, Storage**	**Gas-Fired, Instantaneous**
Materials	76.7	67.3	71.1	55.0
Labor	10.7	4.9	13.3	28.6
Depreciation	5.5	15.0	6.0	7.8
Overhead	7.1	12.8	9.6	8.6

Table 5.11.2 Total Product MPC Breakdown for Direct Heating Equipment

Percentage Cost Breakdown by Direct Heating Equipment Type *baseline, by %*					
	Gas Wall Fan	**Gas Wall Gravity**	**Gas Floor**	**Gas Room**	**Gas Hearth**
Materials	48.0	53.9	48.9	49.0	53.4
Labor	24.5	16.5	28.4	19.0	15.1
Depreciation	15.9	17.8	12.9	18.9	16.7
Overhead	11.6	11.7	9.9	13.2	14.7

Table 5.11.3 Total Product MPC Breakdown for Pool Heaters

	Percentage Cost Breakdown *baseline, by %*
	Pool Heater
Materials	63.8
Labor	14.9
Depreciation	11.0
Overhead	10.3

5.12 MANUFACTURER MARKUP

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

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

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

5.12.1 Manufacturer Selling Price

The MSP is the price at which the manufacturer can recover all production and non-production costs[b] and earn a profit. DOE calculated the MSP for gas-fired instantaneous water heaters, DHE, and pool heaters by multiplying the MPCs by the calculated manufacturer markup. For storage water heaters only, DOE analyzed the shipping cost (typically considered a non-production cost and included in the manufacturer markup) separately from the manufacturer markup for the NOPR analyses. In the case of storage water heaters DOE calculated the MSP by multiplying the MPC by the manufacturer markup, and then added the shipping cost.

5.12.2 Manufacturing Markup Calculation

Applying a manufacturer markup to the MPC of the product yields the MSP. In general, the manufacturer markup should ensure that the MSP of the product is high enough to recover the full cost of the product (*i.e.*, full production and non-production costs), and generate a satisfactory profit.

The law requires publicly owned companies to disclose financial information on a regular basis by filing forms with the U.S. Securities and Exchange Commission (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. In the preliminary analysis, DOE used 10-Ks from publicly owned residential heating product companies to estimate manufacturer markups. 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.

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[b] Non-production costs include selling, general, and administration (SG&A) costs, the cost of research and development, and interest.

For the preliminary analysis, DOE calculated baseline manufacturer markups by using averages of SEC 10-K report figures from 2000 to 2006, then calculated markups.

DOE used the following equations to calculate gross profit and gross profit margins for the preliminary analysis:

$$\text{Gross Profit} = \text{Net Sales} - \text{Cost of Sales} \qquad \textbf{Eq. 5.1}$$

$$\text{Gross Profit Margin} = \frac{\text{Gross Profit}}{\text{Net Sales}} \qquad \textbf{Eq. 5.2}$$

Table 5.12.1presents the calculated gross profit margins for a sample of manufacturers.

Table 5.12.1 Gross Profit Margin for Residential Heating Products Manufacturers*

Manufacturer	Financial Figure	Year						
		2006	**2005**	**2004**	**2003**	**2002**	**2001**	**2000**
A	**Net Sales $**	2,161,300	1,698,200	1,653,100	1,530,700	1,469,100	1,151,200	1,247,900
	Cost of Sales $	1,697,400	1,337,200	1,355,100	1,232,000	1,169,300	948,800	999,800
	Gross Profit $	463,900	352,000	298,000	298,700	299,800	202,400	248,100
	Gross Profit Margin %	**21.5**	**20.8**	**18.0**	**19.5**	**20.4**	**17.6**	**19.9**
	Average Gross Profit Margin 19.8%							
B	**Net Sales $**	158,767	138,999	126,940	120,165	128,301	130,211	116,002
	Cost of Sales $	130,410	114,065	103,320	93,713	100,477	98,712	87,235
	Gross Profit $	28,357	24,934	23,620	26,452	27,824	31,499	28,767
	Gross Profit Margin %	**17.9**	**17.9**	**18.6**	**22.0**	**21.7**	**24.2**	**24.8**
	Average Gross Profit Margin 20.8%							
C	**Net Sales $**	3,671,100	3,366,200	2,982,700	2,789,900	2,727,400	3,119,691	3,247,357
	Cost of Sales $	2,515,900	2,258,200	1,985,200	1,846,600	1,861,300	2,190,041	2,228,046
	Gross Profit $	1,155,200	1,108,000	997,500	943,300	866,100	929,650	1,019,311
	Gross Profit Margin %	**31.5**	**32.9**	**33.4**	**33.8**	**31.8**	**29.8**	**31.4**
	Average Gross Profit Margin 32.0%							
D**	**Net Sales $**		210,603	182,808	180,203	157,966	162,128	170,950
	Cost of Sales $		154,110	137,277	137,008	116,185	116,462	123,405
	Gross Profit $		56,493	45,531	43,195	41,781	45,666	47,545
	Gross Profit Margin %		**26.8**	**24.9**	**24.0**	**26.4**	**28.2**	**27.8**
	Average Gross Profit Margin 26.3%							
E	**Net Sales $**	2,155,225	2,131,505	1,563,394	1,060,303	932,420	882,615	898,247
	Cost of Sales $	1,536,675	1,517,631	1,114,699	771,900	693,720	653,135	642,246
	Gross Profit $	618,550	613,874	448,695	288,403	238,700	229,480	256,001
	Gross Profit Margin %	**28.7**	**28.8**	**28.7**	**27.2**	**25.6**	**26.0**	**28.5**
	Average Gross Profit Margin 28.0%							

Note: Figures in thousands of dollars.
* 2000, 2001, 2002, 2003, 2004, 2005, and 2006 SEC 10-K reports.
** Data are not available for missing years.

To calculate the time-average gross profit margin for each firm for the preliminary analysis, DOE first summed the gross profit for all the years and then divided the result by the sum of the net sales for the same years. Each manufacturer's non-production cost markup was calculated as:

$$\text{Non - production cost markup} = \frac{1}{(1 - \text{Gross Profit Margin})} = \frac{\text{Gross Profit}}{\text{Cost of Sales}} \quad \textbf{Eq. 5.3}$$

Table 5.12.2 shows the manufacturer markups using this method.

Table 5.12.2 Manufacturer Markups for Residential Heating Products Calculated for the Preliminary Analysis

Manufacturer	Manufacturer Markup
A	1.25
B	1.26
C	1.47
D	1.36
E	1.39
Average	**1.35**

For the preliminary analysis, DOE calculated the average manufacturer markup as 1.35 across all three product types. In other words, residential heating products manufacturers, on average, sell their products to the next party in the distribution channel at 35 percent above the full manufacturing production cost.

DOE presented the calculated manufacturer markup to manufacturers during the preliminary interviews. Numerous manufacturers of residential heating products are privately held companies, companies owned through employee stock ownership plans, and companies owned through private stock plans, none of which file SEC 10-K reports. In addition, while publicly owned companies file SEC 10-K reports, the financial information summarized is not only for the heating products portion of their business. It can include financial information from other product sectors, whose margins might be quite different from the residential heating products industries. After considering manufacturer feedback from the preliminary analysis, DOE determined the residential storage water heating, direct heating equipment, and pool heating industry markups to be approximately 1.38 on an aggregate basis. To reflect the differences experienced by manufacturers in the instantaneous water heating market, DOE used 1.45 to represent the manufacturer markup.

To further refine the manufacturer markups used in the engineering analysis, DOE addressed the issue again during the manufacturer interviews conducted for the NOPR phase of the heating products rulemaking. DOE had in-depth discussions with manufacturers about their markups of products with various sizes, features, and efficiencies. DOE aggregated all manufacturer feedback and developed separate manufacturer markups for each product type. Markups typically account for all non-production costs and profit. However, in the case of storage water heaters, DOE separated the shipping costs out of the manufacturer markup to make the engineering analysis more transparent. Additionally, DOE maintained these markups for the final rule analysis because DOE did not receive any new data that would warrant modifying these markups for the final rule analysis. Table 5.12.3 presents the baseline manufacturer markups used in the engineering analysis that was performed for the NOPR and final rule. The markups for storage water heaters do not account for shipping costs, which are analyzed separately (section 5.12.3).

Table 5.12.3 Manufacturer Markups Calculated for the NOPR and Final Rule Analysis

Product Type	Product Class	Markup
Water Heaters	Gas-Fired Storage	1.31
	Electric Storage	1.28
	Oil-Fired Storage	1.30
	Gas-Fired Instantaneous	1.45
Direct Heating Equipment	All	1.35
Pool Heaters	All	1.30

The engineering analysis uses these multipliers to determine the MSPs for each representative product class. DOE used a constant markup to reflect the MSPs of the baseline products as well as more efficient products. DOE took this approach because amended standards may make high-efficiency products, which are currently considered premium products, the baselines.

5.12.3 Shipping Costs for Storage Water Heaters

As mentioned previously, DOE analyzed the cost of shipping storage water heaters separately from other non-production costs. DOE assumed manufacturers ship storage water heaters in a straight frame trailer with dimensions of 53’ x 10’ x 8’. DOE assumed the average cost per trailer load to be approximately $4,000.

Based on the average size of models at each efficiency level and tank gallon capacity, DOE estimated the average shipping cost for a full load of units of each efficiency level/tank gallon size combination to determine the average shipping cost for each particular unit. Because the average unit size varies for each efficiency level and tank gallon size, DOE based assumptions about how many units could fit on a trailer on the size of the average unit at that efficiency level. For example, DOE estimated that, based on the height of a 30-gallon electric storage water heater at efficiency level 1, manufacturers would be able to double stack these units in the trailer. However, the average 80-gallon model at efficiency level 1 is taller, and could not be double stacked in the trailer, leading to an increase in shipping cost. When estimating how many units could fit in each trailer load, DOE also accounted for the space needed for loading and unloading (*e.g.*, space between the boxes and the trailer wall to allow for clamp trucks to load the boxes, space at the top to allow for easier unloading). Table 5.12.4, Table 5.12.5, and Table 5.12.6 show the shipping cost estimates DOE calculated at each efficiency level for various storage volumes of gas-fired, electric, and oil-fired storage water heaters.

Table 5.12.4 Gas-Fired Storage Water Heater Shipping Cost Estimates

Storage Volume *gallons, U.S.*	**Engineering Efficiency Level**	**Shipping Cost** *2009$*
30	Baseline	17
	1	17
	2	20
	3	34
	4	35
	5	40
	6	40
40	Baseline	18
	1	20
	2	26
	3	36
	4	40
	5	52
	6	52
50	Baseline	39
	1	40
	2	54
	3	39
	4	40
	5	54
	6	54
65	Baseline	52
	1	56
	2	56
	3	52
	4	56
	5	56
	6	56
75	Baseline	56
	1	59
	2	61
	3	56
	4	59
	5	61
	6	61

Table 5.12.5 Electric Storage Water Heater Shipping Cost Estimates

Storage Volume *gallons, U.S.*	Engineering Efficiency Level	Shipping Cost *2009$*
30	Baseline	10
	1	14
	2	16
	3	16
	4	17
	5	21
	6	54
	7	56
40	Baseline	13
	1	14
	2	16
	3	16
	4	17
	5	21
	6	54
	7	56
50	Baseline	20
	1	21
	2	21
	3	21
	4	27
	5	56
	6	64
	7	64
66	Baseline	40
	1	42
	2	42
	3	42
	4	54
	5	56
	6	64
	7	64
80	Baseline	44
	1	54
	2	54
	3	56
	4	59
	5	61
	6	67
	7	71
119	Baseline	61
	1	64

	2	71
	3	71
	4	75
	5	79
	6	107
	7	112

Table 5.12.6 Oil-Fired Storage Water Heater Shipping Cost Estimates

Storage Volume ***gallons, U.S.***	**Engineering Efficiency Level**	**Shipping Cost** ***2009$***
32	Baseline	16
	1	17
	2	18
	3	25
	4	18
	5	25
	6	25
	7	16
50	Baseline	26
	1	27
	2	28
	3	29
	4	28
	5	29
	6	29
	7	26

5.13 ENGINEERING ANALYSIS SUMMARY OF RESULTS

The results from the engineering analysis are used in the LCC analysis to determine consumer prices for residential heating products. Using the calculated manufacturer markup, DOE calculated the MSPs of the representative water heaters, DHE, and pool heaters at the baseline and more efficient levels.

5.13.1 Summary of Results for Representative Models

Each of the MPCs and MSPs developed in the engineering analysis for the representative capacity are shown in Table 5.13.1 through Table 5.13.12. DOE was able to receive manufacturer feedback on these MPCs and MSPs during the manufacturer interviews (see chapter 12, MIA). As described in section 5.12.1, the MSP for storage water heaters is calculated by multiplying the MPC by the manufacturer markup, then adding the shipping cost. For instantaneous water heaters, DHE, and pool heaters, the MSP is calculated by multiplying the MPC by the manufacturer markup.

Table 5.13.1 MPC and MSP for a 40-Gallon Gas-Fired Storage Water Heater

Efficiency Level	**MPC** ***2009$***	**MSP*** ***2009$***
Baseline (EF=0.59)	179	252
1 (EF=0.62)	187	265
2 (EF=0.63)	195	281
3 (EF=0.64)	321	457
4 (EF=0.65)	329	471
5 (EF=0.67)	337	493
6 – Max-Tech (EF=0.77)	478	678

*For storage water heaters, DOE calculated the MSP as the MPC multiplied by the manufacturer markup, plus shipping costs.

Table 5.13.2 MPC and MSP for a 40-Gallon Gas-Fired Storage Water Heater with Ultra-Low NOx Burner

Efficiency Level	**MPC** ***2009$***	**MSP*** ***2009$***
Baseline (EF = 0.59)	273	376
1 (EF = 0.62)	290	406
2 (EF = 0.63)	410	573
3 (EF = 0.64)	418	588
4 (EF = 0.65)	426	610
5 (EF = 0.67)	N/A	N/A
6 – Max-Tech (EF = 0.77)	567	795

*For storage water heaters, DOE calculated the MSP as the MPC multiplied by the manufacturer markup, plus shipping costs.

Table 5.13.3 MPC and MSP for a 32-Gallon Oil-Fired Storage Water Heater with Burner Assembly

Efficiency Level	**MPC** ***2009$***	**MSP*** ***2009$***
Baseline (EF = 0.53)	599	795
1 (EF = 0.54)	606	805
2 (EF = 0.56)	613	815
3 (EF = 0.58)	625	838
4 (EF = 0.60)	620	824
5 (EF = 0.62)	633	848
6 (EF = 0.66)	717	957
7 – Max-Tech (EF = 0.68)	722	955

*For storage water heaters, DOE calculated the MSP as the MPC multiplied by the manufacturer markup, plus shipping costs.

Table 5.13.4 MPC and MSP for a 50-Gallon Electric Storage Water Heater

Efficiency Level	MPC *2009$*	MSP* *2009$*
Baseline (EF = 0.90)	131	188
1 (EF = 0.91)	137	196
2 (EF = 0.92)	141	201
3 (EF = 0.93)	145	207
4 (EF = 0.94)	153	223
5 (EF = 0.95)	170	274
6 (EF = 2.0)	556	776
7 – Max-Tech (EF = 2.35)	632	873

*For storage water heaters, DOE calculated the MSP as the MPC multiplied by the manufacturer markup, plus shipping costs.

Table 5.13.5 MPC and MSP for a 0-Gallon Gas-Fired Instantaneous Water Heater, 199,000 Btu/h Input Capacity

Efficiency Level	MPC *2009$*	MSP *2009$*
Baseline (EF = 0.62)	308	447
1 (EF = 0.69)	323	468
2 (EF = 0.78)	352	510
3 (EF = 0.80)	462	670
4 (EF = 0.82)	501	726
5 (EF = 0.84)	796	1,154
6 (EF = 0.85)	848	1,230
7 (EF = 0.92)	928	1,346
8 – Max-Tech (EF = 0.95)	1,032	1,496

Table 5.13.6 MPC and MSP for Gas Wall Fan DHE, Over 42,000 Btu/h Input Capacity

Efficiency Level	MPC *2009$*	MSP *2009$*
Baseline (AFUE = 74)	364	491
1 (AFUE = 75)	390	526
2 (AFUE = 76)	401	541
3 (AFUE = 77)	422	569
4 – Max-Tech (AFUE = 80)	482	650

Table 5.13.7 MPC and MSP for Gas Wall Gravity DHE, Over 27,000 Btu/h and up to 46,000 Btu/h Input Capacity

Efficiency Level	**MPC** ***2009$***	**MPSP** ***2009$***
Baseline (AFUE = 64)	214	290
1 (AFUE = 66)	242	327
2 (AFUE = 68)	259	350
3 (AFUE = 69)	295	399
4 – Max Tech (AFUE = 70)	357	482

Table 5.13.8 MPC and MSP for Gas Floor DHE, Over 37,000 Btu/h Input Capacity

Efficiency Level	**MPC** ***2009$***	**MSP** ***2009$***
Baseline (AFUE = 57)	370	499
1 – Max-Tech (AFUE = 58)	395	533

Table 5.13.9 MPC and MSP for Gas Room DHE, Over 27,000 Btu/h and up to 46,000 Btu/h Input Capacity

Efficiency Level	**MPC** ***2009$***	**MSP** ***2009$***
Baseline (AFUE = 64)	234	316
1 (AFUE = 65)	250	337
2 (AFUE = 66)	265	358
3 (AFUE = 67)	272	368
4 (AFUE = 68)	282	380
5 – Max-Tech (AFUE = 83)	421	568

Table 5.13.10 MPC and MSP for Gas Hearth DHE, Over 27,000 Btu/h and up to 46,000 Btu/h Input Capacity

Efficiency Level	**MPC** ***2009$***	**MSP** ***2009$***
Baseline (AFUE = 64)	372	502
1 (AFUE = 67)	370	499
4 (AFUE = 72)	550	743
5 – Max-Tech (AFUE = 93)	918	1,239

Table 5.13.11 MPC and MSP for a Gas-Fired Pool Heater, 250,000 Btu/h Input Capacity and Standing Pilot

Efficiency Level	**MPC** ***2009$***	**MSP** ***2009$***
Baseline (Thermal Efficiency = 78)	568	738
1 (Thermal Efficiency = 79)	579	753
2 (Thermal Efficiency = 81)	593	771
3 (Thermal Efficiency = 82)	626	814

Table 5.13.12 MPC and MSP for a Gas-Fired Pool Heater, 250,000 Btu/h Input Capacity and Electronic Ignition

Efficiency Level (Thermal Efficiency)	**MPC** ***2009$***	**MSP** ***2009$***
Baseline (Thermal Efficiency = 78)	587	763
1 (Thermal Efficiency = 79)	598	777
2 (Thermal Efficiency = 81)	612	796
3 (Thermal Efficiency = 82)	645	839
4 (Thermal Efficiency = 83)	716	931
5 (Thermal Efficiency = 84)	778	1,011
6 (Thermal Efficiency = 86)	1,031	1,340
7 (Thermal Efficiency = 90)	1,528	1,986
8 – Max-Tech (Thermal Efficiency = 95)	1,669	2,170

5.13.2 Summary of Results for Water Heater Models Outside of the Representative Capacity

As described in section 5.8.6, DOE calculated the MPCs of storage water heaters with rated storage volumes at capacities above and below the representative capacity. These MPCs are used downstream in the LCC analysis to determine the impacts on consumers. Table 5.13.13 through Table 5.13.16 show the MPC results at each efficiency level and each discrete rated storage volume analyzed for gas-fired, electric, and oil-fired storage water heaters.

Table 5.13.13. Manufacturing Production Costs for Gas-Fired Storage Water Heaters with a Standard Burner by Rated Storage Volume

Efficiency Level	Manufacturing Production Cost			
	30 Gallon	**50 Gallon**	**65 Gallon**	**75 Gallon**
Baseline	\$165	\$191	\$220	\$237
1	\$172	\$200	\$230	\$248
2	\$180	\$209	\$241	\$259
3	\$306	\$333	\$364	\$382
4	\$313	\$342	\$375	\$393
5	\$321	\$351	\$386	\$405
6	\$454	\$491	\$537	\$565

Table 5.13.14. Manufacturing Production Costs for Gas-Fired Storage Water Heaters with an Ultra Low NO_X Burner by Rated Storage Volume

Efficiency Level	Manufacturing Production Cost			
	30 Gal	**50 Gallon**	**65 Gallon**	**75 Gallon**
Baseline	\$257	\$285	\$313	\$333
1	\$273	\$303	\$336	\$356
2	\$394	\$422	\$453	\$474
3	\$402	\$431	\$463	\$483
4	\$409	\$440	\$474	\$496
5	N/A	N/A	N/A	N/A
6	\$543	\$583	\$631	\$659

Table 5.13.15. Manufacturing Production Costs for Electric Storage Water Heaters by Rated Storage Volume

Efficiency Level	Manufacturing Production Cost				
	30 Gal	**40 Gallon**	**66 Gallon**	**80 Gallon**	**119 Gallon**
Baseline	\$109	\$122	\$140	\$160	\$216
1	\$115	\$128	\$148	\$168	\$226
2	\$119	\$133	\$153	\$175	\$234
3	\$121	\$135	\$156	\$178	\$238
4	\$127	\$143	\$166	\$188	\$249
5	\$142	\$159	\$185	\$208	\$273
6	\$530	\$546	\$569	\$592	\$655
7	\$593	\$621	\$653	\$683	\$745

Table 5.13.16. Manufacturing Production Costs for Oil-Fired Storage Water Heaters by Rated Storage Volume

Efficiency Level	Manufacturing Production Cost
	50 Gal
Baseline	$662
1	$671
2	$678
3	$688
4	$686
5	$697
6	$779
7	$785

5.14 ENERGY EFFICIENCY EQUATIONS FOR WATER HEATERS

DOE's existing regulations for all types of water heaters are specified in terms of an equation where the required EF is a function of storage volume. For gas-fired storage and electric storage water heaters, DOE modified the energy efficiency equations based on available market data and testing results as described in section 5.14.1. For oil-fired storage and gas-fired instantaneous water heaters, the available market data did not suggest a need to change the efficiency equations, as described in section 5.14.2.

5.14.1 Gas-fired Storage and Electric Storage Energy Efficiency Equations

As part of the engineering analysis for residential water heaters, DOE reviewed the energy efficiency equations that define the existing Federal energy conservation standards for gas-fired and electric storage water heaters. The energy efficiency equations allow DOE to expand the analysis on the representative rated storage volume to the full range of storage volumes covered under the Federal energy conservation standard. In the following section, DOE describes the methodology used to expand the analysis conducted for the representative storage volumes at each efficiency level to the full rated storage volume ranges.

DOE uses energy efficiency equations to characterize the relationship between rated storage volume and energy factor. The energy efficiency equations consider the increases in standby losses as tank volume increases. As the tank storage volume increases, the tank surface area increases. The larger surface area results in higher heat transfer rates which, in turn, result in higher jacket losses. Other losses to consider are feed-through losses and flue losses (for gas-fired water heaters). The current energy efficiency equations show that as the rated storage volume increases for each water heater class, the minimum energy factor decreases.

For the existing Federal energy conservation standards, the slope and the intercept of each energy efficiency equation are constant for each product class. Table 5.14.1

shows the energy efficiency equations of the existing Federal energy conservation standards for gas-fired and electric storage water heaters.

Table 5.14.1 Existing Federal Energy Conservation Standards for Residential Gas-Fired and Electric Storage Water Heaters

Residential Water Heater Class	Minimum Energy Factor
Gas-Fired Storage	0.67 – (0.0019 × Rated Storage Volume in Gallons)
Electric Storage	0.97 – (0.00132 × Rated Storage Volume in Gallons)

DOE reviewed AHRI's March 2008 *Consumers' Directory of Certified Efficiency Ratings for Heating and Water Heating Equipment* and developed a product database that includes all gas-fired and electric storage water heater models subject to this rulemaking. DOE also reviewed manufacturer catalogs to gather information on the design characteristics of each water heater model. The catalogs include information on efficiency ratings, product series descriptions, jacket insulation thicknesses, ignition types, and drafting methods (*i.e.*, natural or power vented drafting). DOE also contracted an independent third party to test the energy factor ratings of 27 gas-fired and electric storage water heaters at various energy factor ratings and storage volumes (section 5.14.1.4).

DOE used its database and additional product information gathered from testing and manufacturer literature to help characterize the relationship between EF and rated storage volume of gas-fired and electric storage water heater models currently on the market. DOE also compared the EFs and rated storage volumes in its database of products to the energy efficiency equations defined by Federal energy conservation standards. Generally, current products demonstrate a similar trend of decreasing efficiency with increasing rated storage volume.

However, as the efficiency of the models increases, the relationship between the EF and rated storage volume does not closely follow the relationship described by current Federal energy conservation standards. Since the January 2001 water heater rulemaking, manufacturers have continued to introduce storage water heaters with higher efficiencies. Manufacturers currently offer several models with similar features (*i.e.*, models from the same product series) that have the same energy factors, but a variety of different rated storage volumes. In theory, the energy factor should decrease with increased storage volume, primarily due to increased losses from the increased tank surface area. However, these few high-efficiency model series seem to exhibit the same EF, though their rated storage volumes vary. There are several plausible explanations for this discrepancy, including (1) the precision of the test procedure at higher efficiencies (*i.e.,* the number of significant digits reported during the EF calculation does not reveal differences in actual values of the energy factors of high-efficiency storage water heaters in the full range of storage volumes); (2) the possibility for small design changes that are not described in the product literature, and (3) the possibility of slight differences in the geometry of the storage tanks for the larger rated volumes, which would affect the heat loss characteristics of the tank. To further investigate the relationship between EF and rated storage volume, DOE reviewed the current market to establish a revised set of energy efficiency equations based on available models for gas-fired and electric storage water heaters.

5.14.1.1 DOE's Review of the Current Water Heater Market

DOE reviewed the gas-fired and electric storage water heaters listed in AHRI's *Consumers' Directory* and described in manufacturer catalogs to examine the relationship between energy factor and rated storage volume. When examining the energy efficiency equations, DOE considered

- input and feedback from interested parties,
- energy efficiency potentials of screened-in technologies,
- standby heat loss,
- analysis from previous rulemakings,
- Federal energy conservation standards (to prevent backsliding), and
- energy efficiency levels developed for this NOPR.

The existing Federal energy conservation standard applies to gas-fired storage water heaters ranging from 20 to 100 gallons. The majority of models in AHRI's *Consumers' Directory* have rated storage volumes between 30 and 75 gallons. DOE selected 40 gallons as the representative rated storage volume for this class of water heater. The corresponding energy conservation standard at 40 gallons is 0.59 EF. Figure 5.14.1 shows the current Federal energy conservation standard and its relationship to models in the AHRI *Consumers' Directory*.

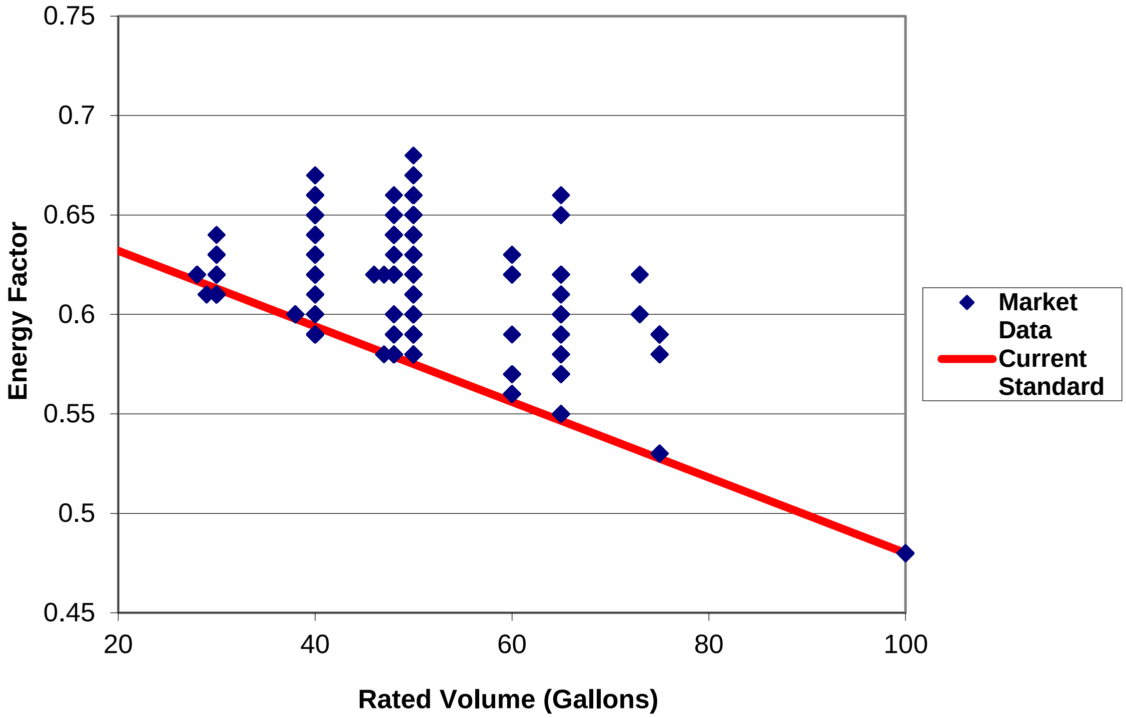

Figure 5.14.1 Distribution of Gas-Fired Storage Water Heater Models by Rated Storage Volume

In general, the EF decreases with rated storage volume. However, DOE found that manufacturers offer models with similar EFs for the two most common storage volumes (40 and 50 gallons) and in some instances for other storage volumes. For example, between 0.60 and 0.65 EF, several 40-gallon models on the market have the same EFs as several 50-gallon models in AHRI's *Consumers' Directory*. This trend does not apply over the entire range of storage volumes offered. For example, gas-fired storage water heaters having rated storage volumes of 60 gallons and above appear to decrease in EF with increasing rated storage volume (Figure 5.14.1).

The existing Federal energy conservation standard applies to electric storage water heaters ranging from 20 to 120 gallons. The majority of models in AHRI's *Consumers' Directory* have rated storage volumes between 30 and 120 gallons. DOE selected 50 gallons as the representative rated storage volume for this class of water heater, and the corresponding conservation standard at 50 gallons is 0.90 EF. Figure 5.14.2 shows the current Federal energy conservation standard and its relationship to models in the AHRI *Consumers' Directory*.

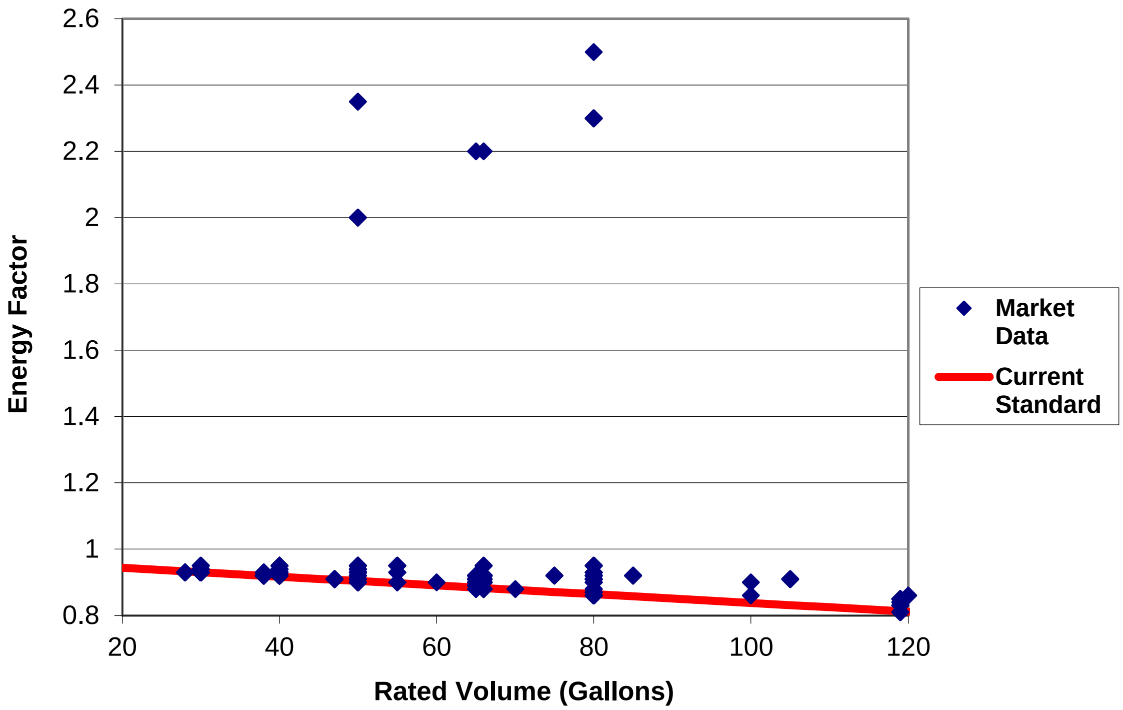

Figure 5.14.2 Distribution of Electric Storage Water Heater Models by Rated Storage Volume

In general, DOE found that EF decreases with rated storage volume. However, for electric storage water heaters ranging from 30 to 80 gallons, DOE found that manufacturers produce models with similar EFs. For example, water heaters ranging from 30 to 80 gallons are available with EFs ranging from the baseline to 0.95 EF, regardless of the rated storage volume. However, Figure 5.14.2 suggests that this trend is not true for the entire market over the entire range of storage volumes. Figure 5.14.2 also demonstrates that manufacturers of 120-gallon electric storage water heaters offer only models with EFs of 0.86 or below.

5.14.1.2 Revised Energy Efficiency Equations

DOE first examined revising the energy efficiency equations by expanding efficiency levels to a full range of tank sizes by using the equation slopes defined by the existing Federal energy conservation standards. DOE did not alter the slopes for this portion of the analysis, and changed only the position of the intercepts (*i.e.*, the point that intersects 0 gallons).

For 40-gallon gas-fired storage water heaters, DOE examined six efficiency levels: 0.62 EF, 0.63 EF, 0.64 EF, 0.65 EF, 0.67 EF, and 0.77 EF (max-tech). DOE then expanded these efficiency levels to the full range of gallon sizes (*i.e.*, 20 to 100 gallons) by relating EF to rated volume using the slope of the Federal energy efficiency equation (*i.e.*, constant slope of -0.0019). Figure 5.14.3 shows the revised energy efficiency equations and their relationship to models in the AHRI *Consumers' Directory*.

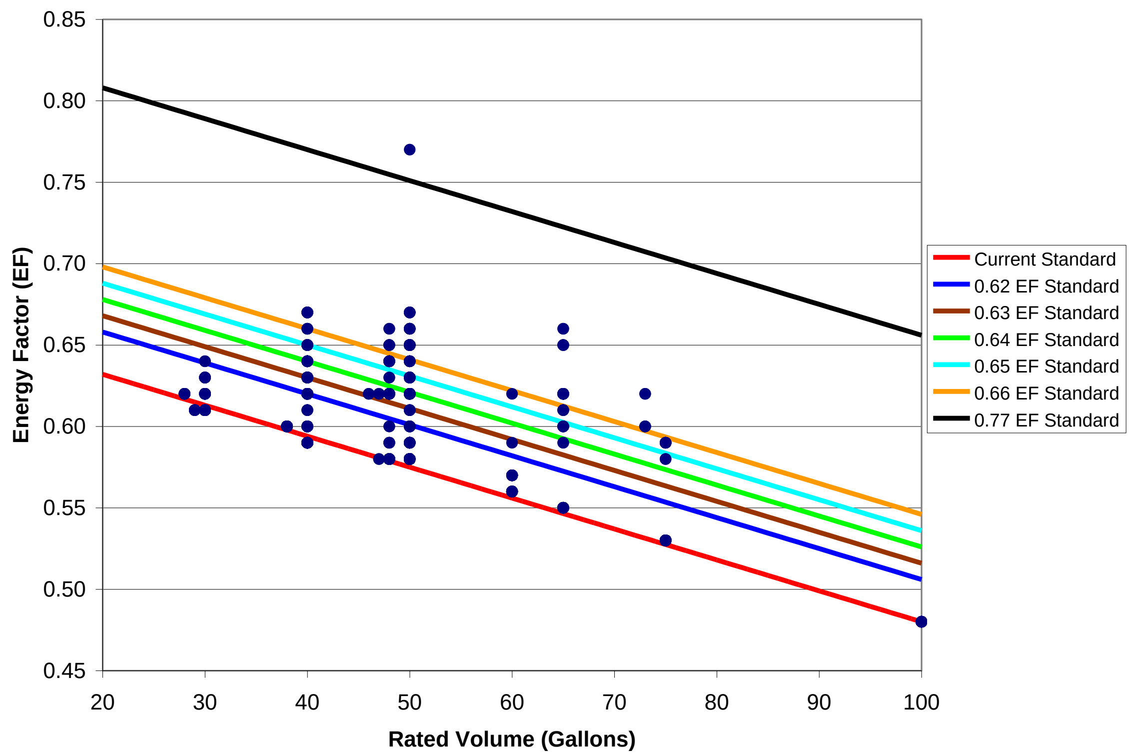

Figure 5.14.3 Gas-Fired Storage Water Heater Efficiency Levels Using the Slope of the Federal Energy Conservation Standard

DOE generally found that products meet or exceed the majority of the considered efficiency levels for volume sizes ranging from 40 to 75 gallons. The market data suggest that the slope of the equation defining the current Federal energy conservation standard may not reflect the characteristics of the entire market because there are models currently available having similar EFs with different rated storage volumes. DOE also found that at small rated volumes (*i.e.*, less than 30 gallons) and large rated volumes (*i.e.*, 100 gallons) manufacturers do not offer models that would meet some of the efficiency levels that DOE is considering. For example, at 100 gallons, the existing water heater market would be eliminated by all of the efficiency levels being considered if equations have the same slope as the current Federal energy conservation standard.

For electric storage water heaters, DOE considered six efficiency levels above the baseline efficiency level: 0.91 EF, 0.92 EF, 0.93 EF, 0.94 EF, 0.95 EF. DOE excluded the 2.0 EF level and the max-tech efficiency level (*i.e.*, 2.35 EF) for this portion of the analysis because of extremely limited market data. DOE expanded each efficiency level below the max-tech (*i.e.*, efficiency levels 0.91 to 0.95 EF) to the full range of rated volumes (*i.e.*, 20 to 120 gallons) by relating EF to rated volume using the slope of the Federal energy efficiency equation (*i.e.*, a constant slope of -0.00132) as shown in Figure 5.14.4.

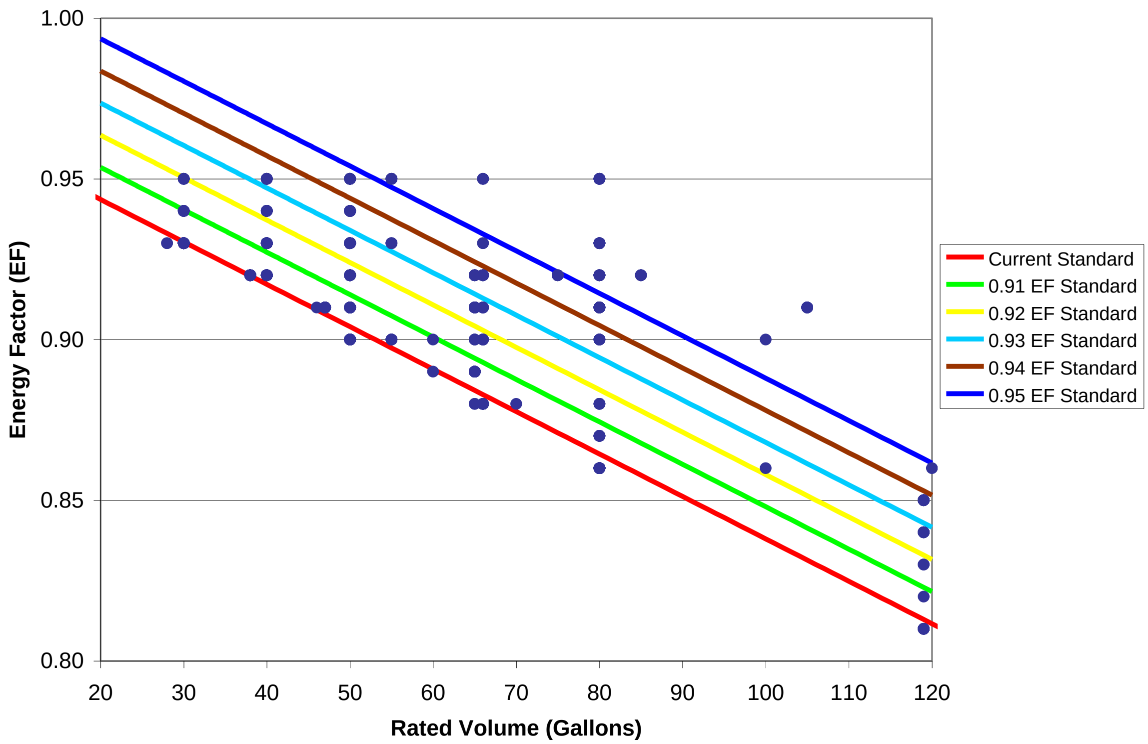

Figure 5.14.4 Electric Storage Water Heater Efficiency Levels Using the Slope of the Federal Energy Conservation Standard

DOE generally found that electric storage water heaters currently manufactured meet or exceed the majority of efficiency levels for volume sizes ranging from 30 to 120 gallons. As with gas-fired storage water heaters, the market data for electric storage water heaters suggested that the slope of the equation defining the current Federal energy conservation standard may not reflect the characteristics of the entire market because there are models currently available with similar EFs, over a wide range of rated storage volumes. DOE also found that manufacturers do not offer models that would meet all of the energy efficiency levels DOE is considering for the full range of rated storage volumes. For example, DOE found that at small rated volumes (*i.e.*, less than 50 gallons) manufacturers do not offer models that would meet the efficiency levels being considered that exceed 0.95 EF.

5.14.1.3 Development of Alternative Energy Efficiency Equations

DOE developed an alternative approach for revising the energy efficiency equations based on the database of products. DOE applied four constraints to the development process:

- For gas-fired water heaters, each energy efficiency equation must include units with the specified efficiency level at the 40-gallon rated storage volume.

- For electric storage water heaters, each energy efficiency equation must include units with the specified efficiency level at the 50-gallon rated storage volume.
- For electric storage water heaters, the energy efficiency equation should not lead to a standard greater than 0.95 EF for the 20- to 120-gallon rated volume range.
- The energy efficiency equations cannot result in a standard that falls below current standards over the entire rated volume range.

DOE chose this approach because it takes into account the models currently on the market, considers the technologies incorporated into those models, and attempts to optimize the number of models across the entire rated volume range that would meet the efficiency levels DOE is considering. This approach also attempts to minimize the number of models that would be eliminated from the market by the efficiency levels DOE is considering across the entire range of storage volumes.

In examining the market data to develop the energy efficiency equations, DOE noted a trend of greater decline in energy efficiency at higher rated storage volumes than at lower storage volumes. As a result, DOE developed energy efficiency equations with varying slopes at several of the efficiency levels covered in the analysis. These equations maintain one slope from the minimum covered rated storage volume of 60 gallons for gas-fired storage water heaters up to 80 gallons for electric storage water heaters, and then maintain a different slope over the remaining range of covered storage volumes. DOE selected 60- and 80-gallon storage volumes as the point where the change in slope of the energy efficiency equations for gas-fired and electric storage water heaters, respectively, should occur because the market data suggested a natural break in the available products at those points. Gas-fired models larger than 60 gallons and electric models larger than 80 gallons typically have efficiencies that reduce much more quickly with increasing storage volume than at the lower volume sizes. The higher ends of the residential storage capacities also have a lower volume of shipments.

For gas-fired storage water heaters, DOE kept the same slope above 60 gallons at each efficiency level. Few gas-fired storage water heaters exist with storage volumes greater than 60 gallons, and therefore market data were very limited. Due to this lack of data, DOE used the slope defining the current standard for residential gas-fired storage water heaters, as listed in DOE’s regulations at 10 CFR Part 430.32(d). DOE maintained the same slope for efficiency levels 1 through 5 for gas-fired storage water heaters above 60 gallons.

For the max-tech efficiency levels considered for gas-fired storage water heaters and electric storage water heaters, DOE maintained a single slope for the entire range of storage volumes, which was the same as the slope for the smaller gallons sizes at the efficiency level immediately below max-tech. Because there are very few products on the market that meet the max-tech efficiency levels, DOE could not perform an analysis or come to the conclusion that at larger storage volumes energy factor decreases more quickly at these efficiency levels, as was done for the lower efficiency levels. With any storage water heater, the standby losses will increase with storage volume due to increased tank surface area. Because there are no data that DOE can use to determine an appropriate slope at these levels, DOE maintained the relationship between storage volume and energy factor developed for water heaters at levels immediately below the max-tech.

Figure 5.14.5 illustrates the energy efficiency equations using the criteria developed for gas-fired storage water heaters. Figure 5.14.6 and Figure 5.14.7 illustrate the energy efficiency equations using the criteria developed for electric storage water heaters.

Table 5.14.2 Alternative Energy Efficiency Equations for Gas Storage Water Heaters

Efficiency Level	20 to 60 Gallons	Over 60 and up to 100 Gallons
Baseline	EF = -0.00190(V_R)+0.670	
1	EF = -0.00150(V_R)+0.675	EF = -0.00190(V_R)+0.699
2	EF = -0.00120(V_R)+0.675	EF = -0.00190(V_R)+0.717
3	EF = -0.00100(V_R)+0.680	EF = -0.00190(V_R)+0.734
4	EF = -0.00090(V_R)+0.690	EF = -0.00190(V_R)+0.750
5	EF = -0.00078(V_R)+0.700	EF = -0.00190(V_R)+0.767
6	EF = -0.00078(V_R)+0.8012	

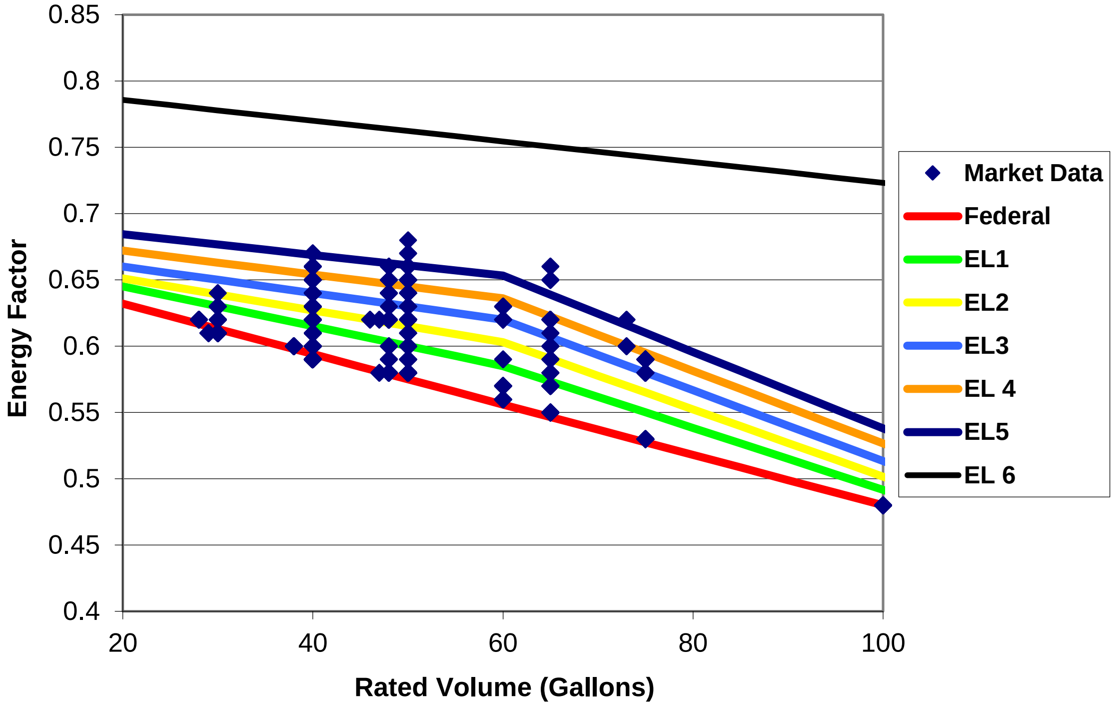

Figure 5.14.5 Energy Efficiency Equations Using a Modified Slope Based on the AHRI Consumers' Directory for Gas-Fired Storage Water Heaters

Table 5.15.3 Alternative Energy Efficiency Equations for Electric Storage Water Heaters

Efficiency Level	20 to 80 Gallons	Over 80 and up to 120 Gallons
Baseline	EF = -0.00132(V_R)+0.97	
1	EF = -0.00113(V_R)+0.97	EF = -0.00149(V_R)+0.999
2	EF = -0.00095(V_R)+0.967	EF = -0.00153(V_R)+1.013
3	EF = -0.00080(V_R)+0.966	EF = -0.00155(V_R)+1.026
4	EF = -0.00060(V_R)+0.965	EF = -0.00168(V_R)+1.051
5	EF = -0.00030(V_R)+0.960	EF = -0.00190(V_R)+1.088
6	EF = -0.00113(V_R)+2.057	
7	EF = -0.00113(V_R)+2.406	

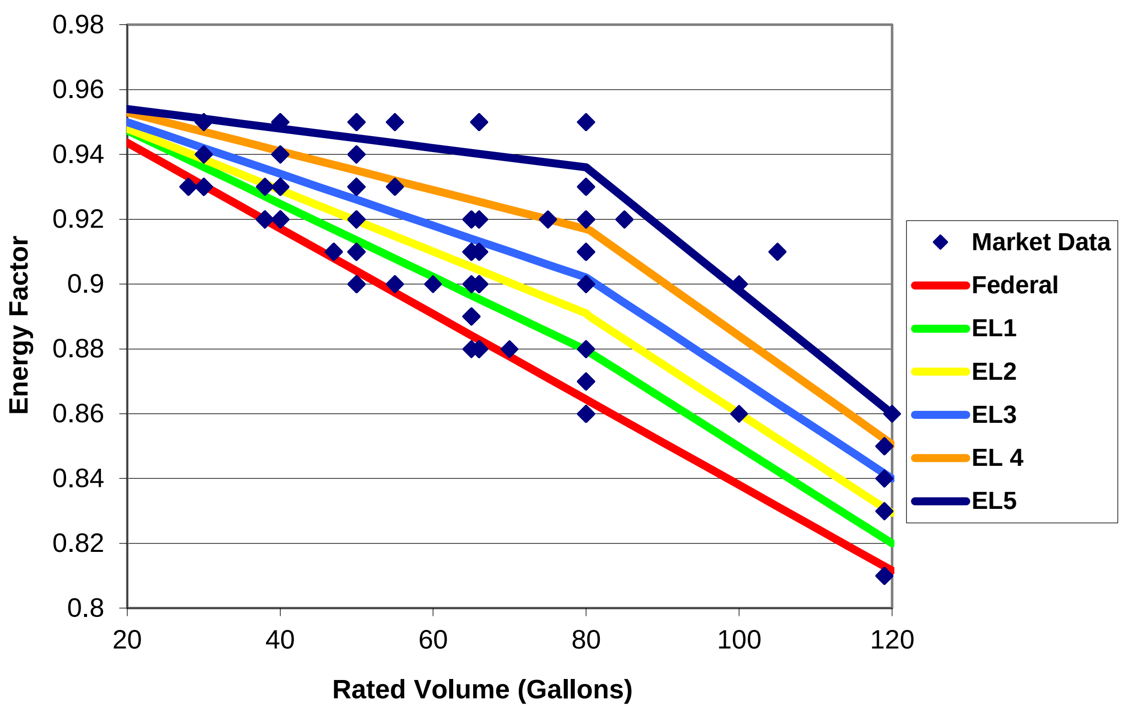

Figure 5.14.6 Energy Efficiency Equations Using a Modified Slope Based on the AHRI *Consumers' Directory* for Electric Storage Water Heaters (Baseline – Efficiency Level 5)

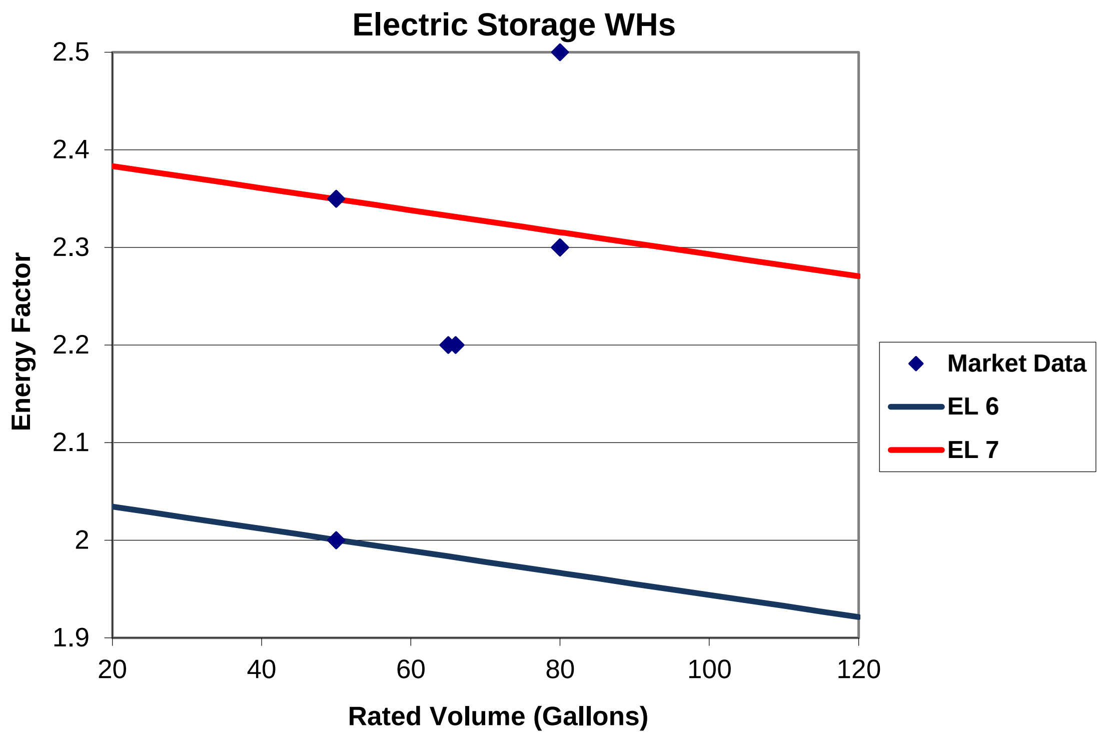

Figure 5.14.7 Energy Efficiency Equations Using a Modified Slope Based on the AHRI *Consumers' Directory* for Electric Storage Water Heaters (Efficiency Levels 6 and 7)

For gas-fired and electric storage water heaters, the energy efficiency equations and the data from AHRI's *Consumers' Directory* generally exhibit the same trend of decreasing EF with increasing rated volume. The existing energy efficiency equations and current market also show a similar trend in which the slope caused by the decreasing EF typically approaches a constant (*i.e.*, a flat line across the range of rated volumes) as the efficiency levels increase. However, these energy efficiency equations eliminate the larger volume water heaters offered by manufacturers at the higher potential amended energy conservation standards.

The product database, manufacturer specifications, and other publicly available literature do not include all the details on the specific energy efficiency features incorporated in each water heater design. Based on the extent of the information, these energy efficiency equations may represent manufacturing practices, consumer preferences, and marketing efforts, but not the energy efficiency potential of screened-in technologies or the heat loss characteristics of the entire rated volume range.

For example, manufacturers offer several models with similar features (*i.e.*, models from the same product series) and the same energy factors in a variety of different rated storage volumes. Water heaters of different volumes can have the same EF as a result of manufacturers adding insulation (*e.g.*, to the top of the tank or the feed-throughs) or making design modifications not described in the manufacturer catalogs as rated volume increases. Such design changes could offset any increase in heat loss as surface area increases. This would alter the relationship between heat loss (and ultimately EF) and rated volume for that particular product series. Manufacturers may produce product lines with EF constant across a range of rated volumes to market high-efficiency water heaters to specific consumers.

DOE could not verify the relationship between EF and rated volume or how EF changes for different rated volume ranges and at various efficiency levels based solely on AHRI data or publicly available literature. Specifically, it is not possible to identify the specific technologies that manufacturers use to maintain the same EF as rated volume increases. In addition, the reporting precision of the test procedure at higher efficiencies does not reveal how small losses affect EF as the rated storage volume increases. It is also impossible to verify that the geometry of the storage tank design is identical through the entire range of storage volumes based solely on the information obtained from the AHRI directory and manufacturer product literature. Therefore, DOE verified this relationship through testing and tear-down analysis, described in section 5.14.1.4.

5.14.1.4 Validation of the Energy Efficiency Equations for Gas-Fired and Electric Storage Water Heaters

To further examine the relationship between EF and rated storage volume, DOE verified the EF of various models through third-party testing and performed a teardown analysis of these same models to identify potential geometry and design differences. As noted previously, when reviewing products on the market, DOE found that some manufacturers produce high-efficiency gas-fired and electric storage water heaters where the energy efficiency technologies remain constant (*e.g.*, the same insulation thickness) across a range of rated volumes while maintaining the same EF for all products. This is contrary to DOE's understanding that jacket losses should increase as the surface area of the tank increases with rated volume. Thus, DOE assumed manufacturers make some minor improvements (small insulation improvements, for example) to offset the increase in heat loss as a result of increasing surface area, or make geometric modifications to the tank design to obtain constant EFs for a range of rated volumes. However, the market data and manufacturers catalogs suggest this is not true for some product series, and this data and the information in manufacturer catalogs are not sufficient to specify how manufacturers achieve constant EF. Consequently, DOE tested and performed a teardown analysis of available water heater models to validate its approach for developing the energy efficiency equations and further supplement its data on the relationship between EF and storage volume.

DOE conducted testing according to the water heater test procedure specified in appendix E to subpart B of 10 CFR 430 (the same test procedure used by manufacturers to certify products in AHRI's *Consumers' Directory*) to verify the EF values. DOE tested model series with similar design characteristics and volumetric designs to isolate how EF changes with rated storage volume. DOE repeated this test for a number of model series at various efficiencies and for a variety of different manufacturers. DOE chose models to test by selecting product series from multiple major manufacturers that spanned the range of rated volumes within each product class and that span the range of efficiency levels. DOE purchased the units selected for testing through a mechanical contractor at the end of the distribution chain similar to one used by a typical consumer. After the testing, DOE performed a teardown analysis of the water heaters to examine the components and verify the technologies used to increase the efficiency of water heaters. DOE closely examined the differences among models rated at the same efficiency factors with different gallon sizes to determine what additional features (if any) are implemented in larger models to achieve the same efficiencies as smaller models. For units that performed below their rated energy factor, DOE searched for any manufacturing irregularities (such as foam voids) that could have lead to these test results. The results of the testing are shown in Table 5.14.3.

Table 5.14.3 Energy Factor Test Results for a Sample of Gas-Fired and Electric Storage Water Heaters

Product Class	Rated Storage Volume *gallons, U.S.*	Rated Energy Factor	Tested Energy Factor
Gas-Fired Storage	29	0.63	0.604
Gas-Fired Storage	30	0.61	0.639
Gas-Fired Storage	40	0.59	0.612
Gas-Fired Storage	40	0.59	0.585
Gas-Fired Storage	40	0.62	0.602
Gas-Fired Storage	40	0.64	0.635
Gas-Fired Storage	40	0.59	0.588
Gas-Fired Storage	50	0.62	0.609
Gas-Fired Storage	50	0.59	0.577
Gas-Fired Storage	50	0.64	0.622
Gas-Fired Storage	50	0.58	0.572
Gas-Fired Storage	65	0.57	0.575
Gas-Fired Storage	65	0.57	0.577
Gas-Fired Storage	75	0.59	0.603
Electric Storage	30	0.93	0.924
Electric Storage	30	0.95	0.938
Electric Storage	30	0.93	0.924
Electric Storage	40	0.95	0.951
Electric Storage	40	0.92	0.922
Electric Storage	50	0.93	0.917
Electric Storage	50	0.91	0.922
Electric Storage	55	0.95	0.952
Electric Storage	66	0.92	0.937
Electric Storage	66	0.95	0.944
Electric Storage	80	0.93	0.943
Electric Storage	80	0.95	0.947
Electric Storage	80	0.86	0.919

5.14.2 Oil-Fired Storage and Gas-Fired Instantaneous Energy Efficiency Equations

As part of the engineering analysis for residential water heaters, DOE reviewed the energy efficiency equations that define the existing Federal energy conservation standards for oil-fired storage and gas-fired instantaneous water heaters. As with gas-fired and electric storage water heaters, the energy efficiency equations allow DOE to expand the analysis on the representative rated storage volume to the full range of storage volumes covered under the Federal energy conservation standard.

For oil-fired storage and gas-fired instantaneous water heaters, DOE uses energy efficiency equations to characterize the relationship between rated storage volume and energy factor. The current energy efficiency equations show that as the rated storage volume increases for these water heater classes, the minimum energy factor decreases. For the existing Federal energy conservation standards, the slope and the intercept of each energy efficiency equation are constant for each product class. Table 5.14.4 shows the energy efficiency equations of the existing Federal energy conservation standards for gas-fired and electric storage water heaters.

Table 5.14.4 Existing Federal Energy Conservation Standards for Residential Oil-Fired Storage and Gas-Fired Instantaneous Water Heaters

Residential Water Heater Class	**Minimum Energy Factor**
Oil-Fired Storage	0.59 – (0.0019 × Rated Storage Volume in Gallons)
Gas-Fired Instantaneous	0.62 – (0.0019 × Rated Storage Volume in Gallons)

DOE reviewed AHRI's March 2009 *Consumers' Directory of Certified Efficiency Ratings for Heating and Water Heating Equipment* and developed a product database that includes all residential water heater models subject to this rulemaking. DOE also reviewed manufacturer catalogs to gather information on the design characteristics of each water heater model. DOE also compared the EFs and rated storage volumes in its database of products to the energy efficiency equations defined by Federal energy conservation standards. Generally, current products demonstrate a similar trend of decreasing efficiency with increasing rated storage volume. The relationship of EF and storage capacity for the oil-fired storage and gas-fired instantaneous models in the database did not provide any justification for revising the existing energy efficiency equations. Therefore, to create the various efficiency levels for these two water heater product classes, DOE maintained the same slope defined by existing standards and adjusted the intercept to create efficiency levels higher than the baseline. Table 5.14.5 and Table 5.14.6 show the energy efficiency equations for oil-fired storage and gas-fired instantaneous water heaters, respectively.

Table 5.14.5 Energy Efficiency Equations for Oil-Fired Storage Water Heaters

Efficiency Level	**Minimum Energy Factor**
1	0.60 – (0.0019 × Rated Storage Volume in Gallons)
2	0.62 – (0.0019 × Rated Storage Volume in Gallons)
3	0.64 – (0.0019 × Rated Storage Volume in Gallons)
4	0.66 – (0.0019 × Rated Storage Volume in Gallons)
5	0.68 – (0.0019 × Rated Storage Volume in Gallons)
6	0.72 – (0.0019 × Rated Storage Volume in Gallons)
7	0.74 – (0.0019 × Rated Storage Volume in Gallons)

Table 5.14.6 Energy Efficiency Equations for Gas-Fired Instantaneous Water Heaters

Efficiency Level	Minimum Energy Factor
1	0.69 – (0.0019 × Rated Storage Volume in Gallons)
2	0.78 – (0.0019 × Rated Storage Volume in Gallons)
3	0.80 – (0.0019 × Rated Storage Volume in Gallons)
4	0.82 – (0.0019 × Rated Storage Volume in Gallons)
5	0.84 – (0.0019 × Rated Storage Volume in Gallons)
6	0.85 – (0.0019 × Rated Storage Volume in Gallons)
7	0.92 – (0.0019 × Rated Storage Volume in Gallons)
8	0.95 – (0.0019 × Rated Storage Volume in Gallons)

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