CHAPTER 3. MARKET AND TECHNOLOGY ASSESSMENT

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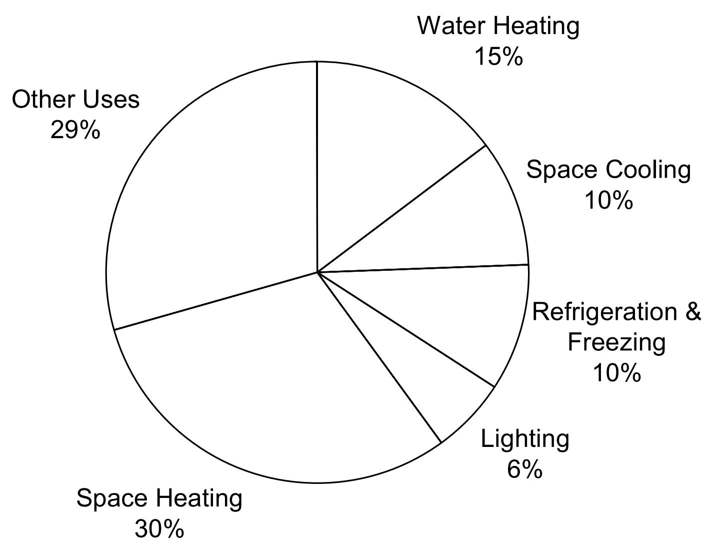
CHAPTER 3. MARKET AND TECHNOLOGY ASSESSMENT

3.1 INTRODUCTION

This chapter presents information regarding water heater markets and technology in the U.S. as background for the analysis to revise the National Appliance Energy Conservation Act (NAECA) efficiency standards.

As indicated in Figure 3.1, water heating is the third largest energy end use in the residential sector in the U.S., after "miscellaneous" other uses and space heating. Water heating in the U.S. residential sector consumes about 2.53 quadrillion Btus (2.53 quads) of primary[a] energy per year. Figure 3.2 shows a breakdown of primary energy consumption for residential water heating by end-use energy source. Roughly comparable amounts of primary energy are consumed by electric and natural gas water heaters, which, together, account for about 90% of primary energy consumption for residential sector water heating.



Source: Derived from AEO 2000, Table A4: Energy Consumption, Residential

Figure 3.1 Primary Energy Consumption in the Residential Sector (1998)

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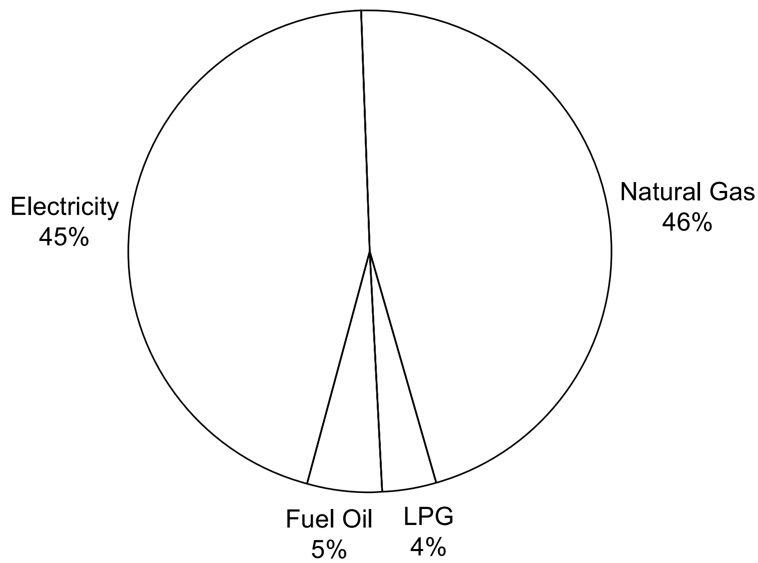
[a] Primary energy includes fuel consumed to generate the electric energy for the residential sector, based on the U.S. national generation mix.



Source: Derived from AEO 2000, Table A4: Energy Consumption, Residential

Figure 3.2 Water Heating Primary Energy Consumption (1998)

Table 3.1 Residential Water Heating Primary Energy Consumption (1998)

Water Heating Fuel	**U.S. Households** *millions*	**On-Site Energy Consumption** *quads per year*	**Primary Energy Consumption** *quads per year*
Electric	40.2	0.40	1.28
Natural Gas	52.8	1.26	1.26
Oil	5.2	0.12	0.12
LPG	3.2	0.10	0.10
Total	101.4	1.88	2.76

Sources: Derived from the 1997 *Residential Energy Consumption Survey* and *AEO2000*, Table A4: Energy Consumption, Residential.

Primary energy consumption for service (potable) residential water heating is about 3.8% of total national primary energy consumption.

3.2 WATER HEATERS: DESCRIPTION AND EFFICIENCY CHARACTERISTICS

Conventional storage type electric and gas-fired water heaters account for the vast majority of both the installed base and current sales of water heaters in the U.S. Typical configurations and efficiency characteristics are described briefly below.

3.2.1 Typical Models and Installation

Figure 3.3 illustrates a conventional, residential electric storage water heater. It consists of an insulated, glass-lined, steel hot water storage tank. Additional components include an anode rod for corrosion protection, hot and cold water connections, a temperature and pressure relief valve, and a drain valve. To heat the water, an electric water heater has two (upper and lower) electric resistance heating elements, each typically 4,500 watts. Input power is controlled by thermostats mounted on one side of the tank; only one element operates at a time: the upper element when the hot water has been nearly exhausted, and the lower element for heating the bulk of the water in the tank.

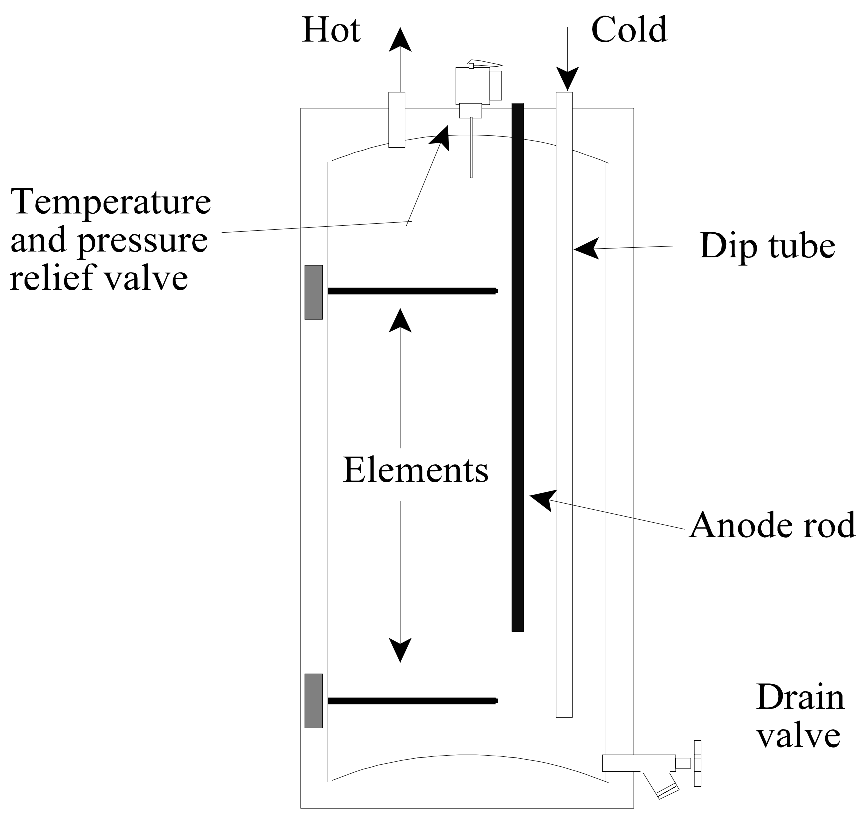


Figure 3.3 Residential Electric Water Heater

A typical gas-fired (natural gas or LPG)[b] residential water heater is shown in Figure 3.4. It is also an insulated, glass-lined, steel hot water storage tank. Additional components similar to those on electric water heaters include an anode rod for corrosion protection, hot and cold water connections, an over temperature/over pressure relief valve, and a drain valve. The heat source of the gas-fired water heater is a simple, inexpensive "sun" type gas burner (typical input is 35,000 Btu/hr). The burner is located underneath the tank bottom and exhausts through a central flue, both serving as heat transfer surfaces. A baffle in the flue enhances heat transfer to the flue walls. The gas burner is cycled on by a thermostat, and controls ensure that the pilot is burning before the main gas valve is opened.

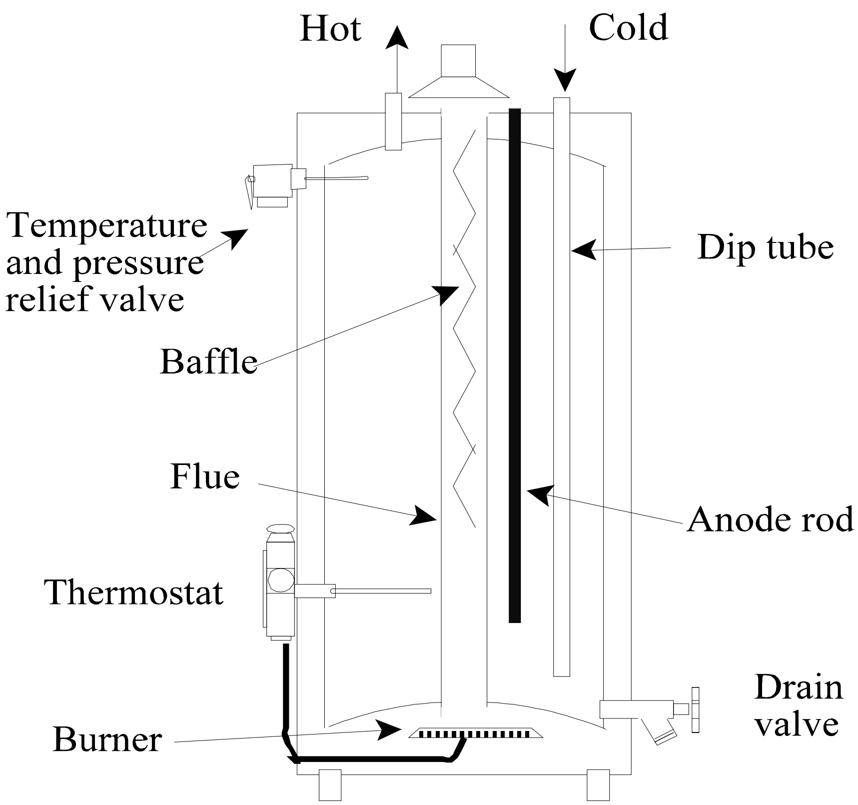


Figure 3.4 Residential Gas-Fired Water Heater

An oil-fired water heater is typically constructed using a glass-lined metal storage tank located above an insulated combustion chamber. There are two basic design types, center flue and rear flue (also referred to as floating tank design). Both designs use an oil burner consisting of an oil pump,

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[b] Water heaters fueled by natural gas and LPG are considered as one product class from the point of view of physical and efficiency characteristics. They are treated separately with respect to manufacturing cost, markup, retail price, and fuel price in the Life-Cycle Cost and subsequent analyses.

blower, ignition device, and controls. The U.S. Department of Energy (DOE) analysis for oil-fired water heaters only considers center-flue designs because they are much more common in residential use.

Installation of conventional water heaters is straightforward. An electric water heater requires hot and cold water connections and an electric power connection—a dedicated 20-amp 208/240 volt circuit. Gas-fired water heaters require hot and cold water connections, gas supply, and a vent connection. In air-tight houses, special provisions to ensure adequate combustion air and flue gas venting may be required. An oil-fired water heater requires hot and cold water connections, oil supply, electrical power connection, an oil-burner consisting of oil pump, blower, ignition device, and controls, and a vent connection.

3.2.2 Efficiency

Residential water heaters are covered by the National Appliance Energy Conservation Act (NAECA); efficiency standards for water heaters have been in effect since January 1, 1990. Efficiency is expressed in terms of energy factor (EF), which is the ratio of the heat delivered (as hot water) to the energy consumed (i.e., electricity, natural gas, LPG, or oil) according to a specific test procedure. The energy factor accounts for both recovery efficiency (RE) and standby losses at a prescribed pattern of hot water draws totalling 64.3 gallon per day. The required minimum energy factor varies with tank size (see Table 3.2). Typical 50-gallon electric and 40-gallon gas-fired (both natural gas and LPG)[a] water heaters have minimum energy factors of 0.88 and 0.54, respectively. For oil, the minimum energy factor for a 32-gallon tank is 0.53.[1]

Table 3.2 Residential Water Heater Efficiency Standards

Product Class	Energy Factor
Electric	0.93 - (.00132 × Rated Storage Volume)
Natural Gas and LPG	0.62 - (.0019 × Rated Storage Volume)
Oil-Fired	0.59 - (.0019 × Rated Storage Volume)

The range of energy factors for electric water heaters currently on the market is 0.81–0.95. The range of energy factors is accounted for primarily by differences in the insulation effectiveness and in tank size. The larger standby losses of a larger tank reduce the energy factor more than is the case with a smaller tank.

The range of energy factors for gas-fired water heaters currently on the market is 0.42–0.86, with the vast majority below 0.65. The difference between 100% efficiency and the actual energy

[a] Water heaters fueled by natural gas and LPG are considered as one product class from the point of view of energy efficiency characteristics. They are treated separately with respect to manufacturing cost, markup, retail price, and fuel price in the Life-Cycle Cost and subsequent analyses.

factor is caused by flue losses when the burner is on (sensible heat plus the latent heat of the moisture content of the combustion products), warm air lost up the flue when the burner is off, and conductive losses through tank insulation and fittings. As is the case with electric water heaters, larger tanks have lower energy factors because of larger standby losses. Two types of higher efficiency gas water heaters are commercially produced; water heaters that minimize flue and standby losses (with resulting energy factors up to 0.75) and condensing gas water heaters that condense the water vapor in the combustion products (with energy factors approaching 0.90). At least three models of condensing water heaters are currently in production, aimed primarily at the commercial water heater market, although they are sometimes used for combined space and water heating in residential applications.

3.3 WATER HEATER MARKET

3.3.1 Sales and Installed Base

Since 1987, annual sales of residential water heaters (primarily storage-type) have averaged about 7.5–9.0 million units per year. Of these, 47% are electric storage-type and 53% cover all other types—natural gas, LPG, oil, indirect, instantaneous, and circulating types.[2]

The installed base for residential water heaters favors gas more strongly than annual sales figures indicate. Compared to unit sales data, the survey data for the number of households (which includes units in multifamily buildings) using each type of fuel for water heating show a higher fraction using gas and oil and a lower fraction using electricity (Table 3.3). This apparent discrepancy is explained by several factors. The Residential Energy Consumption Survey (RECS) data from 1997 cited in Table 3.3 do not include the approximately 3 million second homes in the U.S., a large majority of which have electric water heaters. A significant fraction of the installed base of approximately 9 million gas- and oil-fired steam and hydronic boilers provide domestic hot water via tankless water heating coils. Many of the multifamily buildings that use gas or oil for water heating have large central water heating systems rather than many individual residential-size water heaters. Because of these effects, the total number of electric water heaters will tend to be under-reported by RECS, while gas-fired and oil-fired water heaters will be over-reported.

Table 3.3 U.S. Residential Water Heating Fuels

Water Heater Fuel Type	**Water Heaters Shipped 1987-1997** *%*	**Main Water Heating Fuel 1997** ***% of U.S. households***
Electric	47	39.4
Non-Electric	53	60.6

Sources: U.S. Dept. of Commerce, *Current Industrial Reports*, 1987-1997, and the 1997 *Residential Energy Consumption Survey*

3.3.2 Distribution Channels

The water heater market is dominated by five major manufacturers, each of which sells both residential and commercial size storage water heaters.

There are two major distribution paths for residential-size water heaters. Of the approximately 9 million annual sales, 4.2 million go through plumbing wholesalers to plumbers and contractors (1.2 million of these are for new construction). About 4.7 million go to large retail home-supply outlets where they are purchased by plumbers or homeowners. Relatively small numbers go to mobile home manufacturers (0.2 million) or export (0.2 million).[3] See Figure 3.5 for a schematic of the distribution channels.

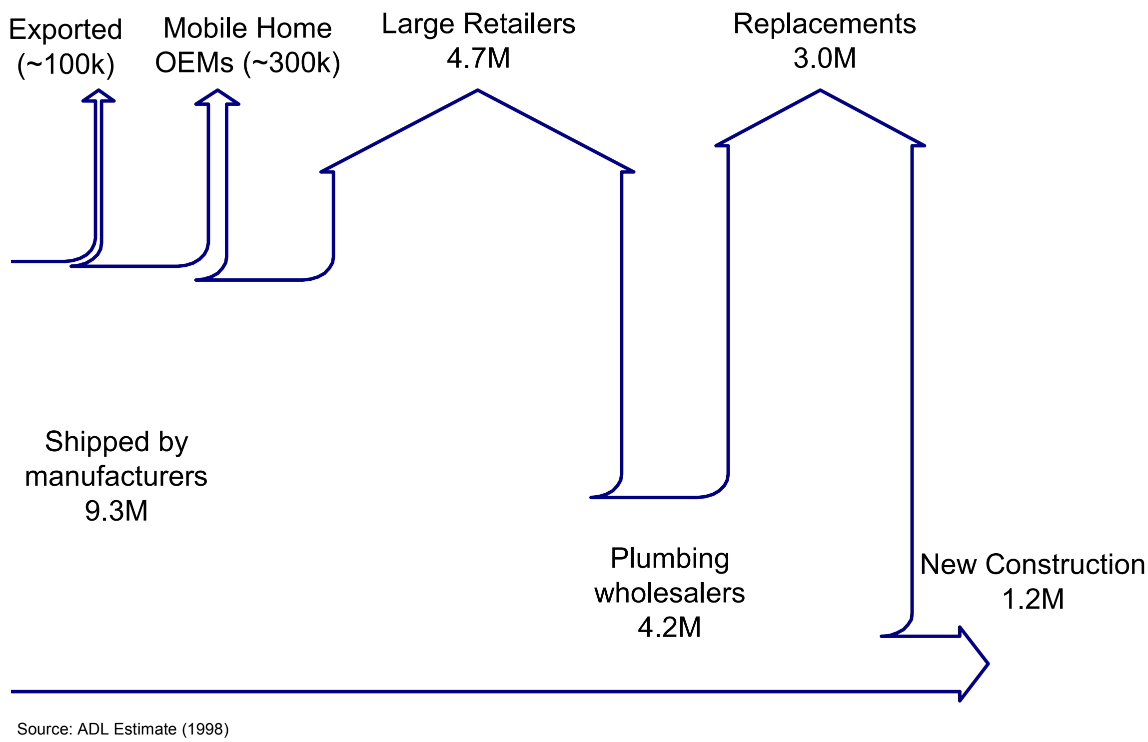

Figure 3.5 Distribution Channels for Residential Water Heaters

3.3.3 Cost Structure

Conventional, residential-size storage water heaters are manufactured and distributed under an extremely cost-competitive market regime where factory costs have been reduced to minimal levels and profit margins and distribution markups are very thin, as indicated in Table 3.4. The cost of the insulated storage tank is the major part of the factory cost; the heat source (i.e., the resistance heating elements and thermostats or the gas burner and gas control valve) only accounts for about 10% of the manufacturing cost.

Standard electric and natural gas water heaters are sold with very small markups. The high-efficiency types tend to be discounted less; customers pay a premium for the higher efficiency and longer warranty. Manufacturer, distributor, and installer markups are summarized in Figure 3.6. The generally low profitability of the water heater business (as a result of the aforementioned low markups) is often cited as a reason that conventional water heater manufacturers have not pursued higher-efficiency products.

Ultimate cost and markup levels in mass production and distribution (for equipment sized for typical residential applications) are estimated in Figure 3.6 and Table 3.4. This analysis assumes that, in high-volume production and distribution, manufacturers', distributors', and contractors' markups for baseline water heaters under future standards would remain at the current levels.

Table 3.4 Existing Cost Structures for Standard Water Heaters

	Standard Water Heater	
	Electric 50-gal ($)	Natural Gas 40-gal ($)
Manufacturer's Cost*	124	121
Manufacturer's Profit	10	10
Distributor's Markup	32	26
Installation, with Markup	270	265
Total Installed Cost	436	422

Source: Barbour, C.E. *et al., Market Disposition of High-Efficiency Water Heating Equipment*, 1996.
*Manufacturer's cost includes materials, labor, overhead, and general and administrative costs (G&A), but not profit.

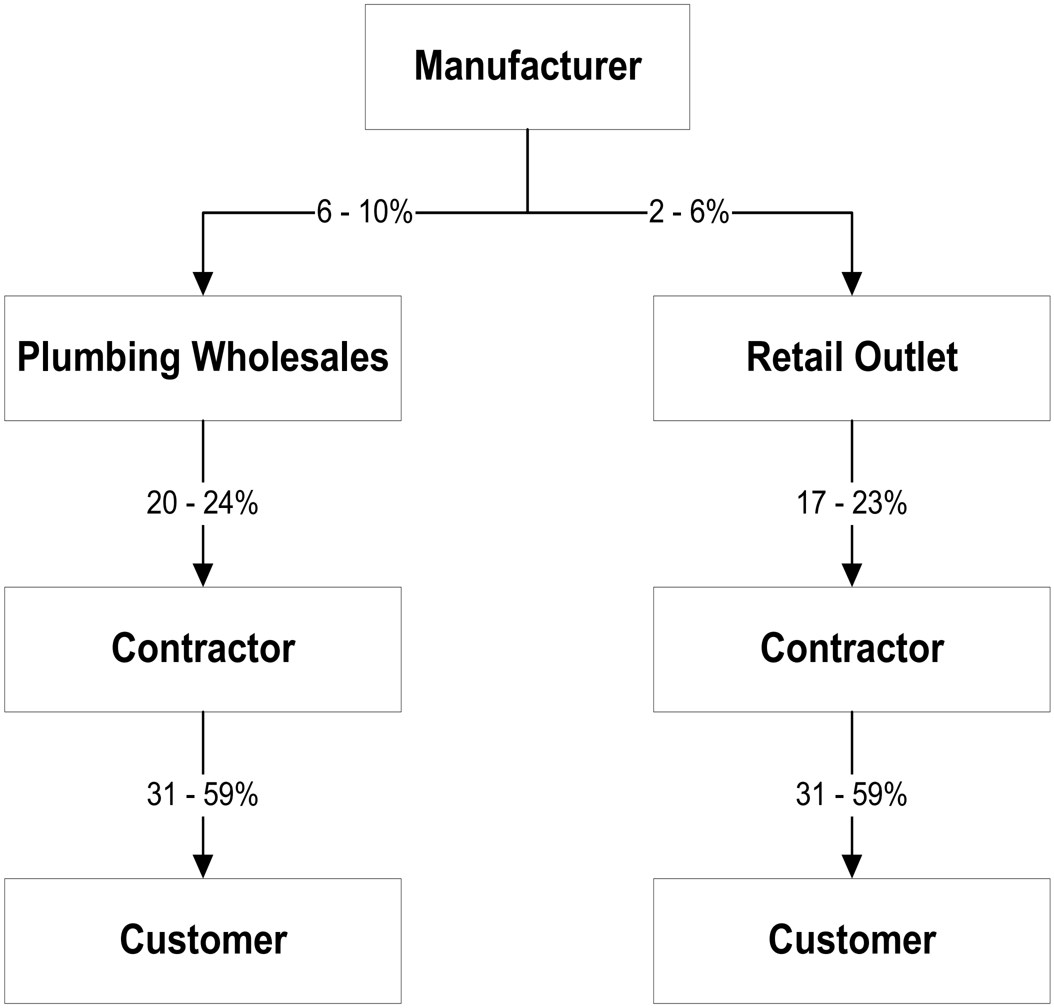

Figure 3.6 Typical Markups for Residential Water Heaters
Source: Barbour, C.E. *et al., Market Disposition of High-Efficiency Water Heating Equipment*, 1996.

3.3.4 Manufacturing Cost

Figure 3.7 shows a typical manufacturing cost breakdown. Slightly over half of the manufacturers' cost is for materials.

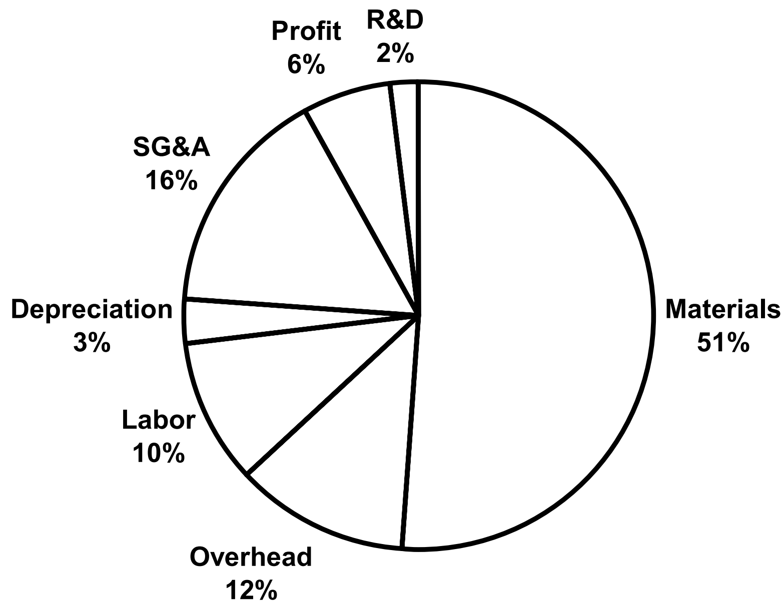

Figure 3.7 Water Heater Manufacturing Cost Breakdown
Source: Barbour, C.E. *et al., Market Disposition of High-Efficiency Water Heating Equipment*, 1996.

The components of this cost breakdown are:[3]

Materials:	Raw materials for producing the water heater. Includes metal for tanks, regulators, burners, elements, insulation, etc.
Overhead:	Fixed costs associated with the factory. Includes rent, utilities, insurance, etc.
Labor:	Direct factory labor to produce the water heaters.
Depreciation:	Depreciation on plant equipment, etc.
SG&A:	Selling, General and Administrative costs. Includes indirect labor, promotion, commissions, transportation, etc.
Profit:	Operating income before taxes or interest.
R&D:	Materials, labor, and administrative costs associated with research and development.

3.3.5 Non-Regulatory Water Heater Efficiency

There is currently no national non-regulatory water heater efficiency improvement program. However, DOE is developing an Energy Star® water heater program and is supporting a program to demonstrate a small heat pump water heater and to develop a residential condensing gas-fired water heater. In addition, the Federal Energy Management Program (FEMP) identifies the upper 25% of the market in terms of energy factor for residential water heaters—these levels are recommended to federal purchasers with the ultimate goal of pulling the entire U.S. market toward higher energy efficiency.[a] Gas and electric utility programs that encourage the use of higher efficiency water heaters include consumer rebate or dealer incentive programs, financing, consumer education, and rental/guarantee programs that often include installation and maintenance costs. In the past decade, the number and scope of utility programs has been reduced due to anticipated restructuring of the electric and gas utility industries. Currently, there are at least 12 programs for high-efficiency electric water heaters and as many as 10 programs for the purchase of high-efficiency gas water heaters.

3.4 TECHNOLOGICAL ISSUES

Regulatory changes outside of the NAECA efficiency standards process will impact the manufacture and installation of water heaters. Some of these changes will affect the efficiency of water heaters as well. These changes are described here, along with the methods that were used in our analysis to address each pending change.

3.4.1 Insulation Blowing Agents

Most residential water heaters are insulated with polyurethane foam in the space between the tank and the jacket. The insulation is foamed into place using polyols and isocyanates that react to form a hard polyurethane foam. A blowing agent included in the mixture is vaporized by the heat of the reaction, creating a frothy mass that hardens quickly into closed-cell foam insulation. Currently, water heater manufacturers use HCFC-141b, an ozone-depleting substance, as a blowing agent. As a result of the Montreal Protocol (1993), the U.S. Environmental Protection Agency has scheduled the phase-out of this blowing agent by the year 2003.[4] After 2003, manufacturers must use other blowing agents with zero Ozone Depletion Potential (ODP) for water heaters.

The industry is considering a number of replacement blowing agents, including HFC-245fa, HFC-356mfc, HFC-134b, pentane, and water-blown polyurethane. Table 3.5 lists characteristics of these blowing agents. The analysis presented in this report is based on the use of one of the leading candidates from this list, HFC-245fa. Our analysis for proposed water heater energy-efficiency

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[a] FEMP's *Product Efficiency Recommendations* on gas and electric water heaters can be accessed from http://www.eren.doe.gov/femp/procurement/begin.html

standards is based on the properties of insulation using HFC-245fa and the most realistic estimates of costs and physical parameters available for it.

Table 3.5 Blowing Agents Characteristics

	Thermal Conductivity*	Ozone Depletion Potential	Global Warming Potential	Cost ** *$/lb*	Comment
HCFC-141b	0.152	0.11	0.1400	1.00	Current blowing agent
HFC-245fa	0.157	0.00	0.2400	1.32	Not commercially available
Water-Blown	0.222	0.00	0.0003	1.00	Used by (2) small mfrs
HFC-356mfc	0.166	0.00	0.2100	na	Similar to HFC-245fa; not yet available in the U.S.
HFC-134a	0.164	0.00	0.2400	1.50	Limited solubility in polyols
Cyclopentane	0.158	0.00	0.0030	0.80	Flammable

* at 100 °F in Btu-in / hr-ft^2-°F.

**This cost covers the blowing agent and all other components of the insulation.

The dimensional stability of a foam determines the uniformity of the insulation in "pour-in-place" applications such as water heater manufacturing. Tests have shown that the range of foam density in the cavity varies by less than 2%, demonstrating a flowability which exceeds the results for HCFC-141b. These findings counter claims that the insulation conductivity derates due to variations in cell structure as the foam rises vertically and spreads horizontally in the jacket cavity.[5] Therefore, the Department chose to use the insulation conductivity values reported by foam manufacturing companies [6] and derated these values by about 10% to account for the incidental heat losses not otherwise accounted for in the simulation model.

3.4.1.1 HFC-245fa-Based Blowing Agent

One of the leading alternatives for use as a blowing agent is HFC-245fa (1,1,1,3,3 - pentafluoropropane). This blowing agent is being adopted by the refrigerator industry and should be available in sufficient quantity by 2003 for use in water heaters as well.[7] Reports from Bayer Corporation and Battelle show that HFC-245fa does have a slightly higher conductivity than the current blowing agent for the temperatures found in water heaters.[8,9] Table 3.6 presents conductivity comparisons of foam insulation blown with HCFC-141b and HFC-245fa. The average increase in conductivity resulting from replacing HCFC-141b with HFC-245fa is 3.0%.

Table 3.6 Conductivity of Foam Insulation Blown with HCFC-141b and HFC-245fa

		Conductivity @ 100°F (37.8°C)	
		HCFC-141b	**HFC-245fa**
Source	**Type of Foam Panel**	***Btu-in/hr·ft·°F (W/m·K)***	
Bayer	5% pack, 2 in. (5.1 cm) panel	0.149 (0.0214)	0.151 (0.0218)
Bayer	10% pack, 2 in. (5.1 cm) panel	0.148 (0.0212)	0.154 (0.0221)
Bayer	5% pack, 3 in. (7.6 cm) panel	0.152 (0.0220)	0.155 (0.0223)
Bayer	10% pack, 3 in. (7.6 cm) panel	0.150 (0.0217)	0.154 (0.0221)
Bayer	not specified	0.146 (0.0211)	0.154 (0.0221)
Battelle	not specified	0.166 (0.0239)	0.172 (0.0247)
Average Conductivity Increase			**3.0%**

The efficiency and energy-use characteristics of water heaters with HFC-245fa insulation are different from those with HCFC-141b insulation. In order to match the characteristics of water heaters with HFC-245fa insulation to those with HCFC-141b, it was necessary to compensate for the 3.0% difference in k-factor. We did this by modeling the baseline HFC-245fa water heater with slightly thicker insulation. In addition to accounting for the extra volume and cost of insulation, we also increased the amount and cost of steel used for the water heater jacket.

3.4.1.2 Water-Based Blowing Agent

Water-blown foams are created when water is introduced into the chemical mixture; this causes the release of carbon dioxide during the reaction and provides the blowing action. Water-blown foams are beginning to be used by the water heater industry. For example, Giant Factories in Canada manufactures electric and gas-fired water heaters using water-blown insulation from Stepan Company (U.S.).[10,6] Table 3.7 presents water-blown foam conductivity data from the Stepan Company. Their tests as well as tests performed by the National Institute of Standards and Technology (NIST) show that this insulation has a significantly higher conductivity than the HCFC-141b-based foam. The average increase in conductivity resulting from replacing HCFC-141b with water-blown is 42.0%.

Table 3.7 Conductivity of Water-Blown Foam Insulation

Source	**Test Sample Description**	**Mean Temperature *°F***	**Thermal Conductivity *Btu-in/hr-ft²-F***
Stepan Company	1-in.(2.5-cm) cross-section from 4-in. (10.2-cm) thick panel	77.0	0.220

3.4.1.3 HFC-134a-Based Blowing Agent

Another leading alternative for use as a blowing agent is HFC-134a. HFC-134a is already approved by EPA as an acceptable substitute for 141b.[11] This blowing agent is considered a practical alternative to HCFC, which is readily available and can be applied today.[12] A report from Oak Ridge National Laboratory show that HFC-134a does have a higher conductivity than the current blowing agent.[13] Table 3.8 presents HFC-134a foam conductivity data from ORNL. The average increase in conductivity resulting from replacing HCFC-141b with HFC-134a is 12.0%. The higher conductivity means that in order to match the characteristics of water heaters with HFC-134a insulation to those with HCFC-141b, it will be necessary to design the water heater with slightly thicker insulation.

Table 3.8 Conductivity of HFC-134a Foam Insulation

Source	Test Sample Description	Mean Temperature *°F*	Thermal Conductivity *Btu-in/hr-ft²-F*
Atofina	1.5-in.(3.8-cm) thick panel	75.0	0.155

I t is expected that for water heater applications, HFC-134a most probably will be blended with other HFCs such as HFC 245fa or HFC 365mfc. Pre-blended HFC 134a is considered one of the easiest replacements from the implementation point of view. Compared to other HFCs (i.e., HFC 245fa), HFC-134a has a higher initial cost, but may require lower loading level (% of total foam), approximately 9% compared to 13%-16%.

3.4.1.4 Pentane-Based Blowing Agent

Pentane-based foams are beginning to be explored by the water heater industry. Pentane is already approved by EPA as an acceptable substitute for 141b.[11] This blowing agent is being already adopted as a principal component of the rigid foam insulation used as a house insulation material and is available in sufficient quantity. Reports from Battelle show that pentane does have a slightly higher conductivity than HCFC-141b. Table 3.6 presents conductivity comparisons of foam insulation blown with HCFC-141b and HFC-245fa. The average increase in conductivity resulting from replacing HCFC-141b with pentane is 3.0% to 7% and the conductivity is comparable to the conductivity of HFC-245fa. Table 3.9 presents data for pentane foam conductivity from ORNL.

Table 3.9 Conductivity of Pentane Foam Insulation

Source	Test Sample Description	Mean Temperature *°F*	Thermal Conductivity *Btu-in/hr-ft²-F*
Battelle	1-in.(2.5-cm) cross-section from 4-in. (10.2-cm) thick panel	100.0	0.148

3.4.1.5 Test Results

DOE, in collaboration with NIST and Pacific Northwest National Laboratory (PNNL), tested the relative performance of HCFC-141b, HFC-245fa, and water-blown foam on water heater performance.[14, 15] NIST applied a two-step approach to evaluate the performance of the blowing agents. First, they measured the thermal conductivity of flat panels made up of the three foam types in a guarded hot plate test. Second, they performed the DOE 24-hour test on water heaters with each insulation type. Twelve commercially available 50-gallon (190-liter) electric water heater tanks were shipped to a chemical manufacturer where four samples (consisting of four panels and four water heaters) were foamed with each material. The procedure was carried out in accordance with standard industry practices. The samples were shipped to NIST for testing.

Guarded Hot Plate. Thermal conductivity of the foam samples was measured using a one-meter guarded hot plate apparatus at three mean temperatures by maintaining the cold plate at 67.5°F (19.7°C) and operating the hot plate at nominal temperatures of 125.0°F (51.7°C), 135.0°F (57.2°C), and 145.0°F (62.8°C). The results of this test are presented in Table 3.10.

Table 3.10 Conductivity of Flat Panels

Mean Temperature *°F*	Thermal Conductivity *Btu-in/hr-ft²-°F*		
	HCFC-141b	**HFC-245fa**	**Water-Blown**
83.8	0.148	0.144	0.211
93.8	0.153	0.149	0.218
103.8	0.159	0.153	0.225
100.0	0.157	0.151	0.222

Note: Thermal conductivity at 100.0°F is an interpolated value.

DOE 24-Hour Test. NIST used the DOE 24-hour simulated use water heater efficiency test to determine EF. The test was performed up to seven times for individual water heaters to ensure the test procedure's repeatability. Figure 3.8 shows the average EF for each set of four water heaters having the same insulation and the uncertainty associated with each value. All final results of the tests are fully documented by NIST.[14]

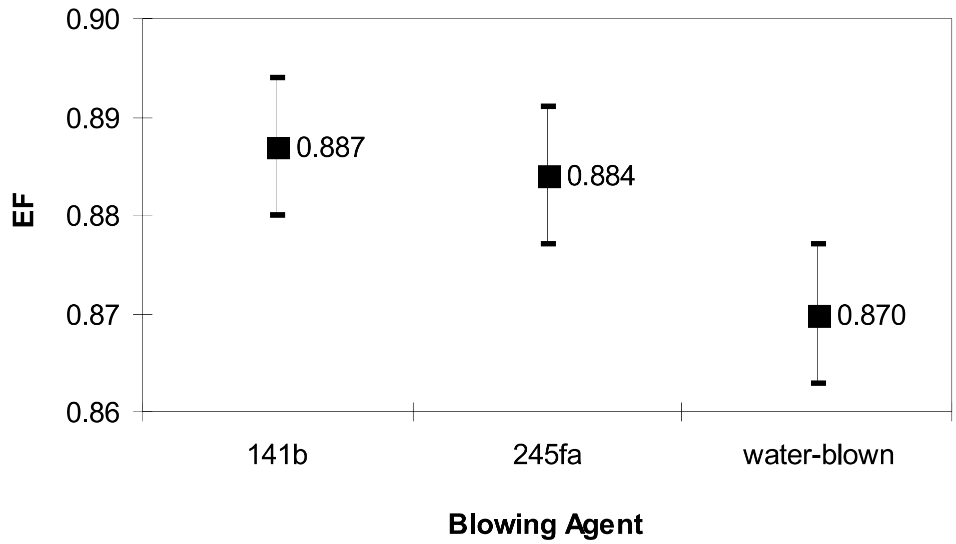

Figure 3.8 Average Energy Factor by Blowing Agent

3.4.2 Flammable-Vapor Ignition

Current designs for gas-fired (both natural gas and LPG)[a] water heaters rely on a standing pilot to ignite the main burner. If flammable vapors are present near a water heater, unintended ignition of the vapors is possible. This is a potential safety problem because water heaters are often installed in garages and basements where flammable liquids such as gasoline or paint thinner may be present.

The Consumer Product Safety Commission (CPSC) is working with the Gas Research Institute (GRI) and the water heater industry to develop a test procedure that will accurately assess the effectiveness of gas-fired water heater designs intended to resist ignition of flammable vapors.[16] The American National Standards Institute (ANSI) has adopted a test procedure regarding water heater resistance to igniting flammable vapors, but the effective date has not yet been selected. [17] Design research on this issue is ongoing in the industry. One manufacturer has announced a product with this feature.[18] Other designs are expected to become available in the near future.

Based on discussions with the Water Heater Industry Joint Research and Development Consortium, DOE used a placeholder value of $35 per water heater as the additional manufacturer cost for designs to resist ignition of flammable vapors. In this analysis, the extra $35 is applied to the manufacturer cost of all design options for natural gas and LPG water heaters, including the 2003

[a] Water heaters fueled by natural gas and LPG are considered as one product class from the point of view of physical and efficiency characteristics. They are treated separately with respect to manufacturing cost, markup, retail price, and fuel price in the Life-Cycle Cost and subsequent analyses.

baseline design. Thus, the added cost of resisting flammable-vapor ignition does not affect the cost effectiveness of any energy-efficiency design improvement on gas-fired water heaters although it may have an effect on choice of energy source. The flammable-vapor ignition-resistant design is assumed not to require electricity at the water heater nor modification of the venting system. No changes in efficiency are expected from water heater designs that resist igniting flammable vapors.

3.4.3 Venting

Use of high-efficiency gas-fired water heaters (both natural gas and LPG) with existing venting systems that are not designed for low-temperature flue gases can lead to excessive corrosion and failure of the vent system in certain climates. The efficiency of water heaters when firing is measured by RE, which is an indication of how much input heat gets to the water. GRI characterizes appliances for venting purposes by flue-loss efficiency. Flue-loss efficiency measures how much of the input heat does not go up the flue. Flue loss efficiency is typically 2-4% higher than RE. The difference is smaller with better insulated tanks. RE of more than 80% is associated with flue-loss efficiencies exceeding 84% and results in flue gas condensation within the vent, which can lead to corrosion and a reduced vent system life. To ensure that condensation does not occur in the vent, improvements that increase RE were limited to a maximum of 80% in the design options we selected for analysis. If the RE is below 80%, we assume that blowers or fans are not needed. However, DOE recognizes that potential venting problems may occur in the 78% to 80% RE range that could require Type-B vent connectors and chimney relining. Where necessary, the costs of vent modifications for gas-fired water heater installation have been included. Appendix D-3 of this report provides details on the effects of high-efficiency water heaters on vent system corrosion and its prevention.

Most water heaters sold today are for the replacement market. In almost all replacement situations, vent systems and reliners are available to meet the venting requirements for water heaters with high flue loss efficiencies. Hence, there is no technological barrier to the use of a water heater in a replacement situation. In the case of new construction, adequate venting systems can be installed according to manufacturers' recommendations, so that there are no problems associated with water heaters that have high-flue-loss efficiencies.

3.4.3.1 Venting Scenarios

GRI has estimated that 53% of U.S. residences have common vent systems for water heaters and gas-fired furnaces.[19] With increased minimum furnace efficiency requirements (since 1992), most replacement furnaces have a higher efficiency than the units they replace. Although masonry chimneys are quite resistant to corrosion, relining may be necessary when an existing (flue-loss efficiency <80%) furnace is replaced with a high-efficiency (>80%) furnace. Low-efficiency furnaces usually dry any condensate deposited in the masonry chimney by water heaters. With high-efficiency furnaces, flue-gas temperatures are lower, increasing the amount of time during which the chimney is wet.

Table 3.9 summarizes the GRI recommendations for relining masonry chimneys for two-appliance vent systems . A base-case configuration is assumed to have two natural-draft appliances (a furnace and a water heater, for example) venting into a common vent system. The flue-loss efficiency of each of these units is assumed to be less than 80%. Vent connectors are assumed to be single-wall metallic connectors, and the vent is assumed to be a properly sized exterior masonry chimney. The recommendations in Table 3.9 are dependant on geographic location as defined by the DOE climate zones. Appendix D-3 of this report provides a map and definitions of the climate zones.

Table 3.11 Recommendations for Relining Exterior Masonry Chimneys for Two-Appliance Configurations

Option	Comment
Base case: both furnace and water heater with flue-loss efficiency less than 80%	No relining is necessary.
Replace base-case water heater with 80% flue-loss efficiency unit	No relining is necessary.
Replace base-case water heater with 83% flue-loss efficiency unit	Relining may be needed for some installations in some climate zones.
Replace base-case furnace with 83% flue-loss efficiency unit (fan-assisted) without replacing base-case water heater	Relining of the chimney is recommended in all climate zones except Zone 5.
Replace both base-case water heater and furnace with high-flue-loss efficient units	If the flue-loss efficiency of the water heater exceeds 80.5% but is less than 83%, chimneys in some climate zones may need relining. If the flue-loss efficiency of either appliance is above 83%, relining is recommended in all zones. In most cases, the cost of relining should be assigned to the furnace.
"Orphaned" water heater	Relining is recommended in all climate zones, but the cost for relining should be assigned to the furnace and not the water heater

Table 3.10 summarizes recommendations for relining exterior masonry chimneys in one-appliance venting configurations.[20] A base-case configuration is assumed to have a natural-draft water heater venting into an exterior masonry vent system. The flue-loss efficiency of the unit is assumed to be less than 80%. Vent connectors are assumed to be single-wall metallic connectors and the vent is assumed to be a properly sized, exterior masonry chimney. This table shows that water heaters with a flue-loss efficiency of 80% or less can be vented with no additional cost into systems that conform to the National Fuel Gas Code (NFGC) standards.[21]

Table 3.12 Recommendations for Relining Exterior Masonry Chimneys for One-Appliance Configurations

Flue-Loss Efficiency	Recommendation
Base case: flue-loss efficiency of the water heater is less than <80%	No relining is necessary
80.5%	No relining is necessary
83%	Relining may be needed in most DOE climate zones, except DOE climate zone 5

Another important consideration is the type of vent connector—the portion of the vent system connecting the gas appliance flue collar or draft hood to the vent. A single-wall vent connector limits the flue-loss efficiency of gas appliances to 80% in a worst-case installation. Therefore, if the flue-loss efficiency of the water heater or the furnace in a two-appliance configuration exceeds 80%, it is recommended that a Type-B vent connector be used in some cases.[19, 22] In addition, according to the NFGC, a Type-B vent connector must be installed in all cases when any portion of the venting system is exposed to cold conditions (i.e., in unconditioned spaces).

3.4.3.2 Venting Modification Costs

Vent Costs for RE of Less Than 78%. For design options with recovery efficiencies less than 78%, no venting modifications are recommended.

Vent Costs for RE 78%. DOE estimates that only a fraction of the installations with recovery efficiency of 78% will need to change from a single-wall vent connector to a Type-B vent connector. The recommendation is to install a Type-B vent connector when replacing an existing water heater with one that has an efficiency of 78% RE or higher only if all of the following conditions are met:

- the house is located in one of the U.S. Census regions in the Northeast or Midwest,
- the house is in a cold climate (HDD65 equal to or over 5,000),
- the house was built before 1950,
- the water heater is installed in a conditioned space, and
- the water heater is classified as a worst-case installation.

Nationally, this accounts for approximately 6% of households for a weighted average cost of installing Type-B vent connectors of $6.73.

Vent Costs for RE 80%. In this case, a Type-B vent connector must be installed based on the criteria outlined above. However, in addition to the installation of a Type-B vent connector, some exterior chimneys in cold climates (HDD65 > 5,000) may need to be relined. Relining would be necessary only if the water heater is the only appliance venting into the chimney. The number of such cases varies regionally; our analysis assumes that 25% of masonry chimneys in cold climates would have to be relined. The average national cost for relining a masonry chimney is calculated to be $36.79.

3.4.4 Water Heater Size Constraints

The use of thicker insulation is an effective method of achieving improved energy efficiency in water heaters. The energy factors in the trial standard levels can be achieved with thicker insulation of 2.5" to 3" compared to the 1" to 2" in common use today. This extra insulation will make water heaters larger and more difficult to install in tight spaces when replacing an existing water heater. Additionally, the access door to the space the water heater is located in may not be large enough to allow the larger water heater to go through.

The large majority of residences will have room to accept water heaters with increased insulation. About 20% of water heaters are placed in new housing; the rest are replacements in existing housing. The new housing design and construction process will readily adapt to increased water heater sizes. For existing housing, most houses will be able to accommodate the increased water heater dimensions without difficulty. Many homes have water heaters in the open spaces of garages, basements, or utility rooms. In these cases, there is generally more than sufficient room for water heaters with slightly increased dimensions. Additionally, water heaters come in a number of different shapes. If water heaters with increased diameters cannot fit into the existing space, a different (for example, taller and thinner) water heater may often fit. For manufactured housing, water heaters are commonly located in a 24" wide by 24" deep space that runs from the floor to the ceiling. In this situation, a tall water heater should be available that will provide the desired tank volume and/or first hour rating.

There will be a small percentage of cases where increases in water heater dimensions will cause a variety of problems. Some replacement applications may be unable to accommodate the tank size currently used. To thoroughly categorize problems related to increases in water heater sizes would take a very extensive national survey of homes, something that has not been done. We believe that the percentage of installations with space-related problems will be small. We believe these problems will be more likely to occur in small, high density housing, such as apartments. In some cases, the door to a closet or attic where the water heater is located may be only large enough to accommodate the original water heater. A water heater with more insulation—hence larger dimensions—may not fit through the door. The cost to enlarge a fraction of door openings has been estimated and accounted for in the life-cycle cost analysis for water heaters with 3" insulation. Additionally, adjustments to the plumbing connections may be necessary in some cases.

We believe that manufacturers and installers can make adjustments to allow water heaters with thicker insulation to maintain the same overall dimensions of the water heater they will replace and provide the same utility (i.e., first hour rating).

3.4.4.1 Methodology

Size constraints are addressed by estimating the number of households with smaller closets and other spaces where water heaters are installed. Costs for adjustments to those installations are then added. To this end, five assumptions are made:

(1) This condition would only apply in those cases where the water heater is installed in conditioned space, e.g. not in a garage or an unconditioned basement.

(2) Oil-fired water heaters are located in unconditioned space and no replacement costs due to space constraints are applied.

(3) This will only apply to small houses or apartments. Excluded are houses or apartments with a floor area of more than 1,000 square feet. (See Figure 3.9)

(4) These assumptions are not intended to accurately identify every individual household that would face space constraints when replacing their water heater. Rather this estimate should roughly identify the number of households effected.

(5) Those households with space constraints are assumed to use the next smaller standard size water heater, and increase the water heater setpoint.

The RECS97 sample showed, of homes of less than 1,000 square footage, 32% of households had electric water heaters and 27% had gas water heaters. We assumed that these smaller households would require extra costs for removing and replacing closet doors and door frames. For the household that has space constraints, two adjustments were made: (1) adjust the setpoint of the smaller water heaters upward so that the total energy content in the amount of water that could be delivered is the same as could have been delivered by the larger, replaced water heater at a lower temperature; and (2) if the setpoint is > 140°F, the cost of a tempering value is added. The cost of a tempering valve is added to 15% of electric and 9% of gas water heater using households.

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