CHAPTER 8. ENGINEERING ANALYSIS

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CHAPTER 8. ENGINEERING ANALYSIS

8.1 OVERVIEW

The objective of the engineering analysis is to determine the costs of increased energy efficiency for residential water heaters by developing price and efficiency data for design options and combinations of design options for each type of water heater. This information will be used in subsequent components of the standards rulemaking process.

The engineering analysis uses computer simulation and other analytical methods to investigate the efficiency improvements resulting from design options and their interactions when multiple design options are used. The engineering analysis is based on the U.S. Department of Energy (DOE, or the Department)'s test procedure for residential water heaters.[1]

Average combined manufacturer, distributor, and installer markups, as well as sales tax, are applied to factory costs to determine prices for water heaters. Additional installation costs required for certain design options are included in the consumer price for those options.

The results of the engineering analysis are summarized in tables showing the increased cost and efficiency resulting from each design option for each water heater type. The design option combinations are shown in order of increasing efficiency. The energy prices used for this ranking are current national average energy prices from DOE's Energy Information Administration (EIA) *Annual Energy Outlook 2000* (*AEO2000*).[2]

8.2 INFORMATION SOURCES AND METHODOLOGY

8.2.1 Information Sources

The primary source of both manufacturer costs and efficiency data for this analysis is the Gas Appliance Manufacturers' Association (GAMA) (See Appendix C-2). GAMA collected cost and efficiency data from water heater manufacturers. These data were aggregated to protect the confidentiality of the individual manufacturers. GAMA did not provide data for four of the design options being considered (2.5- and 3-inch insulation, plastic tank & side arm heater). The missing data were supplemented by cost and efficiency information obtained from consultants[a] familiar with the industry (see Appendix C.3 for details).

Although computer simulation models were used to determine the efficiency gains expected from design options, efficiency estimates from GAMA and the consultants were used to confirm the reasonableness of the models' estimates. Other sources of information include the GAMA directory[3] and manufacturers' product literature. The GAMA directory lists energy factor (EF), recovery

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[a] Max E. Minniear, former Vice President of Engineering at A.O. Smith Water Products Company and Eugene West, formerly of Bradford-White Corporation.

efficiency (RE), rated input, and first-hour rating for residential water heating equipment. Manufacturers' product literature provided additional information about certain design features (e.g., heat traps and thickness of foam insulation). Product literature data were correlated with listings in the GAMA directory to determine what designs were employed to achieve particular efficiency levels.

Manufacturer cost data were confirmed for certain design options, in particular heat traps and foam insulation, by direct contact with component manufacturers. An upper limit to the factory cost of baseline model water heaters was extracted from reports from U.S. Department of Commerce. Factory cost is a manufacturer's cost to make a water heater and includes materials, labor, and overhead. The U.S. Census Bureau Current Industrial Report, Major Household Appliances 1997[4] reports the total value of electric and gas-fired water heaters as $1,253 million for 8.7 million units sold. Thus, the average price per unit would be $144. Because these data include premium models and manufacturers' markups as well as warranty costs, freight, profits, and commissions, the resulting price will be higher than the baseline model factory cost; thus it represents an upper limit.

The costs to the consumer for water heater equipment and installation are taken from the Water Heater Price Database. This database was established by contacting more than 130 retail chains, wholesale distributors, and plumbing contractors (e.g., Home Depot, Orchard Supply Hardware, Lowe's, Ferguson) throughout the United States. The Water Heater Price Database can be found on the Department web site.[5]

Other reports were also consulted. A Gas Research Institute (GRI) report, *Assessment of Technology for Improving the Efficiency of Residential Gas Water Heaters*,[6] was used specifically to establish the installation cost of gas-fired water heaters requiring an electrical circuit and to estimate the maintenance cost associated with electromechanical flue dampers. Arthur D. Little's report, *Market Disposition of High-Efficiency Water Heating Equipment*[7] was used to confirm the reasonableness of cost and price data.

8.2.2 Product Classes

The major water heater product classes and their 1997 market shares are listed in Table 8.2.1.

Table 8.2.1 Product Classes for Water Heaters

Product Class	1997 Market Share *(%)*
Electric Storage	47
Gas-Fired Storage	50
Oil-Fired Storage	2
Instantaneous	1

Source: U.S. Dept. of Commerce, *Current Industrial Reports*, 1998

For the current rulemaking, the Department considers the following three classes:

- electric storage water heaters with an input of 12 kWh or less and a tank size between 20 and 120 gallons,
- gas-fired (including LPG) storage water heaters with an input of 75,000 Btu/hr or less and a tank size between 20 and 100 gallons, and
- oil-fired storage water heaters with an input of 105,000 Btu/hr or less and a tank size of 50 gallons or less.

8.2.3 Baseline Models

Selection of baseline units for our analysis is based on existing DOE water heater efficiency standards [8] and comments from stakeholders in the rulemaking process. The baseline unit represents the most common size water heater with an efficiency equal to the minimum allowed by existing energy-efficiency standards. The general characteristics of the baseline model for each of the three primary product classes (i.e., electric storage, gas-fired storage, and oil-fired storage) are provided below. Each of the baseline models is described in depth later in this chapter.

The baseline electric water heater model has a 50-gallon (190-liter) glass-lined steel tank with 1.5 in. (3.8 cm) of polyurethane foam: HCFC-141b is the insulation blowing agent. The heater has two elements, each with an input of 4,500 W. The elements are interlocked so that only one can be energized at a time. The baseline energy factor is 0.86, the NAECA minimum for this size and type of water heater.

The baseline model for gas-fired and LPG storage water heaters has a bottom-fired, 40-gallon (150-liter), glass-lined steel tank with a 4 in. (10 cm) center flue. The input rate is 40,000 Btu/hr (11,700 W), with a pilot rated at 450 Btu/hr (120 W). The tank is insulated with 1 in. (2.5 cm) of polyurethane foam: HCFC-141b is the insulation blowing agent. The heater has the minimum efficiency allowed by National Appliance Energy Conservation Act (NAECA) with an energy factor of 0.54.[9] It has a recovery efficiency of 76%.

The baseline oil-fired water heater is a center-flue design. It has a rated volume of 32 gallons (120 liters), and is insulated with 1 in. (2.5 cm) of polyurethane foam: HCFC-141b is the insulation blowing agent. The input rate is 0.65 gallons per hour (2.5 liters/hr) of oil or 90,000 Btu/hr (26,000 W). It has an EF of 0.53, the minimum allowed by NAECA. The first hour rating is 105 gallons (398 liters), and the RE is 75%. The burner motor, which powers both the blower and oil pump, is rated at ⅛ hp (282 W). The ignition system is assumed to be the intermittent type.

8.2.4 Efficiency Calculations

The energy performance of the baseline unit is mandated by NAECA minimum efficiency standards, which have been in effect since 1991 (see Table 8.2.2).[10]

Table 8.2.2 NAECA Minimum Efficiency Standards

Product Class	Minimum Allowable Energy Factor
Electric Water Heater	0.93 - (.00132 x Rated Storage Volume in gallons)
Gas-Fired Water Heater	0.62 - (.0019 x Rated Storage Volume in gallons)
Oil-Fired Water Heater	0.59 - (.0019 x Rated Storage Volume in gallons)

Note: Rated Storage Volume is the water storage capacity of a water heater, in gallons, as specified by the manufacturer.

Design options for each of the three classes of water heaters were modeled either with computer simulation programs or an energy calculation method. Output from the computer simulations was used to determine the energy-efficiency characteristics of the water heater (e.g., EF, RE, and standby heat loss coefficient, UA), based on the DOE test procedure. The simulation models and energy calculation methods are discussed briefly below.

8.2.4.1 WATSIM Model for Electric Storage Water Heaters

WATSIM is a detailed electric water heater simulation program developed by EPRI.[11] WATSIM contains two simulation algorithms: one for the detailed simulation of water heater tanks and the other for controlling water draw profiles for use with the tank model. Because the simulation analysis must meet the requirements of the DOE test procedure, the water-draw profile is specified to be the 64.3-gallon (243.4-liter) draw pattern in DOE's procedure. The output of WATSIM does not include the EF, RE, and UA calculations from the DOE test procedure. However, it does provide detailed temperature profiles of the water inside the water heater tank during the simulation run (the temperature profile is provided in a standard WATSIM output file called *tw_vs_t1.out*). These temperature profiles are used to determine the EF and other parameters of the water heater using the test procedure calculations. A spreadsheet tool has been developed to calculate the efficiency characteristics per the specifications of the DOE test procedure from the output contained in the *tw_vs_t1.out* file. Appendix D-1 provides a detailed description of the procedure to determine the efficiency characteristics using the WATSIM output.

Complete verification of the WATSIM program is not currently available to the public. The WATSIM user's manual states that the model "has been vigorously verified for use in tank and system design, equipment sizing, and individual or diversified demand analyses, as well as for energy consumption analysis."[11] Independently, National Institute of Standards and Technology (NIST) tested four 50-gal commercially available electric water heaters with 2-in. HCFC-141b based insulation. Units with such characteristics represent mid-efficiency electric water heater models. NIST reported the EF values among the results.[12] The Department compared the EF NIST tests with

WATSIM simulations of water heater models with the same features as well as with GAMA ratings of about 20 models. The results are as follows: NIST reported an average EF of 0.887,[12] GAMA reported an average EF of 0.875 (based on an average of 20 models with 2-in. insulation listed in the GAMA directory), and WATSIM an EF of 0.877. As can be seen, the results all agree to within one EF unit point of each other.

In addition, NIST tested five high-efficiency electric water heaters from different manufacturers.[13] The measured between measured and reported results indicate lower energy factors than those reported in the April 199 GAMA directory. The differences for all five models are within three and a half EF unit points. A WATSIM simulation of a water heater with the same characteristics as model number E3Z50RD055V (3" top and side insulation, heat traps, 4.5 kW heating elements) yielded EF=0.906. This result is essentially identical with results reported by NIST testing, EF=0.908, for this particular model. The results of the NIST test of five high-efficiency water heaters as compared to their GAMA directory listings are presented in Table 8.2.3.

Table 8.2.3 EF Comparison: High Efficiency Electric Water Heaters

Model #	GAMA EF	NIST EF
MIII50T6DS17	0.93	0.90
E3Z50RD055V	0.92	0.91
RUEPRO52-2	0.93	0.89
32059	0.93	0.89
EEH-52	0.94	0.90

In order to further validate the WATSIM model, we did a detailed study of one particular water heater model (American #E3Z50RD055CV, EF=0.93) to simulate a 24 hour EF testing in conjunction with NIST doing physical tests of two units of the same model.

As part of the study, we cut open (reverse engineered) a water heater of this model to determine the exact physical dimensions of the tank.[14] Among the measurements we took were; the inside diameter and height of the tank, the height of the top and bottom domes, the location of the elements and thermostats, the location of the bottom to the dip-tube, and the height of the drain valve, the inlet, supply and temperature pressure relief valve. We also examined the type, quality, and thickness of insulation at the bottom of the tank, along the sides, across the top and behind the junction box and around the controls. The heat traps and dip-tube was also examined.

By comparing detailed temperature profiles at various locations in the tank from tests of real units with the same temperature profiles at the same points in the simulation model we were able to determine which parts of the simulation model to adjust. Other than modifications to match the physical dimensions of this particular model, we changed the simulation model by increasing the conductivity of the insulation at the top of the tank, reduced the heat loss through the fittings and adjusted the location of the bottom thermocouple in the simulation model to better account for the improved stratification of this model.

After making these adjustment to the simulation model the EF as determined using WATSIM matched the EF determined by NIST testing a physical water heater to within 0.03%. Therefore, the accuracy of WATSIM has been demonstrated at the efficiency levels and with the types of design options that our analysis is using.

The Department has also reviewed GAMA's certification data for high-efficiency gas-fired and electric water heaters. On average, we found no bias in the reporting of high-efficiency gas-fired water heaters but did find that reported EFs on high-efficiency electric water heaters were 0.02 EF unit points higher than the Intertek Testing Services (ITS) tested EFs in every year from 1994 through 1998.[15] Table 8.2.4 shows the 1997 certification results for certain 50-gal high-efficiency electric water heaters tested by ITS on behalf of GAMA. The column "GAMA" shows the EF rating as reported in the October 1998 version of GAMA's consumers' directory.[16] The next column shows the EF measured by ITS. The last column, "ITS vs GAMA, %" shows the percentage difference between the two. This summary shows that GAMA reports 1.4% to 5.5% higher EF than the EFs measured by ITS.

Table 8.2.4 High Efficiency Electric Water Heaters EF: Certification Results

Test No	GAMA	ITS	ITS vs GAMA %
007-3-1#	0.92	0.872	5.5
007-1-1#	0.92	0.872	5.5
007-2-1#	0.92	0.874	5.2
171-1-1#	0.91	0.880	3.4
010-1-1P#	0.93	0.903	3.0
005-1-1P	0.93	0.907	2.5
168-1-1#	0.94	0.921	2.1
166-1-1#	0.93	0.917	1.4

Based on those comparisons, the Department has concluded that the WATSIM adequately represents the performance of the electric heaters. Therefore, DOE based the energy efficiency analysis on modeled results.

8.2.4.2 TANK Model for Gas-Fired Storage Water Heaters

TANK is a detailed gas-fired storage water heater program developed by Battelle for the Gas Research Institute (GRI).[17] TANK calculates energy flows throughout a water heater including water draws, flue heat losses, jacket heat losses, fittings heat losses, and combustion chamber heat losses. Unlike WATSIM outputs, TANK outputs include the EF, RE, and UA from the DOE test procedure.

Therefore, calculations outside of TANK are not necessary for determining a gas-fired water heater's energy-efficiency characteristics under the DOE test procedure.

As will be discussed in more detail later, there are limits to how much the flue-loss efficiency can be increased before changes are required in the vent system to prevent flue gas condensation. Discussions with Battelle [18] indicated that TANK may provide inaccurate estimates of the flue-loss efficiency. No data were provided to substantiate this claim and DOE decided to rely on TANK predictions. Therefore this Engineering Analysis used TANK's estimates of flue-loss efficiency to indicate whether modifications to the vent system are necessary.

To validate the analytical models comprising the TANK program, Battelle conducted actual water heater testing and monitoring. Battelle performed a set of tests to investigate the impacts on EFs of different flue baffle designs, the effect of increased insulation thickness, and the effect of different pilot input rates. The results were compared to the TANK model results. It was reported that the overall agreement between TANK model predictions and the laboratory data is within the experimental error and computer modeling limitations.

Battelle tested additional water heaters under the assumptions of the DOE 24-hour test procedure to validate the analytical predictions of TANK. The results were reported in terms of EF, RE, flue efficiency, and total standby loss. Overall, the agreement for the storage type, center-flue, gas-fired water heaters is very good, with the difference between the experimental values and the predicted values for the EF being less than 0.01.

The detailed explanation of the validation results for the TANK program is available in Chapter 5, "Experiments and Model Validation", of the TANK user's manual.[17]

8.2.4.3 WHAM Energy Calculation for Oil-Fired Storage Water Heaters

A simplified water heater analysis model (WHAM) was used for our engineering analysis for oil-fired water heaters. WHAM is based on the 24-hour simulated use test portion of the DOE test procedure. The model calculates energy consumption from a water heater's RE, UA, and rated input (P_{on}).[19] WHAM energy calculations have been checked against both the WATSIM and TANK simulation calculations. The WHAM energy calculation is based on an idealized version of a water heater. The water temperature is assumed to remain at the setpoint throughout the tank. Also RE and UA are assumed to be constant. The equation is as follows:

$$Q_{in} = \frac{vol \cdot dens \cdot C_p \cdot (T_{\text{tank}} - T_{in})}{RE} \cdot \left| 1 - \frac{UA \cdot (T_{\text{tank}} - T_{amb})}{P_{on}} \right| + 24 \cdot UA \cdot (T_{\text{tank}} - T_{amb})$$

where:

Q_{in}	=	average daily energy input,
RE	=	recovery efficiency from test procedure,

UA = standby heat loss coefficient from test procedure,
P_{on} = rated input,
vol = average volume of water drawn in 24 hours,
T_{tank} = tank thermostat setpoint,
T_{in} = inlet water temperature,
T_{amb} = ambient air temperature surrounding the water heater,
$dens$ = density of water, and
C_p = specific heat of water.

Daily energy use predictions from WHAM for oil-fired water heaters are not directly compared to daily use predictions from any other oil-fired water heater simulation model because no simulation model exists for oil-fired water heaters. However, the results of the WHAM equation have been compared to results of detailed simulation models of residential electric and gas-fired storage water heaters with excellent agreement. A detailed explanation of the WHAM approach is included in Appendix D-2.

It is believed that WHAM is a good predictor of daily energy use for oil-fired water heaters because one of the simplifying assumptions is that all the water drawn from the tank is at the setpoint temperature. For a given draw volume (such as the separate 10.7 gallon (40.5 liter) draws of the DOE test), an oil-fired water heater will fire at approximately the same time as will a gas-fired water heater of similar volume. However, because the recovery rate of oil-fired water heaters is typically more than twice that of residential gas-fired water heaters, the temperature of the water being drawn from the heater will, on average, be closer to the water heater setpoint temperature.

8.2.5 Overall Analytical Approach

In this report, a distinction is made between baseline models containing current technologies and future baseline models that are expected to incorporate new mandated features. The former are referred to as "existing" baseline models and the latter as "2003" baseline models (for the year 2003, when other regulations will take effect). An important feature of existing water heater technology is insulation made using HCFC-141b as a blowing agent. For purposes of this analysis, a representative or "typical" tank size (rated volumes of 50-gallon for electric, 40-gallon for gas-fired, and 32-gallon for oil-fired) has been chosen from all the standard sizes for each fuel type.

8.3 ELECTRIC WATER HEATERS

The engineering analysis models design options for electric water heaters using WATSIM, a detailed computer simulation model for water heaters developed by EPRI.[11] A 50-gallon (190-liter) rated volume electric resistance water heater is used as the existing baseline model for this analysis.

8.3.1 Existing Baseline Model

The goal of using WATSIM to simulate the typical existing baseline model was to create the characteristics of a 50-gallon (190-liter) baseline electric water heater with an EF of 0.86 (the minimum allowed by NAECA for an electric water heater).

Several models of 50-gallon (190-liter) electric water heaters with an energy factor of 0.86 are found in the GAMA directory and various manufacturers' product literature. Two models achieve this EF through the use of heat traps and 1 in. (2.5 cm) of foam insulation (American E51-50H-045D and Bradford White M-I-50T6DS). (The foam insulation in these models is blown with HCFC-141b, which is scheduled for phase-out in 2003.) However, the literature indicates that a 0.86 EF is achievable with the use of only 1 in. (2.5 cm) of foam insulation. Therefore, our initial existing baseline water heater incorporated only this energy-efficiency design feature. Table 8.3.1 summarizes the primary characteristics of the typical existing baseline water heater initially simulated with WATSIM.

Table 8.3.1 Initial Existing Electric Water Heater Baseline Characteristics

Tank Rated Capacity	50 gal (190 l)
Tank Diameter	15.84 in. (40.23 cm)
Tank Length	54.48 in. (138.38 cm)
Insulation Thickness - Sides	1.00 in. (2.54 cm)
Insulation Thickness - Top	1.00 in. (2.54 cm)
Conductivity of Feed-Throughs (equivalent to steel)	0.40 Btu/ft·min·°F (41.54 W/m·K)
Natural Convection UA for Feed-Through Calcs (no heat traps	0.578 Btu/hr·°F (default in WATSIM)

Note: Units in the table are consistent with the units used by the WATSIM simulation model.

Simulations of a water heater with the baseline characteristics listed in Table 8.3.1 yielded a surprisingly low EF of 0.805. WATSIM's simulation results were then compared to those from TANK (GRI's gas-fired water heating simulation model) to determine the cause of the low EF estimate. For comparably sized water heaters, WATSIM's pipe heat-loss estimates were approximately twice that of TANK's. Because TANK has been validated against actual test data, we suspected that WATSIM's method of calculating feed-through losses must be inaccurate, so we performed additional simulations. These simulations did not identify any physical parameters, besides the addition of heat traps or an increase in the thickness of the foam insulation, that could reduce water heater losses enough to yield a significantly large impact on EF. Therefore, we concluded that WATSIM's default feed-through losses were the likely cause for its low EF estimates. EPRI confirmed that WATSIM's default feed-through loss estimates were indeed too high, although no indication was given as to the magnitude of the error.[20]

We performed new simulations after reducing WATSIM's feed-through loss estimates to match those predicted by TANK. Lower feed-through losses were achieved by lowering the natural convection UA values at supply and draw lines and adding 1/8" pipe insulation for modeling purposes only. By using the same initial baseline characteristics as listed previously, with the exception of a natural convection UA value of 0.185 Btu/hr·°F rather than 0.578 Btu/hr·°F, an EF of 0.830 was predicted.

Because the EF estimate was still 0.030 points lower than the target value of 0.860 EF, we next increased the thickness of the foam insulation from 1 to 1.5 in. (2.5 to 3.8 cm). This strategy has been confirmed by one manufacturer who says that the efficiency required by the standard cannot be achieved with 1 in. (2.5 cm) of insulation. This manufacturer reports that most of the minimum efficiency models use 1.5 in. (3.8 cm) of insulation. Two water heater models listed in the Water Heater Price Database and currently sold in stores (Rheem 81SV52D and A.O.Smith EESC-52D) have EF = 0.86 (according to the 1998 GAMA directory of certified water heaters). This is accomplished using insulation that is at least 1.5 in. (3.8 cm) thick. Some models currently listed in the GAMA directory, though they are labeled as having EF=0.86, apparently have lower EFs. These models had passed an earlier DOE water heater test procedure but do not pass DOE's current test procedure, which was put into effect in 1993. Models that passed the earlier test procedure and were "grandfathered" in have 1 in (2.5 cm) of insulation. When we modeled the insulation at a thickness of 1.5 in. (3.8 cm), we achieved an EF of 0.858. In other words, using 1.5 in. (3.8 cm) of foam insulation, we were able to simulate a typical existing baseline model and achieve the minimum allowable NAECA efficiency of 0.86 EF.

Table 8.3.2 shows the parameters of the typical existing baseline model electric water heater used in WATSIM for this analysis.

Table 8.3.2 Existing Baseline Electric Water Heater Model Characteristics

Descriptive Parameter		Value
Tank Rated Capacity		50 gal. (190 l)
tank:	diameter	15.8 in. (40.1 cm)
	height	54.5 in. (138.4 cm)
	wall thickness	0.063 in. (0.16 cm)
	wall conductivity	0.40 Btu/ft·min·°F (41.5 W/m·K)
	support ring conductivity	0.40 Btu/ft·min·°F (41.5 W/m·K)
height of concave bottom dome		1.5 in. (3.8 cm)
heat-transfer coefficient for tank wall film		20.0 Btu/hr·ft^2·°F (113.5 W/m^2·K)
tank insulation - thickness	top:	1.5 in. (3.8 cm)
	side:	1.5 in. (3.8 cm)
	bottom:	0.75 in. (1.91 cm)
tank insulation - conductivity	top:	0.000233 Btu/ft·min·°F (0.0242 W/m·K)
	side:	0.000233 Btu/ft·min·°F (0.0242 W/m·K)
	bottom:	0.000333 Btu/ft·min·°F (0.0346 W/m·K)
cold water inlet height		7.5 in. (19 cm)
hot water outlet height		54.5 in. (138 cm)
heater elements - height	bottom:	7.44 in. (18.9 cm)
	top:	38.9 in. (98.8 cm)
heater elements - power	bottom:	4.50 kW
	top:	4.50 kW
heater elements - efficiency	bottom:	100%
	top:	100%
thermostats - height	bottom:	12.0 in. (30.5 cm)
	top:	43.7 in. (111 cm)
feed-throughs - height	hot water pipe:	54.5 in. (138 cm)
	cold water pipe:	54.5 in. (138 cm)
	drain valve:	1.56 in. (3.96 cm)
	pressure relief valve:	54.5 in. (138 cm)

Table 8.3.2 Electric Water Heater Existing Baseline Model Characteristics (continued)

feed-throughs - conductivity	hot water pipe: cold water pipe: drain valve: pressure relief valve:	0.40 Btu/ft·min·°F (41.5 W/m·K) 0.40 Btu/ft·min·°F (41.5 W/m·K) 0.0018 Btu/ft·min·°F (0.1869 W/m·K) 0.40 Btu/ft·min·°F (41.5 W/m·K)
feed-throughs - insulation thickness	hot water pipe: cold water pipe: drain valve: pressure relief valve:	0.14 in. (0.30 cm) 0.14 in. (0.30 cm) 0 0
feed-throughs - orientation	hot water pipe: cold water pipe: drain valve: pressure relief valve:	vertical vertical horizontal vertical
feed-throughs - radius	hot water pipe: cold water pipe: drain valve: pressure relief valve:	0.44 in. (1.3 cm) 0.44 in. (1.3 cm) 0.44 in. (1.3 cm) 0.44 in. (1.3 cm)
feed-throughs - length	hot water pipe: cold water pipe: drain valve: pressure relief valve:	24.0 in. (61.0 cm) 24.0 in. (61.0 cm) 6.0 in. (15.2 cm) 3.6 in. (9.1 cm)
feed-throughs - wall thickness	hot water pipe: cold water pipe: drain valve: pressure relief valve:	0.045 in. (0.091 cm) 0.045 in. (0.091 cm) 0.045 in. (0.091 cm) 0.045 in. (0.091 cm)
feed-throughs - insulation conductivity	hot water pipe: cold water pipe: drain valve: pressure relief valve:	0.000233 Btu/ft·min·°F (0.024196 W/m·K) 0.000233 Btu/ft·min·°F (0.024196 W/m·K) 0 0
feed-throughs - natural convection pipe loss	hot water pipe: cold water pipe: drain valve: pressure relief valve:	0.200 Btu/hr·°F 0.200 Btu/hr·°F 0.0 0.0
Note: Units in the table are consistent with units used by the WATSIM model.		

8.3.2 Modeling Design Options

Four design options are being considered to improve the efficiency of electric storage water heaters. Each option is briefly discussed below along with the way it was modeled in WATSIM. The discussion begins with analysis of the baseline model using foam insulation blown with HFC-245fa as a blowing agent. As noted above, this baseline model is referred to as the 2003 baseline.

8.3.2.1 2003 Baseline

The blowing agent currently used by the water heater industry for foam insulation (HCFC-141b) is scheduled to be phased out by the year 2003. Because new energy-efficiency standards will take effect after the phase-out of HCFC-141b, the baseline model for our analysis uses HFC-245fa as the blowing agent.

As explained in Chapter 3, Section 3.4, Technological Issues, HFC-245fa blowing agent has a 3.0% higher conductivity than HCFC-141b, which reduces the effectiveness of the insulation.

The conductivity value of the foam insulation in the existing baseline model listed above in Table 8.3.2 was increased by 3.0% to a value of 0.000240 Btu/ft·min·°F (0.0249 W/m·K) for HFC-245fa. The thickness of the foam insulation surrounding the tank was increased to 1.55 in. (3.94 cm) to compensate for the insulation's increased conductivity.

Table 8.3.3 summarizes changes that were made to the jacket insulation conductivity of a typical existing baseline model with HCFC-141b in order to simulate its performance with the 2003 baseline model.

Table 8.3.3 Electric Water Heater Modeling Baseline - Jacket Insulation Characteristics

Descriptive Parameter	Baseline w/ HFC-141b	Baseline w/ 245fa
Insulation thickness	1.50 in. (3.81 cm)	1.55 in. (3.94cm)
Insulation conductivity	0.000233 Btu/ft·min·°F (0.02420 W/m·K)	0.000240 Btu/ft·min·°F (0.024922 W/m·K)

Note: Units in the table are consistent with the units used by the WATSIM simulation model.

8.3.2.2 Heat Traps

The heat conducted and convected through water heater fittings (water pipes, drain valve, pressure relief valve, and thermostat) accounts for about 30% of the total heat loss in a typical 50-gal electric water heater. A heat trap is a device that keeps the buoyant hot water from circulating out into the piping distribution system because of natural convection. When there is no hot water use, this device prevents water in the hot water outlet line from getting back into the tank as it cools off and prevents hot water in the tank from circulating into the cold water inlet line. The cold water inlet line heat trap is generally mounted in the cold water supply pipe (the dip tube assembly); the heat trap mechanism resides near the top of the water heater within the tank. The hot water outlet line heat trap is mounted at the top of the water heater; the heat trap mechanism is part of a plastic cartridge enclosed within the steel pipe that houses the entire heat trap/anode device. By containing the hot water in the storage tank, the heat traps minimize standby heat loss.

Several types of conventional heat traps are currently made. One uses a floating plastic ball to block the cold water inlet. The buoyancy of the plastic holds the ball in place until water is drawn. The force of water entering the tank is strong enough to push the ball out of the way. Another type is used for the hot water outlet; the plastic ball is denser than water and the weight of it seals the outlet until hot water is drawn and water pressure lifts it out of the way. A small bypass channel is left for water to escape back into the inlet line from the tank. This bypass is necessary because cold water flowing into the tank expands as it is heated. Other heat trap designs include U-shaped pipes,[21] flexible seals,[22] flaps, and springs.

Based on efficiency data provided by the water heater industry, heat traps prevent a loss of approximately 540 Btu/day from a 50-gallon electric water heater. To model the effect of heat traps in WATSIM, we lowered UA values for the natural convection heat transfer losses at the supply and draw lines by a magnitude of 0.185 Btu/hr·°F.[20]

Table 8.3.4 summarizes the changes made to the 2003 baseline model in order to simulate the performance of heat traps.

Table 8.3.4 Electric Water Heater Modeling Heat Traps

Descriptive Parameter	2003 Baseline	with Heat Traps
feed-throughs - natural convection pipe loss	1: 0.200 Btu/h·°F 2: 0.200 Btu/h·°F	0.015 Btu/h·°F 0.015 Btu/h·°F

Note: Units in the table are consistent with the units used by WATSIM.

8.3.2.3 Increased Jacket Insulation

Most electric water heaters on the market today have jacket (side and top) foam insulation that is at least 1.5-in. (3.8-cm) thick, however there still exist electric water heaters with 1-in. (2.5-cm) insulation. Some manufacturers provide 2- to 3-in. (5.1- to 7.6-cm) thick insulation. Although increasing the insulation thickness reduces standby heat loss, the increase in overall diameter of the water heater may pose installation problems. Shipping costs also increase because fewer water heaters can fit in a truck. Because of these installation problems, we limited maximum insulation thicknesses to 3 in. (7.6 cm) for this analysis.

Table 8.3.5 summarizes the changes made to the 2003 baseline model to simulate the performance of an electric water heater insulated with 2-, 2.5, and 3-in. (5.1-cm, 6.4-cm, and 7.6-cm) foam insulation. Changes in insulation conductivity over the range of thicknesses is discussed in Chapter 3.4.

Table 8.3.5 Electric Water Heater Modeling Baseline 2-, 2.5, & 3-in. Foam Insulation

Descriptive Parameter		245fa 2003 Baseline	with 2-in. foam insulation	with 2.5-in. foam insulation	with 3-in. foam insulation
tank insulation -	top:	1.55 in. (3.94 cm)	2.00 in. (5.08 cm)	2.50 in. (6.35 cm)	3.00 in. (7.62 cm)
thickness	side:	1.55 in. (3.94 cm)	2.00 in. (5.08 cm)	2.50 in. (6.35 cm)	3.00 in. (7.62 cm)

8.3.2.4 Insulating the Tank Bottom

There is no standard approach to insulating the bottom of electric water heater tanks to reduce standby loss. Some manufacturers currently use fiberglass insulation. For the baseline model in this analysis, the height of the existing baseline model's concave dome is assumed to be 1.5 in. (3.8 cm) with 0.75 in. (1.9 cm) of fiberglass insulation stuffed below it.

We assume that a foamed "disk/bottom insulation" assembly is used for the tank bottom insulation. WATSIM models heat losses through the bottom of the tank in two separate heat transfer paths: the "bottom" is the concave dome, and the "support ring" is the perimeter, a continuation of the tank wall to the base pad. The "bottom insulation" portion of this assembly fills the domed space underneath the tank. The "disk" portion is assumed to lie underneath both the support ring and the "bottom insulation". Although the "disk" portion of this assembly is assumed to be only 0.125 in. (3.2 mm) thick, water heater construction practices prevent the support ring from deforming it when the tank is filled with water. The adhesive and structural properties of the foam insulation keep the tank from crushing the disk portion of the bottom insulation. The bottom insulation portion of the disk/bottom insulation assembly reduces the heat losses from the bottom of the tank, the disk portion reduces conductive heat losses through the support ring, by introducing a thermal break between the tank and the jacket bottom.

Table 8.3.6 summarizes the changes made to the 2003 baseline model to simulate the performance of electric water heaters with bottom insulation. The support ring is assumed to be 50% steel and 50% foam insulation for conductivity modeling. As a result, its conductivity is close to that of foam insulation.

Table 8.3.6 Electric Water Heater Modeling Differences: 2003 Baseline Model vs. Model with Foamed Bottom Insulation

Descriptive Parameter	2003 Baseline	Foamed Bottom Insulation
support ring conductivity	0.40 Btu/ft·min·°F (41.54 W/m·K)	0.000472 Btu/ft·min·°F (0.0490 W/m·K)
bottom thickness insulation	0.75 in. (1.91 cm)	1.5 in. (3.8 cm)
bottom insul. conductivity	0.000333 Btu/ft·min·°F (0.0346 W/m·K)	0.000240 Btu/ft·min·°F (0.0249 W/m·K)

Note: Units in the table are consistent with these used by WATSIM.

8.3.2.5 Plastic Tank

There are at least two methods for constructing plastic water heater tanks. One method uses a seamless, blow-molded polybutylene inner tank with a filament-wound fiberglass outer tank, similar to the method used for fabrication of water softener tanks.[23] A second method consists of constructing a thin steel shell with an internal plastic tank. The steel exterior is constructed first; then, plastic powder is injected into the shell, and the tank is rotated in a furnace to coat the interior with the plastic. The steel exterior serves as the primary structural support for the tank. It is approximately 0.063 in. (1.6 mm) thick; the plastic interior, 0.063 in. to 0.125 in. (1.6 mm to 3.2 mm) thick, provides a non-corrosive surface and some structural support. In both types of plastic tanks, the lower heat conductivity of the plastic compared to steel reduces the amount of heat conducted through the tank wall to the insulation. Both plastic tank construction methods enable improved insulation to the tank bottom, relative to current (metal tank) models. In typical electric water heaters with metal tanks, the metal of the tank wall extends below the bottom of the tank and acts as a support ring. This support ring has direct contact with the floor through the bottom jacket and thus provides a path for conduction heat losses to the floor. Because plastic tanks are completely insulated, standby losses from the bottom of the tank are significantly reduced.

This analysis used "steel shell/plastic interior"style tanks because they are the least expensive to manufacture. In modeling this plastic tank type with WATSIM, we used tank wall thickness and conductivity appropriate to plastic. (The conductivity of the plastic/steel composition at the thicknesses described above is virtually identical to plastic.) In addition, the support ring material was changed from steel to foam insulation, and bottom insulation was increased to match the thickness of the jacket insulation. Table 8.3.7 summarizes the changes made to the 2003 baseline model to simulate the performance of a plastic tank.

Table 8.3.7 Electric Water Heater Modeling Plastic Tank

Descriptive Parameter	2003 Baseline	2003 Baseline w/ Plastic Tank
tank wall thickness	0.063 in. (0.16 cm)	steel 0.0853 in. (0.16 cm) plastic 0.126 in. (0.32 cm)
wall conductivity	0.40 Btu/ft·min·°F (41.54 W/m·K)	0.0018 Btu/ft·min·°F (0.1869 W/m·K)
support ring conductivity	0.40 Btu/ft·min·°F (41.54 W/m·K)	0.000240 Btu/ft·min·°F (0.024507 W/m·K)
bottom insulation conductivity	0.000333 Btu/ft·min·°F (41.54 W/m·K)	0.000240 Btu/ft·min·°F (0.024507 W/m·K)
jacket insulation conductivity	0.000333 Btu/ft·min·°F (0.0346 W/m·K)	0.000240 Btu/ft·min·°F (0.0249 W/m·K)

Note: Units in the table are consistent with the units used WATSIM.

8.3.3 Manufacturer Costs

Manufacturer cost estimates are for production of a 50-gallon (190-liter) electric water heater and are disaggregated into variable (material, labor, transportation, overhead) and fixed (capital, product design) costs. Variable and fixed costs are defined on a per-unit basis and expressed as an incremental increase over the existing baseline design. Costs were derived primarily from data provided by GAMA[24] with the exception of costs for bottom insulation and plastic tank design, which were provided by an independent consultant.[25]

8.3.3.1 Existing Baseline Model

Cost estimates for the existing baseline model—a water heater with 1.5 in. (3.8 cm) of foamed jacket insulation using HCFC-141b as a blowing agent—were supplied by GAMA. We calculate the amount and cost of materials associated with other thicknesses of HCFC-141b insulation. The material costs associated with a particular level of insulation can easily be determined by either subtracting from or adding to GAMA's baseline costs. Table 8.3.8 summarizes the material costs associated with varying levels of foam insulation blown with HCFC-141b. The material costs for the HCFC-141b foam insulation ($1/lb or $2.2/kg) and sheet metal ($0.30/lb or $0.66/kg) are based on estimates by an independent consultant.[26]

Table 8.3.8 Electric Water Heater Material Costs with Varying Thicknesses of HCFC-141b Foam Insulation

Polyurethane Foam HCFC-141b				Jacket Sheet Metal				Misc	Total
Thickness	Volume	Weight*	Cost†	Area	Volume	Weight‡	Cost§	Cost¶	Cost
in. (cm)	*ft³ (m³)*	*lb (kg)*	*$*	*ft² (m²)*	*ft³ (m³)*	*lb (kg)*	*$*	*$*	*$*
1.0 (2.5)	1.83 (0.05)	3.65 (1.66)	3.65	23.99 (2.23)	0.038 (0.001)	18.57 (8.42)	5.57	0.00	9.23
1.5 (3.8)	2.84 (0.08)	5.68 (2.58)	5.68	25.66 (2.38)	0.041 (0.001)	19.87 (9.01)	5.96	0.00	11.64
2.0 (5.1)	3.92 (0.11)	7.84 (3.56)	7.84	27.37 (2.54)	0.043 (0.001)	21.19 (9.61)	6.35	5.67	19.86
2.5 (6.4)	5.07 (0.14)	10.14 (4.60)	10.14	29.12 (2.71)	0.046 (0.001)	22.54 (10.22)	6.76	8.04	24.94
3.0 (7.6)	6.29 (0.18)	12.59 (5.71)	12.59	30.90 (2.87)	0.049 (0.001)	23.92 (10.85)	7.18	11.59	31.35

* Foam density = 2 lb/ft³ (32 kg/m³)

† Foam cost = $1/lb ($2.2/kg)

‡ Sheet metal density = 489 lb/ft³ (7833 kg/m³)

§ Sheet metal cost = $0.30/lb ($0.66/kg)

¶ Miscellaneous cost includes additional cost for dams to contain the insulation in a larger cavity during foaming.

8.3.3.2 2003 Baseline Model

To convert the baseline manufacturer costs associated with foam insulation blown with HCFC-141b to insulation blown with HFC-245fa, we estimated the amount and cost of materials associated with varying thicknesses of insulation. These costs were added to the baseline costs and are shown in Table 8.3.10, which summarizes the material costs associated with varying levels of insulation. Table 8.3.9 shows the calculation of the total foam cost for HFC-141b and HFC-245fa[27] insulation, based on component cost estimates.

Table 8.3.9 Foam Components Cost Estimate

Foam Components	Fraction (in foam)	Component Cost	Total Cost (141b)	Total Cost (245fa)
	%	*$/lb*	*$/lb*	*$/lb*
HCFC-141b	13.00	1.50	0.20	–
HFC-245fa*	13.00	4.00	–	0.52
Isocyanurate	51.00	0.75	0.38	0.38
Polyols	31.00	0.65	0.20	0.20
Catalysts, refractants, etc.	5.00	4.50	0.23	0.23
Total	100.00		1.00	1.32

*Source: Allied Signal

Table 8.3.10 Electric Water Heater Material Costs with Varying Thicknesses of HFC-245fa Foam Insulation

Polyurethane Foam 245fa				Jacket Sheet Metal				Misc	Total
Thickness	Volume	Weight	Cost	Area	Volume	Weight	Cost	Cost	Cost
in. cm	*ft^3 m^3*	*lb kg*	*$*	*ft^2 m^2*	*ft^3 m^3*	*lb kg*	*$*	*$*	*$*
1.0 (2.5)	1.83 (0.05)	3.65 (1.66)	4.82	23.99 (2.23)	0.038 (0.001)	18.57 (8.42)	5.57	0.00	10.39
1.55 (3.94)*	2.95 (0.08)	5.90 (2.68)	7.78	25.84 (2.40)	0.041 (0.001)	20.00 (9.07)	6.00	0.00	13.78
2.0 (5.1)	3.92 (0.11)	7.84 (3.56)	10.35	27.37 (2.54)	0.043 (0.001)	21.19 (9.61)	6.35	5.67	22.37
2.5 (6.4)	5.07 (0.14)	10.14 (4.60)	13.39	29.12 (2.71)	0.046 (0.001)	22.54 (10.22)	6.76	8.04	28.19
3.0 (7.6)	6.29 (0.18)	12.59 (5.71)	16.61	30.90 (2.87)	0.049 (0.001)	23.92 (10.85)	7.18	11.59	35.38

* Thickness increased due to increased conductivity of 245fa relative to 141b.

We assume that manufacturers will maintain the level of thermal resistance for their baseline model when switching from HCFC-141b to HFC-245fa foam insulation. Therefore, in Table 8.3.10, the actual thickness level for 1.5 in. (3.8 cm) of HFC-245fa foam insulation is assumed to be slightly greater, i.e., 1.55 in. (3.9 cm), than for HCFC-141b because of HFC-245fa's higher conductivity.

Table 8.3.13 presents manufacturer cost estimates for a 50-gallon (190-liter) electric water heater with 1.5 inches (3.8 cm) of HCFC-141b foam insulation and the costs for the same baseline model with HFC-245fa-blown insulation. The material costs for the HFC-245fa baseline model were adjusted upward by the difference in material costs ($2.14) calculated between the HCFC-141b and HFC-245fa models.

Table 8.3.11 Electric Water Heater for Manufacturer Costs Baseline Models

Design	Variable Costs (per unit) Material $	Labor $	Transp $	Overhd $	Total $	Fixed Costs (per unit) Capital $	Product Design $	Total $	Total Mfg Cost $
Baseline w/ 141b - 1.5 in (3.81 cm)	62.16	10.57	10.11	38.89	121.73	0.00	0.00	0.00	121.73
Baseline w/ 245fa - 1.55 in (3.94 cm) Baseline w/	64.30	10.57	10.11	38.89	123.87	0.00	0.00	0.00	123.87

8.3.3.3 Heat Traps

Manufacturer costs for heat traps are based on data provided by GAMA. Data from heat trap manufacturer Perfection, Inc. [28] showed a similar range of material cost for most heat trap designs ($1.70 to $4.00 per set applied to both the supply and draw lines). Heat trap material costs are applicable for the following designs: 1) a 0.75-in. (1.9-cm) by 3-in. (7.6-cm) pipe nipple assembly design sold on the open market which uses a metal nipple with an inserted plastic heat trap assembly (this assembly is used for both supply and draw lines), and 2) a plastic drop-in-tube design used for the supply line and a plastic cartridge heat trap design within a combined outlet and anode rod assembly which is used for the draw line.

Table 8.3.12 summarizes incremental manufacturer costs for incorporating heat traps into an electric water heater. The costs reflect the addition of heat traps to both the supply and draw lines.

Table 8.3.12 Electric Water Heater: Incremental Manufacturer Costs for Heat Traps

Design	Incremental Variable Costs (per unit) Material $	Labor $	Transp $	Overhead $	Total $	Incremental Fixed Costs (per unit) Capital $	Product Design $	Total $	Total Incremental Mfg Cost $
Heat Traps	2.59	0.20	0.00	0.83	3.62	0.00	0.00	0.39	4.01

8.3.3.4 Increased Jacket Insulation

Table 8.3.8 depicts the material costs for varying levels of HFC-141b foam insulation. GAMA variable cost and fixed cost data for jacket insulation include increases from a baseline level of 1.5 in. (3.81 cm) to a thickness of 2.0 in. (5.1 cm) only.

Data provided by a consultant were used to calculate ratios of variable and fixed costs for 2.5-in. and 3-in. insulation. GAMA's costs for upgrading to 2.0-in. (5.1-cm) insulation, modified for HFC-245fa, were multiplied by those ratios to approximate the variable and fixed costs for 2.5-in. (6.4-cm) and 3-in. (7.6-cm) of insulation. Note that the overhead portion of the variable cost for models with 3-in. (7.6 cm) jacket insulation includes 25% additional shipping cost, associated with the less efficient use of the transport capacity resulting from increased water heater size.

Table 8.3.13 summarizes the incremental manufacturer costs for HFC-245fa jacket insulation caused by the increases from a baseline level of 1.5 in. (3.81 cm) to a thickness of 2.0 in. (5.1 cm), 2.5 in. (6.4 cm) and 3.0 in. (7.6 cm).

Table 8.3.13 Electric Water Heater: Incremental Manufacturer Costs for Increased Jacket Insulation

Design	Incremental Variable Cost					Incr. Fixed Costs			Total Incremental Mfg Cost
	Material	Labor	Transp	Overhead	Total	Capital	Produc Design	Total	
	$	$	$	$	$	$	$	$	$
Incr. Insulation - 2.0 in (5.1 cm)	8.59	0.50	1.44	2.26	12.79	–	–	4.61*	17.40
Incr. Insulation - 2.5 in (6.4 cm)	14.41	1.00	2.88	4.52	22.81	–	–	6.92	29.73
Incr. Insulation - 3.0 in (7.6cm)	21.60	1.50	5.40	6.78	35.28	–	–	9.22	44.50

Note: GAMA provided total incremental fixed cost only.

8.3.3.5 Tank Bottom Insulation

Manufacturer costs for insulating tank bottoms are based on data from consultants.[25],[29] Table 8.3.14 summarizes these incremental manufacturing costs.

Table 8.3.14 2003 Electric Water Heater: Incremental Manufacturing Costs for Tank Bottom Insulation

Design	Incremental Variable Costs					Incremental Fixed Costs			Total Incremental Mfg Cost
	Material	Labor	Transp	Overhead	Total	Capital	Product Design	Total	
	$	$	$	$	$	$	$	$	$
Tank Bottom Insulation	2.28	0.12	0.00	0.36	2.76	–	–	1.15	3.91

8.3.3.6 Plastic Tank

Manufacturer costs for a plastic tank electric water heater design are based on data provided by an independent consultant.[25] The plastic tank design fixed costs were provided as the "lump sum" amount required to convert baseline production to the new design; the "lump sum" amount was converted to a per unit cost by amortizing it over a five-year period and dividing it by the assumed baseline model production volume of 40,000 units per year. Table 8.3.15 summarizes the incremental manufacturer costs for switching from a metal to a plastic tank design.

Table 8.3.15 Plastic Tank Design for Electric Water Heaters: Incremental Manufacturer Costs

Design	Incremental Variable Costs					Incremental Fixed Costs			Total
	Material	Labor	Transp	Overhead	Total	Capital	Product Design	Total	Total Incremental Mfg Cost
	$	*$*	*$*	*$*	*$*	*$*	*$*	*$*	*$*
Plastic Tank	5.25	0.80	0.00	3.20	9.25	15.00	3.00	18.00	27.25

8.3.4 Design Option Retail Prices

For purposes of this analysis, retail price is considered to be the cost to the consumer of the water heating equipment only. The cost to the consumer of installing the water heater is not considered to be part of the retail price and is discussed in Section 8.3.5.

The retail price for a baseline 50-gallon (190-liter) electric water heater (with HCFC-141b foam insulation) was determined using information from a large number of retailers, wholesalers, plumbing contractors, and utilities. The price of a water heater is a function of the length of the manufacturer's warranty. The baseline models chosen for this analysis have up to six year warranties. The five- to six-year warranty is the shortest warranty period offered by water heater manufacturers (although a one-year warranty is offered in special cases) and is typically reserved for models produced in large volume (i.e., baseline models). A longer warranty period, in addition to raising the price, suggests the presence of a design feature not normally found in baseline models.

Table 8.3.16 provides the list of retail prices used to generate the markup of the baseline model. For each price listed, the source is also provided. All data presented in Table 8.3.16 are from the Water Heater Price Database, which was developed from information gathered from more than130 contacts from all regions of the U.S. The Database contains information on 1,064 units representing 1,031 models, including retail prices, fees (installation, delivery, etc.), and warranties. Detailed information on the retail cost development is provided in Chapter 5 of this report.

Table 8.3.16 Electric Water Heater Retail Prices

Source Location	Manufacturer	Brand	Model	Retail price $
Denver, CO	State Industries	Reliance	5-52-2ORT	128.00
Atlanta, GA	American Water Heater Company	American	E52-50R-045DV	129.00
Dale City, VA	American Water Heater Company	U.S. Craftmaster	E2F-50R-D045V	133.00
Atlanta, GA	American Water Heater Company	American	E52-50R-045DV	135.00
Stockbridge, GA	American Water Heater Company	American	E52-50R-045DV	138.00
Marietta, GA	American Water Heater Company	American	E52-50R-045DV	138.00
Salem, OR	American Water Heater Company	American	E51-50L-045D	140.00
Ashland, OR	Bradford White	Bradford White	M-I-50S6DS	140.00
Charlotte, NC	American Water Heater Company	American	E52-50R-045DV	141.00
Dallas, TX	State Industries	Reliance	5-52-2ORT	146.00
West Allis, WI	American Water Heater Company	American	E51-50H-045D	147.00
Waterloo, IA	American Water Heater Company	American	E52-50R-045DV	148.00
Chicago, IL	American Water Heater Company	American	E52-50R-045DV	148.00
Minneapolis, MN	American Water Heater Company	American	E52-50R-045DV	148.00
Sw. Jackson, MS	American Water Heater Company	American	E52-50R-045DV	149.00
Lexington, KY	American Water Heater Company	American	E52-50R-045DV	149.00
New Orleans, LA	American Water Heater Company	American	E52-50R-045DV	149.00
Greenville, IL	A.O. Smith	A.O. Smith	EC-52	152.00
Nashville, TN	American Water Heater Company	American	E52-50R-045DV	157.00
Atlanta, GA	A.O. Smith	A.O. Smith	EES-52D	157.00
Eugene, OR	State Industries	Reliance	5-52-2ORT	160.00
Rapid City, SD	Rheem	Richmond	8V52-2	160.00
St Louis, MO	American Water Heater Company	American	E52-50R-045DV	160.00
Naples, FL	A.O. Smith	A.O. Smith	EC-52D	165.00
Denver, CO	State Industries	Reliance	5-52-2ORT	168.00
Salt Lake City, UT	American Water Heater Company	American	E52-50R-045DV	168.00
Reno, NV	American Water Heater Company	American	E52-50R-045DV	168.00
Ashland, OR	Bradford White	Bradford White	M-I-50S6DS	168.00
Richmond, CA	State Industries	Sears / Kenmore	31256	170.00
South Bend, WA	State Industries	Reliance	5-52-2ORT	170.00
Raymond, WA	State Industries	Reliance	5-52-2ORT	170.00

Table 8.3.16 Electric Water Heater Retail Prices —*Cont.*

Source Location	Manufacturer	Brand	Model	Retail price $
Raymond, WA	State Industries	Reliance	5-52-2ORT	170.00
Harrisonburg, VA	State Industries	State	CD5-52-2ORT	170.00
Cary, NC	A.O. Smith	A.O. Smith	EES-52	171.00
Amarillo, TX	American Water Heater Company	American	E52-50R-045DV	171.59
Naples, FL	A.O. Smith	A.O. Smith	EES-52D	171.60
Sacramento, CA	American Water Heater Company	American	E52-50R-045DV	172.00
Seattle, WA	State Industries	Reliance	5-52-2ORT	175.00
Naples, FL	A.O. Smith	A.O. Smith	EESC-52D	175.00
Syracuse, NY	A.O. Smith	A.O. Smith	EEST-52	175.00
Nashville, TN	American Water Heater Company	American	E52-50R-045DV	177.00
Winchester, VA	Rheem	Rheem	81V52D	177.60
Phoenix, AZ	State Industries	Reliance	5-52-2ORT	179.00
Las Vegas, NV	State Industries	Reliance	5-52-2ORT	179.00
Cary, NC	Rheem	Rheem	81V52D	179.56
Fredericksburg, VA	State Industries	State	CD5-52-2ORT	179.95
Rapid City, SD	Rheem	Richmond	8V52-2	179.98
Corpus Christi, TX	Rheem	Rheem	81V52	180.00
Jacksonville, FL	A.O. Smith	A.O. Smith	EES-52	181.58
Boise, ID	State Industries	Reliance	5-52-2KRT	183.00
Boise, ID	State Industries	Reliance	5-52-2ORT	184.00
Tipton, OK	A.O. Smith	A.O. Smith	EES-52	185.00
Oklahoma City, OK	State Industries	Reliance	5-52-2ORT	187.00
St Louis, MO	American Water Heater Company	American	E52-50R-045DV	189.00
Benton, MT	State Industries	Reliance	5-52-2ORS	189.99
Boston, MA	State Industries	Sears / Kenmore	31256	190.00
Parkersburg, WV	A.O. Smith	A.O. Smith	EES-52	190.80
Charlotte, NC	American Water Heater Company	U.S. Craftmaster	E2F-50R-D045V	191.00
Ashland, OR	Bradford White	Bradford White	M-I-50S6DS	191.88
Rapid City, SD	Rheem	Richmond	8V52-2	192.13
Indianapolis, IN	State Industries	State	CD5-52-2ORT	196.50
Salt Lake City, UT	American Water Heater Company	American	E52-50R-045DV	198.00
Ashland, OR	Bradford White	Bradford White	M-I-50S6DS	199.00
Ashland, OR	Bradford White	Bradford White	M-I-50S6DS	199.00
Livermore, CA	State Industries	Sears / Kenmore	31655	199.99
Boston, MA	State Industries	Sears / Kenmore	31256	200.00
Cary, NC	State Industries	State	CD5-52-2ORT	200.20
Naples, FL	A.O. Smith	A.O. Smith	EEST-52D	202.18
Columbus, NE	A.O. Smith	A.O. Smith	EES-52	204.50
Naples, FL	A.O. Smith	A.O. Smith	ELJC-50D	205.55
Boise, ID	State Industries	Reliance	5-52-2KRT	208.00

Table 8.3.16 Electric Water Heater Retail Prices —*Cont.*

Source Location	Manufacturer	Brand	Model	Retail price $
Cary, NC	Bradford White	Bradford White	M-I-50S6DS	208.00
Syracuse, NY	A.O. Smith	A.O. Smith	ELJF-50	210.00
Talent, OR	Bradford White	Bradford White	M-I-50S6DS	210.60
Naples, FL	A.O. Smith	A.O. Smith	ELJF-50D	212.00
Burton, MI	GSW	John Wood	JW550SDE	216.86
Cleveland, OH	GSW	John Wood	JW550SDE	219.45
Casa Grande, AZ	American Water	American	E52-50R-045DV	221.07
Berkeley, CA	Rheem	Rheem	81V52D	227.00
Talent, OR	Rheem	Rheem	81MVR52D	227.50
Auburn, IL	Rheem	Rheem	6E722	227.93
Anchorage, AK	Bradford White	Bradford White	M-I-50L6DS	230.00
Ashland, OR	Bradford White	Bradford White	M-I-50S6DS	231.30
Tampa, FL	Rheem	Rheem	81V52D	234.36
Massillon, OH	Bradford White	Bradford White	M-I-50S6DS	235.00
Berkeley, CA	Rheem	Rheem	81SV52D	239.00
Jacksonville, FL	Rheem	Rheem	81V52D	240.00
Ashland, OR	Bradford White	Bradford White	M-I-50S6DS	245.00
Ashland, OR	State Industries	Reliance	5-52-2ORT	250.00
Talent, OR	Bradford White	Bradford White	M-I-50S6DS	250.00
Jacksonville, FL	Rheem	Rheem	81SV52D	275.00
Blackwell, OK	A.O. Smith	A.O. Smith	EES-52	276.00
Bristow, VA	Rheem	Rheem	81V52D	281.91
Boise, ID	State Industries	Reliance	5-52-2KRT	297.00
Springfield, VA	A.O. Smith	A.O. Smith	EES-52	306.20
Springfield, VA	Rheem	Rheem	81V52D	385.00
Rapid City, SD	A.O. Smith	A.O. Smith	EES-52	385.00

As shown in Table 8.3.16, the mean retail price for a baseline 50-gallon (190-liter) electric storage water heater is $192.70 (not including tax). The manufacturer cost of an existing baseline water heater is $121.73.[24] Dividing the mean retail price ($192.70) by the manufacturer cost ($121.73) yields a manufacturer cost-to-retail price markup of 1.58. Adding the average national value for tax of 5%[30] yields a retail price of $202.33.

The baseline manufacturer cost-to-retail price markup is assumed to be constant for all design options considered for this analysis. Thus, the retail price for any modified design is simply determined by multiplying the manufacturer cost by the derived markup of 1.58 and adding a 5% sales tax.

8.3.5 Installation and Maintenance Costs

The installation cost is the cost to a consumer of installing a water heater; installation is not considered part of the retail price. The cost of installation covers all labor and material costs associated with the simple replacement of an existing water heater. Delivery, removal, and permit fees are also included.

Installation cost data for the 50-gallon (190-liter) baseline electric water heater came from the Water Heater Price Database. Table 8.3.17 lists these data. The median installation cost is $155.00.

Table 8.3.17 Electric Water Heater Installation Costs

Source	Manufacturer	Brand	Model	Installation *$*
Livermore, CA	State Industries	Sears / Kenmore	31655	15.00
Berkeley, CA	Rheem	Rheem	81SV52D	65.00
Berkeley, CA	Rheem	Rheem	81V52D	65.00
Ashland, OR	Bradford White	Bradford White	M-I-50S6DS	67.50
Anchorage, AK	Bradford White	Bradford White	M-I-50L6DS	90.00
Anchorage, AK	Bradford White	Bradford White	M-I-50S6DS	90.00
Seattle, WA	Bradford White	Bradford White	M-I-50T6DS	100.00
Boise, ID	State Industries	Reliance	5-52-2KRT	114.00
Boise, ID	State Industries	Reliance	5-52-2KRT	114.00
Boise, ID	State Industries	Reliance	5-52-2KRT	114.00
Boise, ID	State Industries	Reliance	5-52-2ORT	114.00
Stockbridge, GA	American Water Heater Company	American	E52-50R-045DV	119.00
Salt Lake City, UT	American Water Heater Company	American	E52-50R-045DV	125.00
Salt Lake City, UT	American Water Heater Company	American	E52-50R-045DV	125.00
Denver, CO	State Industries	Reliance	5-52-2ORT	130.00
Denver, CO	State Industries	Reliance	5-52-2ORT	130.00
Sw. Jackson, MS	American Water Heater Company	American	E52-50R-045DV	135.00
Waterloo, IA	American Water Heater Company	American	E52-50R-045DV	135.00
Phoenix, AZ	State Industries	Reliance	5-52-2ORT	136.00
Casa Grande, AZ	American Water Heater Company	American	E52-50R-045DV	136.00
Atlanta, GA	American Water Heater Company	American	E52-50R-045DV	142.00
Nashville, TN	American Water Heater Company	American	E52-50R-045DV	145.00
Nashville, TN	American Water Heater Company	American	E52-50R-045DV	145.00
Charlotte, NC	American Water Heater Company	American	E52-50R-045DV	145.00
Medford, OR	Bradford White	Bradford White	M-I-50S6DS	148.30
Marietta, GA	American Water Heater Company	American	E52-50R-045DV	149.00
Reno, NV	American Water Heater Company	American	E52-50R-045DV	154.00
Dallas, TX	State Industries	Reliance	5-52-2ORT	155.00
Charlotte, NC	American Water Heater Company	U.S. Craftmaster	E2F-50R-D045V	155.00
West Allis, WI	American Water Heater Company	American	E51-50H-045D	159.00

Table 8.3.17 Electric Water Heater Installation Costs—*Cont.*

Source	Manufacturer	Brand	Model	Installation $
Cary, NC	A.O. Smith	A.O.. Smith	EES-52	159.00
St Louis, MO	American Water Heater Company	American	E52-50R-045DV	160.00
St Louis, MO	American Water Heater Company	American	E52-50R-045DV	160.00
Glendale, AZ	Bradford White	Bradford White	M-I-50T6DS	165.00
Dale City, TX	American Water Heater Company	U.S. Craftmaster	E2F-50R-D045V	169.00
Las Vegas, NV	State Industries	Reliance	5-52-2ORT	170.00
Springfield, VA	Rheem	Rheem	81V52D	170.00
Springfield, VA	A.O. Smith	A.O. Smith	EES-52	170.00
Richmond, CA	State Industries	Sears / Kenmore	31256	174.00
Oklahoma City, OK	State Industries	Reliance	5-52-2ORT	180.00
Naples, FL	A.O. Smith	A.O. Smith	EES-52D	184.00
Ashland, OR	Bradford White	Bradford White	M-I-50S6DS	185.10
Ashland, OR	Bradford White	Bradford White	M-I-50S6DS	189.00
Ashland, OR	Bradford White	Bradford White	M-I-50S6DS	191.00
Ashland, OR	Bradford White	Bradford White	M-I-50S6DS	194.00
Lexington, KY	American Water Heater Company	American	E52-50R-045DV	200.00
Chicago, IL	American Water Heater Company	American	E52-50R-045DV	209.00
Sacramento, CA	American Water Heater Company	American	E52-50R-045DV	210.00
Boston, MA	State Industries	Sears / Kenmore	31256	220.00
Boston, MA	State Industries	Sears / Kenmore	31256	220.00
New Orleans, LA	American Water Heater Company	American	E52-50R-045DV	225.00
Talent, OR	Rheem	Rheem	81MVR52D	230.00
Seattle, WA	State Industries	Reliance	5-52-2ORT	231.00
Atlanta, GA	American Water Heater Company	American	E52-50R-045DV	234.00
Ashland, OR	Bradford White	Bradford White	M-I-50S6DS	249.00
Minneapolis, MN	American Water Heater Company	American	E52-50R-045DV	258.00
Ashland, OR	Bradford White	Bradford White	M-I-50S6DS	269.00

Design options which include 2-, 2.5-, and 3-in. may incur an additional installation cost relative to the baseline. This can occur either when the water heater requires a replacement drain pan of a larger size or it requires the addition of a tempering valve. The analysis recognizes this potential need and incorporates the additional costs in the total installation cost for the affected households.

Some households may require a drain pan replacement of a larger size when a wider water heater (due to increased insulation) is installed under the new standard. The drain pan size is a function of the water heater diameter. Manufacturers recommend that the drain pan diameter be 2 inches larger than the water heater' diameter. We used RECS 97 to identify the households which would need a drain pan. We assumed that houses would use drain pans, if they did not have a slab-on-grade floor, or a garage or an unconditoned basement.

The details of the drain pan replacement approach as well as the development of the associated costs are described in Appendix E-5. In the Engineering Analysis, we use a weighted average cost for each water heater diameter from the LCC Analysis. The following average costs were applied: for water heaters with 2-in. insulation, the drain pan cost is $0.61 and for 2.5- and 3-in. insulation, the drain pan cost is $1.81.

In some households, the original water heater location may be too small to accommodate a replacement water heater of the same rated volume under the new standard, specifically when the water heater insulation thickness is 2.5 or 3 inches. When such space constraints exist, some households are assumed to use the next smaller standard size water heater, and increase the water heater setpoint to compensate for the lower storage volume. If the new setpoint is too high it may require a tempering valve. We used RECS97 to identify which households would have such space constraints. We assumed that such constraints would only exist in cases where:

- the water heater is installed in conditioned space, e.g., not in a garage or an unconditioned basement, and
- the water heater is in a small house or apartment with a floor area of less than 1,000 ft^2.

For households with space constraints, we adjusted the setpoint of the smaller water heater upward so that the total energy content of the water that could be delivered is the same as could have been delivered by the original water heater at a lower temperature, and if the new setpoint is > 140°F, the cost of a tempering valve was added. The details of the space constraint approach as well as the tempering valve costs are described in the Appendix E-5. In the Engineering Analysis, we used a weighted average cost of $15.26 for adding tempering and check valves (when ≥2.5 in. insulation) from the LCC Analysis.

Design options that include 3-in. insulation require an additional cost in some cases to account for the impact on installation cost in replacement applications (e.g., to disassemble and reassemble doorjambs). We have added a $160 installation cost for removal and replacement of door jambs for 50% of all water heaters located in the conditioned space. From the RECS 1997 data, we determined that 54% of water heaters are located in a conditioned space. In the Engineering Analysis, we used the calculated average cost of $43.19 for all design options that include 3-in. insulation.

Information gathered to date suggests that there is virtually no maintenance of residential electric water heaters. Thus, maintenance costs were not included for the baseline model or for the different design options.

8.3.6 Cost-Efficiency Data

The results of the design option analysis for 50-gallon (190-liter) electric water heaters are presented below (see Tables 8.3.18 and 8.3.19). Disaggregated manufacturer costs, retail prices, installation costs, maintenance costs, energy factor, energy use, and payback periods are included in the cost and efficiency tables. Design options were added incrementally to the baseline model in order of shortest payback period.

The existing baseline design with HCFC-141b foam insulation is also presented in the two tables to show the manufacturer cost and retail price differences. For purposes of this analysis, the cost effectiveness of all design options was evaluated relative to the 2003 baseline design. Energy costs are from national average energy prices for the year 2003 from DOE/EIA's *Annual Energy Outlook 2000.*

The results show that, using HFC-245fa as the blowing agent, the highest EF attainable is 0.912, which can be achieved by using heat traps, 3-in. (7.6-cm) jacket insulation, insulated tank bottom, and a plastic tank. The payback period for this design is 9.85 years. Energy savings are 250 kWh/yr. Models incorporating heat traps, 2.5-in. insulation, and tank bottom insulation have an EF of 0.901 and a payback of 5.19 years. This design saves 203 kWh/yr in electricity based on the DOE test procedure.

Figure 8.3.1 depicts the relationship between increased consumer cost and increased operating cost (expressed as a simple payback period) and EF for the selected design options relative to the 2003 baseline.

Table 3.3.20 shows the combinations of selected design options for electric water heaters using HFC-245fa as a blowing agent.

Table 8.3.18 Cost Table for 50-gal (190-liter) Electric Water Heaters

Design No.	Design Options	Incremental Variable Costs[1] Mat'l $	Labor $	Transp $	Overhd $	Total Var. $	Incr. Fixed Costs[1] Capital $	Product Design $	Total Fixed $	Total Mfg Cost $	Mfg to Retail Markup	Retail Price[2] $	Install. Cost $	Maint. Cost $
00	Existing Baseline	62.16	10.57	10.11	38.89	121.73	–	–	0.00	121.73	1.66	202.33	155.00	0.00
0	2003 Baseline	2.14	0.00	–	–	2.14	–	–	0.00	123.87	1.66	205.89	155.00	0.00
1	Heat Traps	2.59	0.19	–	0.82	3.60	0.15	0.24	0.39	127.86	1.66	212.52	155.00	0.00
2	Tank Bottom Insul.	4.87	0.31	–	1.18	6.36	–	–	1.54	131.77	1.66	219.03	155.00	0.00
3	2" Insulation	13.54	0.81	1.44	3.44	19.23	–	–	6.15	149.25	1.66	248.08	155.61	0.00
4	Plastic Tank	19.36	1.31	2.88	5.70	29.25	–	–	8.46	161.58	1.66	268.57	172.07	0.00
5	2.5" Insulation	22.25	1.99	2.88	8.54	35.66	–	–	25.31	184.84	1.66	307.22	172.07	0.00
6	3" Insulation	29.44	2.49	5.40	10.80	48.13	–	–	27.61	199.61	1.66	331.78	215.26	0.00

[1] Incremental variable and fixed costs are per unit costs.

[2] Retail prices are calculated based on a manufacturer to retail markup of 1.6621. An additional sales tax of 5% is applied.

Table 8.3.19 Efficiency Table for 50-gal (190-liter) Electric Water Heaters

Design No.	Design Options	Energy Factor	Recov. Effic. %	UA	Energy Use Daily *kWh/day*	Energy Use Yearly *kWh/yr*	Payback Period[1] *years*
00	Existing Baseline	0.8600	98	3.64	13.583	4958	NA
0	2003 Baseline	0.8601	98	3.64	13.582	4958	NA
1	Heat Traps	0.8719	98	3.27	13.422	4899	1.51
2	Tank Bottom Insul.	0.8767	98	3.10	13.355	4875	2.10
3	2" Insulation	0.8900	98	2.67	13.168	4807	3.75
4	Plastic Tank	0.9012	98	2.32	13.025	4754	5.19
5	2.5" Insulation	0.9039	98	2.22	12.998	4744	7.35
6	3" Insulation	0.9118	98	1.98	12.897	4708	9.85

[1] Annual operating cost for payback period calculation established with an electricity price of 0.0756 $/kWh in 1998$.

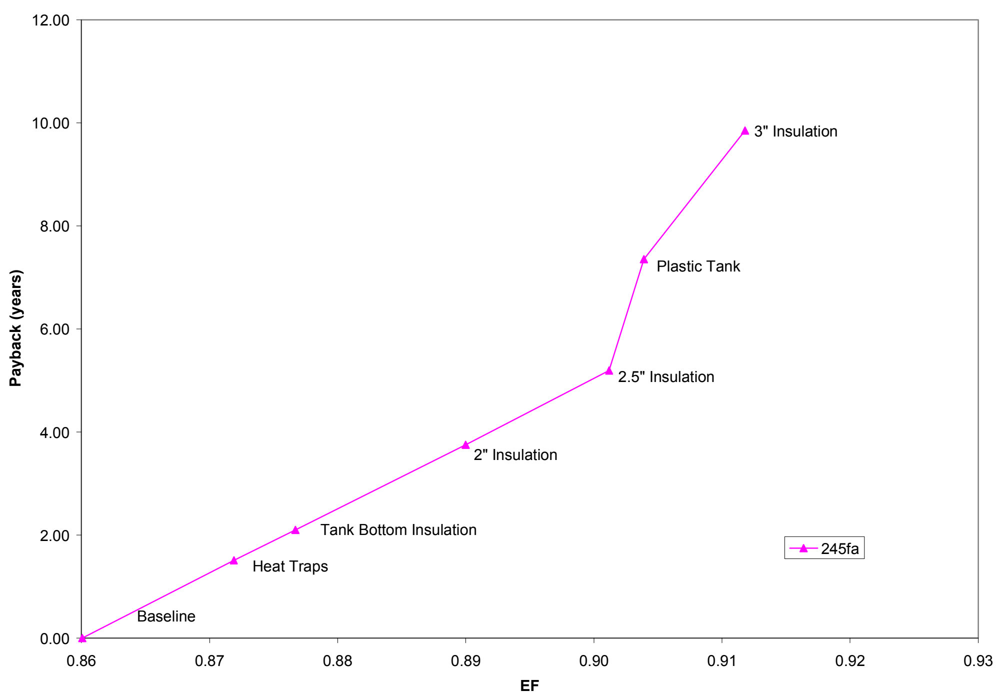

Figure 8.3.1 Payback Period vs. Energy Factor: Electric Water heaters, 50-gal (190-lit)

Table 8.3.20 Definition of Design Options—Electric Water Heaters: HFC-245fa

	Short Name	Full Description
00	Existing Baseline	Baseline (141b)
0	2003 Baseline	Baseline (245fa)
1	Heat Traps	2003 Baseline + Heat Traps
2	Tank Bottom Insulation	2003 Baseline + Heat Traps + Tank Bottom Insulation
3	2" Insulation	2003 Baseline + Heat Traps + Tank Bottom Insulation + 2" Insulation
4	2.5" Insulation	2003 Baseline + Heat Traps + Tank Bottom Insulation + 2.5" Insulation
5	Plastic Tank	2003 Baseline + Heat Traps + 2.5" Insulation + Plastic Tank
6	3" Insulation	2003 Baseline + Heat Traps + 3" Insulation + Plastic Tank

8.4 GAS-FIRED WATER HEATERS

The engineering analysis models energy-efficiency design options for gas-fired water heaters using TANK, a computer simulation model for water heaters developed by Battelle for the GRI.[17] A 40-gallon (150-liter) rated volume gas-fired water heater is used as the baseline model for this analysis.

8.4.1 Existing Baseline Model

The baseline model for this analysis is a 40-gallon (150-liter) gas-fired water heater with HCFC-141b foam insulation, an EF of 0.54 (the minimum EF allowed by NAECA for a 40-gallon gas-fired water heater) and a RE close to 76%.

GAMA directory of certified water heaters[3] and product literature from various manufacturers, reveal that models of 40-gallon (150-liter) gas-fired water heaters achieved 0.54 EFs through the use of 1-in. (2.5-cm) foam insulation only; heat traps were not necessary. Rated input varied from 34,000 to 40,000 Btu/hr (10,000 to 11,700 W). Preliminary simulation work showed that EFs close to 0.54 could only be achieved with input ratings of 40,000 Btu/hr (11,700 W) and flue diameters of 4 in. (10.2 cm). Thus, the baseline model used here has an input rating of 40,000 Btu/hr (11,700 W), a flue diameter of 4 in. (10.2 cm), 1 in. (2.5 cm) of foam insulation, and no heat traps.

We consulted Battelle in developing the baseline model because they had also conducted simulations to characterize baseline gas-fired water heaters. Battelle's initial results were presented to a meeting of GRI's Water Heater Technical Advisory Group (TAG) in November, 1997[31] and are depicted in Table 8.4.1. Battelle's specifications are nearly identical to ours. Battelle's measurements revealed that insulation thicknesses in gas-fired water heaters are actually slightly less than the nominal values (e.g., a "1-in." nominal thickness is actually 0.981 in. (2.492 cm)). The same is true for the flue diameter (e.g., a "4-in." nominal flue diameter represents an actual internal diameter of 3.84 in. (9.75 cm)).

Table 8.4.1 Battelle Baseline Model Characteristics

Parameter	Value
Input Rating	39630 Btu/hr (11614 W)
Pilot Input	450 Btu/hr (117 W)
Excess Combustion Air (%)	40.90
Pressurized Tank Dimensions	
Inside Diameter	15.84 in. (40.23 cm)
Steel Wall Thickness	0.08 in. (0.20 cm)
Height	47.6 in. (120.9 cm)
Volume	38.0 gallons (143.8 liter)
Jacket Description	
Foam insulation thickness	0.981 in. (2.492 cm)
Sheet metal thickness	0.019 in. (0.483 mm)
Thermal conductivity of foamed assembly	0.0155 Btu/hr·ft·°F (0.0268 W/m·K)
Off-cycle pressure loss coefficient	13.0042
Flue baffle effectiveness multiplier	1.896
Flue diameter	3.84 in. (9.75 cm)
Recovery efficiency (RE) (%)	75.0
Energy factor (EF)	0.54

From discussions with Battelle we learned that three input variables: excess combustion air, flue baffle effectiveness multiplier, and off-cycle pressure loss coefficient, were varied in an attempt to achieve both an EF of 0.54 and an RE of 76%. By varying the three input variables, Battelle achieved an EF of 0.54 but an RE of only 75%.

Because Battelle's baseline specifications do not result in an RE of 76% we performed additional simulations to try to develop an EF of 0.54 and an RE of 76%. Feed-through losses were kept the same for gas-fired water heaters as for electric. In addition, the same conductivities were specified for the jacket insulation for both gas and electric water heaters.

The excess combustion air, flue baffle effectiveness multiplier, and off-cycle pressure loss coefficient cannot be varied independently to achieve the desired EF and RE values. The off-cycle pressure loss coefficient can be expressed as a function of both the flue baffle effectiveness multiplier and excess combustion air. The EF and RE can also be expressed as functions of the flue baffle effectiveness multiplier and excess combustion air (for a given set of input characteristics). Figure 8.4.1 depicts the variations in EF and RE with excess combustion air and flue baffle effectiveness multiplier. As Figure 8.4.1 demonstrates, EFs of 0.54 and REs of 76% occur with different sets of excess combustion air and flue baffle effectiveness multiplier values.

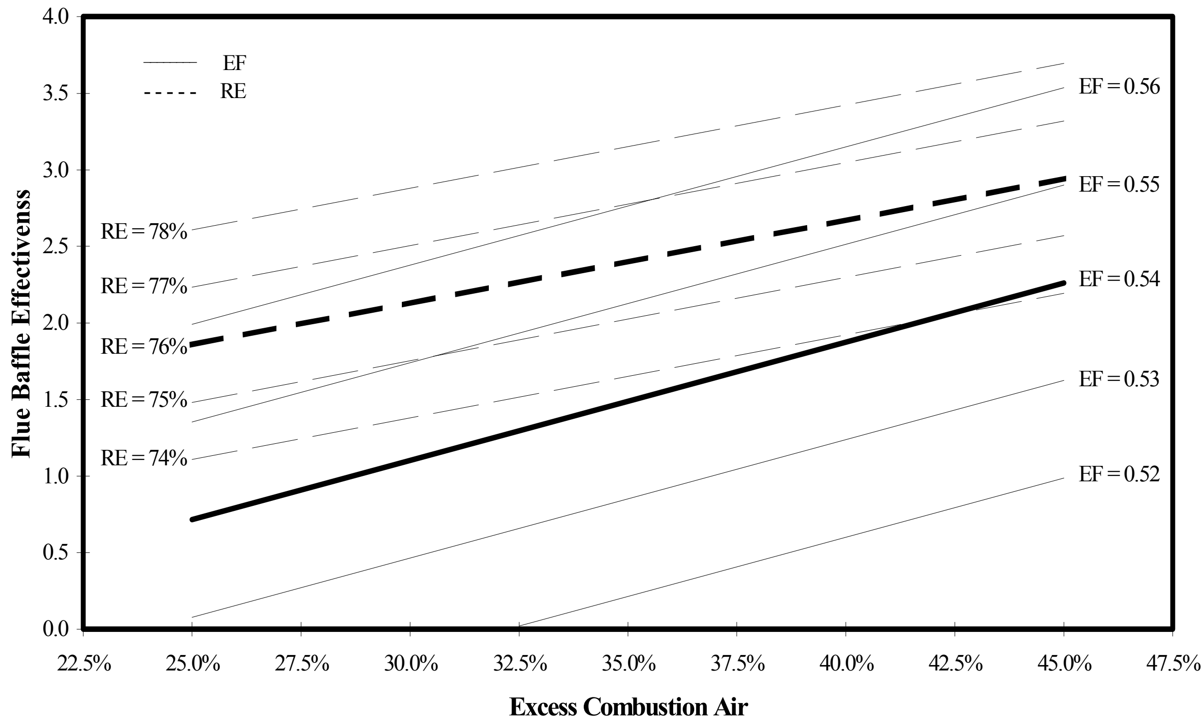

Figure 8.4.1 Energy Factor and Recovery Efficiency vs. Flue Baffle Effectiveness and Excess Combustion Air

We investigated other TANK input variables to see if changing them would increase RE (without significantly impacting EF) or decrease EF (without significantly impacting RE). Table 8.4.2 shows the input variables investigated. The acceptable range provided for combustion chamber inner wall thickness; flue wall thickness; flue baffle thickness; thermostat R-value; skirt insulation; and tank, flue, and flue baffle emissivities were based on reasonable values for these variables. The off-cycle pressure loss coefficient is not provided in Table 8.4.2 because it is dependent on flue baffle effectiveness and excess combustion air and is calculated by TANK.

Table 8.4.2. TANK Input Variables: Approximate Impact on EF and RE

Input Variable	TANK Default	Acceptable Range	Impact on EF and RE
Flue Baffle Effectiveness	1.896	1.2 - 2.0	Increase causes increased EF and RE
Excess Combustion Air	32%	25% - 70%	Increase causes decreased EF and RE
Pressure Vessel Wall Thickness - *in (cm)*	0.08 (0.20)	> 0.05 (> 0.13)	Decrease causes small RE incr., small EF decreased
Combustion Chamber Height - *in (cm)*	8.5 (21.6)	7.5-9.5 (19.1-24.1)	Decrease causes increased RE; low impact on EF
Comb. Chamber Inner Wall Thick. - *in (cm)*	0.04 (0.10)	> 0.03 (>0.08)	Decrease causes increased RE; low impact on EF
Multiplier for Dome-Shaped Comb. Chamber	1.15	1.00 - 1.30	Increase causes increased EF and RE; larger RE incr
Flue Wall Thickness - *in (cm)*	0.08 (0.20)	> 0.05 (>0.13)	Increase causes small RE incr.; no impact on EF
Flue Baffle Thickness - *in (cm)*	0.063 (0.16)	> 0.04 (> 0.10)	Increase causes increased RE; low impact on EF
R-value T'stat Fitting - *hr·ft² ·°F/Btu (K·m2/W)*	0.10 (0.02)	0.05-0.10 (0.01-0.02)	Decrease causes small EF decrease; no impact on RE
Skirt Insul. Conduct - *Btu/hr-ft-°F (W/m2·K)*	0.03 (0.05)	0.02-0.04 (0.03-0.07)	Increase causes decreased EF and RE; larger EF decrease
Emissivity for Tank, Flue, and Flue Baffle	0.95	< 0.97	Decrease causes decreased EF & RE; larger RE decrease

Starting with a flue baffle effectiveness (2.0) and excess combustion air value (40%) that yielded an EF close to 0.54 and as high an RE as possible, we adjusted the above input variables in an attempt to increase RE to 76% without significantly increasing EF. To realize an EF and an RE within a half a percentage point of the desired values some of the input variables had to be set beyond their acceptable ranges. Table 8.4.3 shows the input values used to arrive at acceptable EF and RE values. Input values in Table 8.4.3 appearing in bold font (combustion chamber height, combustion chamber inner wall thickness, flue baffle thickness, and skirt insulation conductivity) were the only variables set beyond acceptable limits; none was significantly outside the acceptable range. Although these parameters may not match the physical characteristics of actual water heaters, they allow the model to simulate the desired level of EF and RE.

Table 8.4.3 TANK Input Values Yielding Acceptable EF and RE

Input Variable	Value Used	Acceptable Range
Flue Baffle Effectiveness	2.0	1.2 - 2.0
Excess Combustion Air	40.9%	25% - 70%
Pressure Vessel Wall Thickness - *in. (cm)*	0.054 (0.137)	> 0.05 (> 0.13)
Combustion Chamber Height - *in. (cm)*	**6.5 (16.5)**	7.5 - 9.5 (19.1 - 24.1)
Comb. Chamb. Inner Wall Thick. - *in. (cm)*	**0.01 (0.025)**	> 0.03 (> 0.08)
Multiplier for Dome-Shaped Comb. Chamber	1.25	1.00 - 1.30
Flue Wall Thickness - *in. (cm)*	**0.05 (0.13)**	> 0.05 (> 0.13)
Flue Baffle Thickness - *in. (cm)*	0.03 (0.076)	> 0.04 (> 0.10)
R-value for Thermostat Fitting - $hr{\cdot}ft^2{\cdot}°F/Btu$ $(K{\cdot}m^2/W)$	0.05 (0.01)	0.05 - 0.10 (0.01 - 0.02)
Skirt Insulation Conductivity - *Btu/hr·ft·°F (W/m·K)*	**0.042 (0.073)**	0.02 - 0.04 (0.03 - 0.07)
Emissivity for Tank, Flue, and Flue Baffle	0.95	< 0.97

Note: Values in bold are outside acceptable range.

The input variables in Table 8.4.3 yielded EF of 0.5436 and an RE of 75.71%. Table 8.4.4 summarizes the primary baseline characteristics. Note that the conductivity of the jacket insulation was changed from the TANK default value to match the foam conductivity test results and to account for the insulation conductivity derating due to variations encountered during manufacturing. It also matches the foam conductivity value used in the baseline electric water heater model. The values in Table 8.4.4 describe the baseline gas-fired water heaters in the engineering terms used by the TANK program.

Table 8.4.4 Gas-Fired Water Heater Baseline Model Characteristics

Descriptive parameter	Value
Input Rating	40000 Btu/hr (11723 W)
Pilot Input	450 Btu/hr (117 W)
On-cycle power consumption	0.0 W
Off-cycle power consumption	0.0 W
Excess Combustion Air	40.9 (%)
Off-cycle pressure loss coefficient	12.5800
Flue baffle effectiveness multiplier	2.000
Natural Gas -- Higher Heating Value	1028 Btu/scf (38302 kJ/m^3)
Pressurized Tank Dimensions	
Inside Diameter	15.84 in. (40.23 cm)
Steel Wall Thickness	0.054 in. (0.1372 cm)
Height	47.6 in. (120.9 cm)
Volume	38.0 gallons (143.8 liter)
Jacket Description	
Foam insulation thickness	0.981 in. (2.492 cm)
Sheet metal thickness	0.019 in. (0.0483 cm)
Thermal conductivity of foamed assembly	0.0140 Btu/hr·ft·°F (0.0242 W/m·K)
Outer Jacket Emissivity	0.92
Flue Description	
Internal Diameter	3.84 in. (9.75 cm)
Area Fraction for Upflow	0.066
Flue Wall Thickness	0.050 in. (0.127 cm)
Flue Baffle Emissivity	0.95
Flue Baffle Thickness	0.030 in. (0.0762 cm)
Combustion Chamber Description	
Skirt Insulation Thermal Conductivity	0.042 Btu/hr·ft·°F (0.073 W/m·K)
Chamber Height	6.5 in. (16.5 cm)
Chamber Inner Wall Thickness	0.010 in. (0.0254 cm)
Flame Radiation View Factor to Skirt	0.2
Distance between Burner and Flue Entrance	4.00 in. (10.16 cm)
Dome Heat Transfer Area Multiplier	1.25
Pipes and Fittings	
Heat Traps (0 = none, -1 = plastic)	0
Supply and Draw Pipe Inside Diameter	0.785 in. (1.994 cm)
Pressure Relief Valve Exposed Area	18.0 in^2 (116.1 cm^2)
Drain Valve Exposed Area	9.0 in^2 (58.1 cm^2)
Thermostat Exposed Area	9.0 in^2 (58.1 cm^2)
Anode Rod Fittings Exposed Area	0.0 in^2 (0.0 cm^2)
Volume to Thermostat	4.05 gallons (15.33 liter)

8.4.2 Modeling Design Options

The following seven design options to improve the efficiency of gas-fired water heaters were considered:

- heat traps
- increased jacket insulation
- improved flue baffle
- electronic ignition
- electro-mechanical flue damper
- side arm heater
- plastic tank

Each design option is discussed briefly below along with the technique used to model it with TANK. The discussion begins with analysis of the 2003 baseline model HFC-245fa.

TANK determines pressure loss coefficients based on a water heater's characteristics. Although the pressure loss coefficient is primarily dependent on the excess combustion air and flue baffle effectiveness multiplier, any water heater characteristic can affect the off-cycle pressure loss coefficient. Thus, before a TANK simulation run was conducted for a design option, the off-cycle pressure loss coefficient was determined with TANK based on the water heater characteristics. After the off-cycle pressure loss coefficient was established, it was specified as one of the water heater's characteristics and TANK was used to model the water heater's performance. Some design options, such as heat traps and increased jacket insulation, had little impact on the off-cycle pressure loss coefficient; the improved flue baffle design option had a significant effect, however.

Because TANK is not able to model side arm heaters, the WHAM energy calculation method was used to estimate the efficiency improvement of this design option.

8.4.2.1 2003 Baseline

As discussed above in Chapter 3.4, the blowing agent HFC-245fa has a 3.0% higher conductivity than HCFC-141b, which is currently used. To compensate for increased conductivity, we increased the thickness of the HFC-245fa insulation. The conductivity value of the foam insulation in the baseline model listed in Table 8.4.4 was increased to a value of 0.0144 Btu/hr·ft·°F (0.0249 W/m·K) to match the conductivity of HFC-245fa insulation . In addition, the thickness of the foam insulation surrounding the tank was increased from 0.981 in. (2.492 cm) to 1.00 in. (2.54 cm) to compensate for the HFC-245fa based insulation's increased conductivity. This increase in insulation thickness also caused an increase of jacket sheet metal material.

Table 8.4.5 summarizes the changes to the existing baseline model with HCFC-141b in order to match its performance with the 2003 baseline model.

Table 8.4.5 Baseline Gas-Fired Water Heater Models—Jacket Insulation Characteristics

Descriptive Parameter	Baseline w/ HFC-141b	Baseline w/ 245fa
Insulation thickness	0.981 in. (2.492 cm)	1.00 in. (2.54 cm)
Insulation conductivity	0.0140 Btu/hr·ft·°F (0.0242 W/m·K)	0.0144 Btu/hr·ft·°F (0.0249 W/m·K)

8.4.2.2 Heat Traps

Heat traps were analyzed for gas-fired water heaters. TANK simulates the performance of two heat trap designs called metal heat traps and plastic heat traps. A research project funded by GRI provided measured data, which were used by GRI to develop an analytical model to calculate the impact of these two heat trap designs.[32] The program provides an option of designating the presence of heat traps with a value of "1" for metal heat traps or "-1" for plastic heat traps. Both prevent the losses associated with the circulation of hot water into the plumbing when hot water is not being drawn. Based on efficiency data provided by GAMA[24] and from one of the water heater manufacturers [33], we determined that the energy factor impact of the heat trap' presence is best described by the plastic heat trap design.

8.4.2.3 Increased Jacket Insulation

Most gas-fired water heaters on the market today have at least 1 inch (2.5-cm) thick polyurethane foam insulation; some manufacturers provide 2 or 2.5 inch (5.1-or 6.4-cm) thick insulation. Although increasing insulation thickness reduces standby losses, the increase in water heater diameter may pose installation problems. Shipping costs will also increase because fewer water heaters will fit in a truck. Because of these potential problems, we did not consider insulation thicker than 3 in. (7.6 cm) for this analysis.

Table 8.4.6 summarizes the changes made to the 2003 baseline model to simulate the performance of a gas-fired water heater insulated with 2-, 2.5-, and 3-in. (5.1 cm, 6.4-cm, and 7.6-cm) foam insulation blown with HFC-245fa.

Table 8.4.6 Gas-Fired Water Heater Modeling Baseline, 2, 2.5, & 3 inch Foam Insulation

Descriptive Parameter		245fa 2003 Baseline	With 2-in. Foam Insulation	With 2.5-in. Foam Insulation	With 3-in. Foam Insulation
tank insulation	top:	1.00 in. (2.56 cm)	2.00 in. (5.08 cm)	2.50 in. (6.35 cm)	3.00 in. (7.62 cm)
thickness	side:	1.00 in. (2.56 cm)	2.00 in. (5.08 cm)	2.50 in. (6.35 cm)	3.00 in. (7.62 cm)

8.4.2.4 Improved Flue Baffle

The standard flue baffle is a twisted strip of metal inserted into the flue. It increases the turbulence of flue gases and improves heat transfer to the flue walls. The geometry of the flue baffle can be modified to increase its effectiveness.

A research project funded by GRI reviewed technical literature, manufacturers' literature, and patents to determine what new technologies are applicable to heat exchangers that involve flue gases from combustion of natural gas.[34] The project concluded that significant increases in convective heat-transfer coefficient could be achieved with the use of heat transfer enhancement devices. The study suggested that, in some cases, an increase in heat-transfer coefficient might be accompanied by an increase in pressure drop (because of an increase in friction factor). The study identified twisted-tape inserts as a potential heat transfer enhancement device for water heaters.

The burner in a fuel-fired water heater is placed below the storage tank, and the flue extends up through the center of the tank to a draft hood. Combustion products enter the flue tube at a very high temperature (approximately 2,300˚F (1,260°C)) and transfer heat by convection and radiation to the tube wall and then by conduction to the water. A baffle, such as a flat plate, inserted in the flue, increases heat transfer from the hot combustion products to the flue wall. The increase in heat transfer is even greater when a twisted baffle is inserted in the flue way of a water heater. The twisted baffle augments convective heat transfer from the flue gases to wall surfaces. In addition, the hot baffle transfers heat to the water-tube walls by radiation.

Beckermann and Goldschmidt [35] investigated, experimentally and empirically, the effects on overall heat transfer (conduction, convection and radiation) of the velocity of flue gases, the twist (i.e., number of turns) of the baffle, and the surface emissivities in a fuel-fired water heater. They reported that, compared to an empty tube, the flue tube with twisted baffle enhances overall heat transfer by as much as 50%.

An improved flue baffle can increase RE from 76% to 78-85%, depending on the specific geometry. (See discussion of impacts of RE levels in Chapter 3.4.) At the upper end of the RE range, a water heater would require power venting or induced draft and corrosion resistant flues for safe operation.

In addition to increasing RE, improved flue baffles also reduce off-cycle standby loss because of restrictions to airflow that result from increased baffling. But because enhanced or increased flue baffling increases pressure drop across the flue, combustion products may have to be forced through the flue with a fan or blower. Releasing combustion products through a horizontal venting system also requires a fan or blower. When the blower forces fresh air into the chamber, the configuration is called a forced draft system. If the blower is located in the flue-gas exit, the configuration is called an induced draft system. In an induced draft system, the blower is exposed to hot and potentially corrosive flue gases and, therefore, should be made of materials that can withstand these conditions.

Using a fan to force flue gases through the baffle with either an induced-draft blower or a forced-draft blower can increase RE and reduce off-cycle flue losses. The increased RE resulting from this design option may necessitate relining or otherwise modifying some venting systems to prevent corrosion or damage from condensation.

Several manufacturers currently make water heaters with induced-draft blowers. However, this feature is usually added to allow sidewall venting and may not be accompanied by any performance improvement due to more effective flue baffling.

Some manufacturers make water heaters with induced draft fans that, in addition to pulling combustion products through the water heater, draw excess air into flue gases prior to venting. The additional air cools the flue gases enough so that plastic piping can be used for venting, which avoids corrosion. Plastic piping is often cheaper and easier to install than sheet metal or masonry chimneys. Although this technique of flue gas dilution does not necessarily increase water heater efficiency, it can, when combined with an improved flue baffle that increases RE, help avoid venting problems.

Design options with REs greater than 80% were not considered in this analysis (see Chapter 3.4). At REs above 80%, flue-loss efficiencies exceed 84%, resulting in flue gas condensation in the flue, which could lead to corrosion and a shortened water heater life unless corrosion resistant materials are used. In this analysis, we considered REs of 78% and 80%. In models with these REs, we assumed that forced- or induced-draft blowers would not be needed to overcome increased pressure drops resulting from the improved baffle system. These REs are achieved using improved flue baffle designs. Discussions with manufacturers confirmed this approach. The manufacturers' literature report water heater models with 80% RE, which is achieved without applying forced ventilation (see A.O.Smith Product Catalog, model PGCG-40, State Industries Product Catalog, PRG-40-NXRT).[36, 37]

Table 8.4.7 summarizes the changes made to the 2003 baseline model to simulate the performance of a gas-fired water heater with an improved flue baffle. In order to model a water heater with an RE of 78% or 80%, we decreased the excess combustion air and increased the flue baffle heat exchanger multiplier accordingly.

Table 8.4.7 2003 Baseline Models vs. Gas Fired Water Heater with Improved Flue Baffle

Descriptive Parameter	2003 Baseline Models	w/ Improved Flue Baffle RE = 78%	w/ Improved Flue Baffle RE = 80%
Excess Combustion Air (%)	40.9	34.0	27.0
Flue baffle effectiveness multiplier	2.0	2.2	2.7

8.4.2.5 Electronic Ignition

The most commonly used ignition system in gas-fired storage water heaters is a standing pilot ignition system. The disadvantage of a standing pilot is that it burns continuously at a rate of approximately 450 Btu/h (154 W); only part of this heat is converted to useful energy. In addition to the standing pilot, three electronic ignition devices are commonly used in gas-fired appliances:

Intermittent pilot ignition. An intermittent pilot ignition device generates a spark to light a pilot, which, in turn, lights the main burner. This design is probably the most acceptable for the water heater manufacturers today because gas controls are available for this type of two stage ignition. The gas safety systems have historically been based on the use of the thermocouple as the safety circuit. Standard 12 VAC gas valves combined with electronic ignition systems used on other products are used in some water heaters. Gas control device suppliers have not developed specialized 110V based electronic nor electro-mechanical controls to support residential water heater ignition systems. Some 110 V based controls are now available for other products.

Electronic ignition devices that generate a spark require an outside electricity source for ignition, usually a 24- or 120-V system. The power draw of the electrically operated gas valve is between 5 W and 12 W, and power is consumed only when there is a call for heat. Electronic ignition systems also require a control module, which houses the electronic control circuitry and consumes 6 W of power when the burner is on. These systems need an electronic thermostat that draws 1.2 W of power during heating periods and 0.4 W of power during standby periods.

Intermittent direct ignition. An intermittent direct ignition device lights the main burner directly by generating a spark. When reliable flame sensors and controls become available, the water heater manufacturers may adopt direct spark ignition. The system then will light the main burner directly with a spark and be checked by a flame sensor.

Hot Surface Ignition. A hot surface ignition (HSI) device lights the main burner directly by generating high surface temperatures. This is a simple, reliable system, which has been used in residential gas clothes dryers for more than 15 years. A hot surface is located near the main burner so it will ignite the gas. The hot surface is typically a resistance device running on 110 VAC. The ignition system starts by applying 110 VAC across the hot surface device. An infra-red or heat sensor is positioned so it will sense the heat from the hot surface igniter or the flame from the burner. When the heat sensor detects the correct temperature it will open the gas valve and shut off the hot surface igniter. The main obstacle to the HSI design acceptance is the requirement of 110 VAC at the water heater.

The HSI is a electric resistance device. It draws about 2.5 amps at 110 V (about 300 W of power) for approximately 30 seconds during ignition.

Unlike standing pilots that consume gas continuously, electric ignition devices operate only at the beginning of each "on"cycle. Although there is no increase in steady-state efficiency with use of electronic ignition devices, overall fuel consumption may be reduced. However, burner "on" time may increase to make up for the heat the standing pilot would have supplied during standby periods.

For this analysis, the only type of non-standing pilot ignition system we analyzed for gas-fired storage water heaters was an intermittent pilot ignition system. Total "on"-cycle power consumption was assumed to be 15.7 W. It includes the power draw of the gas valve, which consumes an average of 8.5 W; the control module, which consumes 6 W; and the electronic thermostat, which draws 1.2 W during a call for heat. The total "off"-cycle power consumption was assumed to be 0.4 W, which is drawn by the electronic thermostat during the standby period. Table 8.4.6 summarizes the changes made to the 2003 baseline models to simulate the performance of an intermittent pilot ignition system.

Table 8.4.8 2003 Baseline Gas-Fired Water Heater vs. Model with Electronic Ignition

Descriptive Parameter	2003 Baseline Models	with Electronic Ignition
Pilot Input	450 Btu/hr (154 W)	0 Btu/hr (0 W)
"On"-cycle power consumption	0.0 W	15.7 W
"Off"-cycle power consumption	0.0 W	0.4 W

8.4.2.6 Flue Damper (Electromechanical)

Gas-fired storage water heaters are equipped with a draft hood connecting the flue to a vent pipe or chimney. During "off"-cycles, a water heater loses heat by natural convection up the flue. A damper can be installed either at the flue exit or in the vent pipe to minimize "off"-cycle heat losses. A flue damper is installed upstream of the draft diverter; the vent damper is installed downstream of the draft diverter.

Electric flue dampers are activated by an external electricity source. The dampers open before combustion starts and close immediately after combustion stops. When the dampers reach the open position, an interlock switch energizes a solenoid and enables the gas ignition circuit. The burner cannot be ignited when the damper is closed. Because the dampers open and close immediately, no bypass is needed. For flue dampers installed on water heaters using a standing pilot, a knockout is provided to vent the pilot's flue gases. In this situation, "off"-cycle losses are greater than in water heating equipment using a non-standing pilot ignition system. The electric flue damper needs a 24-volt electric source and consumes about 5 W when the gas supply is off.

Flue dampers are assumed to have no effect on water heater RE.

For this analysis, we considered, electromechanical flue dampers only in conjunction with electronic ignition systems. Because electricity is required to operate the flue damper, we assumed that the standing pilot would be converted to an electronic ignition system in order to take advantage of the electrical power at the water heater. Flue dampers were modeled according to the procedure outlined in the user's manual for TANK [17]. Typically, TANK calculates the "off"-cycle pressure loss coefficient based on a water heater's physical characteristics. In the case of a flue damper, the "off"-cycle pressure loss coefficient is manually determined based on the following equation:

$$e_{vd} = \frac{1}{(c \cdot f)^2}$$

where:

e_{vd} = the effective pressure loss coefficient of the flue damper,
c = the discharge coefficient of the flue damper, and
f = the fraction of center flue area remaining open after the flue damper has closed, which is calculated using the equation

$$f = \frac{D_f^2 - D_d^2}{D_f^2}$$

where:

D_f = the internal flue diameter, and
D_d = the electromechanical flue damper diameter.

Because a flue damper is usually designed to not completely seal the flue, the percentage of the center flue remaining open after the damper closes is approximately 10%. Discharge coefficients vary from 0.6 for knife-edged damper plates to 1.0 for smooth-edged damper plates. For purposes of this analysis, we assumed a value of 0.8 for the discharge coefficient and a value of 10% for the fraction of the center flue remaining open when we calculated the pressure loss coefficient for a water heater utilizing a flue damper. Table 8.4.9 summarizes the changes made to the 2003 baseline model to simulate the performance of an electromechanical flue damper.

Table 8.4.9 2003 Baseline Model vs. Gas-Fired Water Heater with Electromechanical Flue Damper

Descriptive parameter	2003 Baseline Models	with Electromechanical Flue Damper
"Off"-cycle pressure loss coefficient	12.58	168
"Off"-cycle power consumption	0.0 W	5.0 W

8.4.2.7 Side Arm Heater

The side arm heater design avoids large flue losses by removing the flue from the center of the tank. Water is withdrawn from the bottom of the tank, heated over a burner in a small, separate heat exchanger, and returned to the top of the tank. A small circulation pump moves water through the heat exchanger when the burner is on. The burner could use electronic ignition, reducing the pilot light losses. Auxiliary power is supplied by a low-voltage plug-in transformer. A water heater using this design in combination with electronic ignition and a plastic tank was commercially available until 1998.

The expected EF and RE for a gas-fired water heater with a side arm heater were based on information provided by an independent consultant [25]. Table 8.4.10 provides EF estimates for three types of 40-gallon (150-liter) gas-fired storage water heaters with side arm heaters and metal storage tanks. In addition, three REs were analyzed: 76%, 78%, and 80%. The basic designs incorporate an intermittent pilot ignition device and 1 in. (2.56 cm) of HFC-245fa insulation.

Table 8.4.10 Energy Factor Estimates for Side Arm Gas-Fired Water Heater

Side Arm Water Heater Design	Energy Factors (2003 Baselines)
with 76% RE	0.620
with 78% RE	0.633
with 80% RE	0.646

Because TANK cannot simulate the performance of water heaters equipped with side arm heaters, the WHAM energy calculation method was used. If both the EF and RE are known, WHAM can determine the UA of the water heater and, in turn, its energy consumption. Appendix D-2 provides a detailed explanation of how the WHAM energy calculation method was used to determine the energy consumption of side arm heater designs.

Because side arm heaters require a small circulation pump to move water through their heat exchangers, a total energy input includes the consumption of electrical energy. For this analysis, we assumed that the circulation pump had an "on"-cycle power consumption of 30 W. Daily electrical energy use was determined by modeling the flue damper water heater using TANK and specifying an "on"- and "off"-cycle power consumption equal to those assumed for a side arm heater. Because side arm heaters need electricity to operate, we assumed they would use an intermittent pilot ignition system. For modeling purposes, the "on"-cycle power consumption was assumed to be 45.7 W (30 W for the circulation pump and 15.7 W for the intermittent ignition device) and the "off"-cycle power consumption was assumed to be 0.4 W (for the intermittent ignition device only). Using these assumptions, TANK calculates electrical energy consumption of 80.3 watt-hours.

8.4.2.8 Plastic Tank

The lower heat conductivity of a plastic tank reduces the amount of heat conducted through the tank wall to the insulation. However, plastic tanks cannot be used with standard center-flue gas-fired water heaters because plastic cannot withstand the high temperatures produced by the flames. Therefore, this option was considered only with indirect water heating techniques (e.g., the side arm water heater). As in the case of side arm heater with metal tank, we analyzed designs with REs of 76%, 78%, and 80%.

Because indirect water heating techniques cannot be modeled with TANK, the efficiency benefits of plastic tanks were estimated using WHAM. A side arm heater coupled with a plastic tank insulated with 1 in. (2.56 cm) of HFC-245fa and an intermittent pilot ignition device yields only a slightly higher EF than comparable metal tank designs [25]. Table 8.4.11 provides the EF estimates for 40-gallon (150- liter) gas-fired side arm water heater designs with REs of 76%, 78%, and 80%.

Table 8.4.11 Energy Factor Estimates for Side Arm Gas-Fired Water Heater with Plastic Tank

Side Arm Water Heater Design w/ Plastic Tank	Energy Factors (2003 Baselines)
with 76% RE	0.627
with 78% RE	0.640
with 80% RE	0.654

8.4.3 Manufacturer Costs

As with electric water heaters, manufacturer costs were primarily based on data provided by GAMA. The side arm heater and plastic tank were the only design options, which were analyzed using manufacturing costs provided by an independent consultant [25]. All manufacturing cost estimates were based upon the production of a 40 gallon (150 liter) gas-fired water heater and were disaggregated into variable (material, labor, overhead, transportation) and fixed (capital, product design) costs. Variable and fixed costs are defined on a per-unit basis and expressed as an incremental increase over the existing baseline for the design options.

8.4.3.1 Existing Baseline Model

GAMA gathered existing baseline model cost estimates for a 40-gallon (150-liter) gas-fired storage water heater with a nominal 4" flue diameter and with 1 in. (2.5 cm) of foamed jacket insulation blown with HCFC-141b from manufacturers (see Table 8.4.1).

Most water heaters on the market use a 3-in flue, however. Therefore, the manufacturer cost of the baseline model was adjusted downward to reflect the smaller flue diameter. This calculation is done only for the purpose of developing an overall markup that reflects current market practices. Our consultant estimated the incremental manufacturing cost difference between water heaters with 3-in and 4-in flues for the baseline 40-gal gas-fired water heater.[38] The adjustment includes the incremental variable material cost as well as the fixed cost due to manufacturers cost allocations and the product failure costs.. Appendix C-3 contains the details of the derivation of the incremental manufacturer costs to switch from 4-in to 3-in flue diameter.

The baseline model costs were used for this Engineering Analysis. Table 8.4.12 presents the baseline model manufacturer costs. Note that no fixed costs were assumed for the baseline model with the exception of the fixed cost to account for manufacturers allocations and the product failure costs for 3" flue diameter baseline model.

Table 8.4.12 Existing Baseline Model Manufacturer Costs for Gas-Fired Water Heater

Design	Variable Costs					Fixed Costs			Total Mfg Cost
	Material	Labor	Transp	Overhead	Total	Capital	Product Design	Total	
	$	*$*	*$*	*$*	*$*	*$*	*$*	*$*	*$*
Existing Baseline w/ 4" flue diameter	75.02	10.74	$9.67	38.35	133.78	0.00	0.00	0.00	133.78
Existing Baseline w/ 3" flue diameter	72.91	10.74	$9.67	38.35	131.67	0.00	0.00	1.29	130.38

Material cost estimates for the existing baseline model—a water heater with a nominal 1 in. (2.5 cm) of foamed jacket insulation using HCFC-141b as a blowing agent—were supplied by GAMA. We calculate the amount and cost of materials associated with different thicknesses of HCFC-141b insulation. The material costs associated with a particular level of insulation can easily be determined by either subtracting from or adding to GAMA's baseline costs. Table 8.4.14 summarizes the material costs associated with varying levels of foam insulation blown with HCFC-141b. The material costs for the HCFC-141b foam insulation ($1/lb or $2.2/kg) and sheet metal ($0.30/lb or $0.66/kg) are estimates by an independent consultant [26].

Table 8.4.13 Material Costs of HCFC-141b Foam Insulation Gas-Fired Water Heater

Polyurethane Foam 141b				Jacket Sheet Metal				Misc	Total
thickness	volume	weight*	cost†	area	volume	weight ‡	cost §	cost ¶	cost
in. (cm)	*ft^3 (m^3)*	*lb (kg)*	*$*	*ft^2 (m^2)*	*ft^3 (m^3)*	*lb (kg)*	*$*	*$*	*$*
0.98 (2.49)	1.57 (0.04)	3.15 (1.43)	3.15	23.76 (2.21)	0.038 (0.001)	18.40 (8.35)	5.52	0.00	8.66
1.50 (3.81)	2.50 (0.07)	5.00 (2.27)	5.00	25.48 (2.37)	0.040 (0.001)	19.73 (8.99)	5.92	1.58	12.50
2.00 (5.08)	3.45 (0.10)	6.91 (3.13)	6.91	27.18 (2.53)	0.043 (0.001)	21.05 (9.55)	6.31	3.95	17.17
2.50 (6.35)	4.47 (0.13)	8.94 (4.06)	8.94	28.92 (2.69)	0.046 (0.001)	22.33 (10.13)	6.72	5.81	21.46
3.00 (7.62)	5.55 (0.16)	11.11 (5.04)	11.11	30.69 (2.85)	0.049 (0.001)	23.78 (10.79)	7.13	8.59	26.82

* Foam density = 2 lb/ft^3 (32 kg/m^3)

† Foam cost = $1/lb ($2.2/kg)

‡ Sheet metal density = 489 lb/ft^3 (7833 kg/m^3)

§ Sheet metal cost = $0.30/lb ($0.66/kg)

¶ Miscellaneous cost includes additional cost for foam dams to contain insulation in a larger cavity.

8.4.3.2 2003 Baseline Model

To convert the baseline manufacturer costs associated with foam insulation blown with HCFC-141b to insulation blown with HFC245fa, we estimated the amount and cost of materials associated with varying thicknesses of insulation. These costs are shown in Tables 8.4.14 and 8.4.15, which summarize the material costs associated with varying levels of insulation. The material costs of HFC-245fa foam insulation ($1.32/lb or $2.9/kg) were estimates by Allied Signal (see Table 8.3.10).

We assume that manufacturers will maintain the same level of thermal resistance for their baseline model when switching from HCFC-141b to HFC-245fa foam insulation. Therefore, in Table 8.4.14, the actual thickness level for 1 nominal in. of HFC-245fa foam insulation is 1 in. (2.54 cm) compared to 0.981 in. (2.49 cm) for HCFC-141b. The value is assumed to be slightly greater than for HCFC-141b because of HFC-245fa's higher conductivity (see Chapter 3.4).

Table 8.4.14 Material Costs of HFC-245fa Foam Insulation Gas-Fired Water Heater

Polyurethane Foam Insulation				Jacket Sheet Metal				Misc	Total
thickness *	volume	weight †	cost ‡	area	volume	weight §	cost ¶	cost £	cost
in. (cm)	*ft^3 (m^3)*	*lb (kg)*	*$*	*ft^2 (m^2)*	*ft^3 (m^3)*	*lb (kg)*	*$*	*$*	*$*
1.00 (2.54)	1.61 (0.05)	3.21 (1.46)	4.24	23.82 (2.21)	0.038 (0.001)	18.44 (8.36)	5.53	0.00	9.77
1.50 (3.81)	2.50 (0.07)	5.00 (2.27)	6.60	25.48 (2.37)	0.040 (0.001)	19.73 (8.95)	5.92	1.58	14.10
2.00 (5.08)	3.45 (0.10)	6.91 (3.13)	9.12	27.18 (2.53)	0.043 (0.001)	21.05 (9.55)	6.31	3.95	19.38
2.50 (6.35)	4.47 (0.13)	8.94 (4.06)	11.80	28.92 (2.69)	0.046 (0.001)	22.39 (10.16)	6.72	5.81	24.33
3.00 (7.62)	5.55 (0.16)	11.11 (5.04)	14.66	30.69 (2.85)	0.049 (0.001)	23.76 (10.78)	7.13	8.59	30.38

* Thickness increased due to increased conductivity of 245fa relative to 141b.
† Foam density = 2 lb/ft^3 (32 kg/m^3)
‡ Foam cost = $1.32/lb ($2.9/kg)
§ Sheet metal density = 489 lb/ft^3 (7833 kg/m^3)
¶ Sheet metal cost = $0.30/lb ($0.66/kg)
£ Miscellaneous cost includes additional cost for dams to contain foam insulation in a larger cavity.

Table 8.4.15 presents manufacturer cost estimates for a 40 gallon (150 liter) gas-fired water heater with 1 nominal in. of HCFC-141b foam insulation. The material costs for the HCFC-141b baseline model were adjusted upward by the calculated difference in material costs ($1.11) between the HCFC-141b and HFC-245fa models.

Table 8.4.15 Manufacturer Costs of Gas-Fired Water Heater Baseline Models with HCFC-141b and HFC-245fa

	Variable Costs					Fixed Costs			Total
							Product		Mfg
Design	**Materi**	**Labo**	**Trans**	**Overhe**	**Total**	**Capita**	**Desig**	**Tota**	**Cost**
	$	*$*	*$*	*$*	*$*	*$*	*$*	*$*	*$*
Baseline w/ 141b - 0.981 in	75.02	10.74	9.67	38.35	133.7	0.00	0.00	0.00	133.78
Baseline w/ 245fa - 1.00 in	76.13	10.74	9.67	38.35	134.8	0.00	0.00	0.00	134.89

*Note: The cost of the flammable vapor ignition device is not included in the 2003 baselines cost shown in this table.

8.4.3.3 2003 Baseline Model with Flammable-Vapor Ignition-Resistant Design

In order to resist the ignition of flammable vapors, gas-fired water heater manufacturers will need to redesign their product. Based on discussions with the Water Heater Industry Joint Research and Development Consortium, DOE assumed a placeholder value of $35 was added to the total manufacturing cost ($15 variable costs and $20 fixed cost) for product redesign. The design would not require electricity at the water heater or modifications to the vent system. In addition, DOE assumed that water hater efficiency would not change. Table 8.4.18 presents the manufacturer cost estimates for the baseline model with the Flammable-Vapor Ignition-Resistant design.

Table 8.4.16 "2003" Baseline Model Flammable-Vapor Ignition-Resistant Design Manufacturer Costs for Gas-Fired Water Heater

	Variable Costs					Fixed Costs			Total
							Product		Mfg
Design	Material	Labor	Transp	Overhead	Total	Capital	Design	Total	Cost
	$	$	$	$	$	$	$	$	$
Baseline w/ 245fa	91.13	10.74	9.67	38.35	149.89	20.00	0.00	20.00	169.89

8.4.3.4 Heat Traps

Manufacturer costs for heat traps were based on data provided by GAMA. Data from the heat trap manufacturer Perfection, Inc. were used as a reference. Heat trap material costs are for a 0.75-in. (1.9-cm) by 3-in. (7.6-cm) metal nipple with an inserted plastic heat trap assembly. This assembly is used for both supply and draw lines. An alternate design, a plastic drop-in tube used for the supply line and a plastic cartridge heat trap design within a combined outlet and anode rod assembly used for the draw line, has a similar cost.

Table 8.4.17 summarizes the incremental manufacturer costs for incorporating heat traps into a gas-fired water heater. The costs reflect the addition of heat traps to both the supply and draw lines.

Table 8.4.17 Incremental Manufacturer Costs for Heat Traps for Gas-Fired Water Heaters

	Incremental Variable Costs					Incremental Fixed Costs			Total
							Product		Incremental
Design	Material	Labor	Transp	Overhead	Total	Capital	Design	Total	Mfg Cost
	$	$	$	$	$	$	$	$	$
Heat Traps	2.75	0.16	0.00	0.21	3.12	0.07	0.13	0.20	3.32

Note: GAMA's heat trap variable and fixed costs are different for electric water heaters and gas-fired water heaters.

8.4.3.5 Increased Jacket Insulation

Table 8.4.13 depicts the material costs for varying levels of HFC-141b foam insulation. GAMA variable cost and fixed cost data for jacket insulation include increases from a baseline level of 1 in. (2.54 cm) to a thickness of 2.0 in. (5.1 cm) only.

Data provided by a consultant were used to calculate ratios of variable and fixed costs for 2.5- in., and 3-in. insulation. GAMA's costs for upgrading to 2.0-in. (5.1-cm) insulation, modified for HFC-245fa foam, were multiplied by those ratios to approximate the variable and fixed costs for 2.5-in. (6.4-cm) and 3-in. (7.6-cm) insulation. Note that the overhead portion of the variable cost for models with 3-in. (7.6 cm) jacket insulation includes 25% additional shipping cost, associated with the less efficient use of truck capacity resulting from increased water heater size.

Table 8.4.18 summarizes the incremental manufacturer costs for 245fa jacket insulation increases from a baseline level of 1 in. (2.54 cm) to a thickness of 2.0 in. (5.1 cm), 2.5 in. (6.4 cm), and 3 in. (7.6 cm).

Table 8.4.18 Increased Jacket Insulation for HFC-245fa 2003 Gas-Fired Water Heaters: Incremental Manufacturer Costs

Design	Incr. Variable Cost					Incr. Fixed Costs			Total Increment Mfg Cost $
	Materi $	Labo $	Trans $	Overhe $	Total $	Capital $	Produc Design $	Total $	
Incr. Insulation - 2.0 in	9.61	0.59	2.56	2.40	15.16	0.84	0.59	1.43	16.59
Incr. Insulation - 2.5 in	14.55	1.18	5.12	4.80	25.65	1.26	1.18	2.44	28.09
Incr. Insulation - 3.0 in	20.61	1.77	9.60	7.20	39.18	1.68	1.77	3.45	42.63

8.4.3.6 Improved Flue Baffle

Manufacturer costs for the improved flue baffle design were provided by GAMA. Table 8.4.19 summarizes the incremental manufacturing costs for an improved flue baffle. The costs were based on a design that increased the RE to 78%. Our consultant estimated that the manufacturing cost to increase the RE from the baseline to 80% is the same as the manufacturing cost to increase the RE to78%. It is interesting to note that the largest component of the manufacturing cost increase is product design.

Table 8.4.19 Improved Flue Baffle Design for Gas-Fired Water Heaters: Incremental Manufacturer Costs

Design	Incr. Variable Cost $					Incr. Fixed Costs $			Total Incremental Mfg Cost $
	Materia $	Labo $	Transp $	Overhe $	Total $	Capit $	Produc Design $	Tota $	
Improved Flue	0.97	1.25	0.00	1.38	3.60	1.14	1.70	2.84	6.44

8.4.3.7 Electronic Ignition

Manufacturer costs for electronic ignition were based on replacing a standing pilot with an intermittent pilot ignition device. The cost of the electronic ignition system was based on data from GAMA. Table 8.4.20 summarizes the incremental manufacturing costs for switching from a standing pilot to an intermittent pilot ignition device.

Table 8.4.20 Electronic Ignition for Gas-Fired Water Heaters: Incremental Manufacturer Costs

Design	Incr. Variable Cost					Incr. Fixed Costs			Total Incremental Mfg Cost
	Material	Labor	Transp.	Overhead	Total	Capital	Product Design	Total	
	$	$	$	$	$	$	$	$	$
Electronic Ignition (IID)	43.78	2.60	4.84	7.55	58.77	2.05	1.44	3.49	62.26

8.4.3.8 Flue Damper (Electromechanical)

Manufacturer costs for including an electromechanical flue damper with a gas-fired water heater were from GAMA. Table 8.4.21 summarizes the incremental manufacturing costs of putting an electromechanical flue damper on a gas-fired water heater. Because electromechanical flue dampers were analyzed only in conjunction with electronic ignition systems, the incremental manufacturer costs associated with both design options are also summarized in Table 8.4.21. As stated previously, because electricity is required for the operation of the flue damper, it was assumed the standing pilot would be converted to an electronic ignition system to take advantage of the electrical power at the water heater.

Table 8.4.21 Flue Damper w/ Electronic Ignition for Gas-Fired Water Heaters: Incremental Manufacturer Costs

Design	Incr. Variable Cost					Incr. Fixed Costs			Total Incremental Mfg Cost
	Material	Labor	Transp.	Overhead	Total	Capital	Product Design	Total	
	$	$	$	$	$	$	$	$	$
Flue Damper	85.05	3.29	7.17	9.49	105.00	3.41	2.00	5.41	110.41
Flue Damper + IID	128.83	5.89	12.01	17.04	163.77	5.45	3.45	8.90	172.67

8.4.3.9 Side Arm Heater and Plastic Tank

Manufacturer costs for the side arm heater for a gas-fired water heater design were from an independent consultant[25]. Table 8.4.22 summarizes the costs for six types of side arm heater designs: 76%, 78% and 80% RE designs that use a metal tank and 76%, 78% and 80% RE designs using a plastic tank. For this analysis we assumed that the cost difference between the 76% and 78% RE designs and between the 76% and 80% RE designs was equal to the cost of the improved flue baffle design. This assumption means that heat exchanger costs for a 78% RE design would be higher than those for a 76% RE design. It was also assumed that the cost to switch from a 76%T RE design to an 80% RE design is the same. Because side arm heaters were analyzed only in conjunction with electronic ignition systems, the incremental manufacturer costs associated with all six design options including the electronic ignition are also summarized in Table 8.4.23. As discussed previously, plastic tanks cannot be considered as a stand-alone design option for standard center-flue gas-fired water heaters due to the high temperature of combustion. Thus, plastic tanks can only be considered with indirect heating designs, such as a side arm heater.

Table 8.4.22 Side Arm Heaters for Gas-Fired Water Heaters: Incremental Manufacturer Costs

Design	Incr. Variable Cost					Incr. Fixed Costs			Total Increm. Mfg Cost
	Material	Labor	Transp	Overhead	Total	Capital	Product Design	Total	
	$	$	$	$	$	$	$	$	$
76% RE Side Arm Heater w/	24.50	2.10	2.50	11.80	40.90	0.80	2.00	2.80	43.70
78% RE Side Arm Heater w/	25.47	3.35	2.50	13.18	44.50	0.80	2.00	2.80	47.30
80% RE Side Arm Heater w/	25.47	3.35	2.50	13.18	44.50	0.80	2.00	2.80	47.30
76% RE Side Arm Heater w/	29.75	2.90	4.90	13.60	51.15	3.80	2.60	6.40	57.55
78% RE Side Arm Heater w/	30.72	4.15	4.90	14.98	54.75	3.80	2.60	6.40	61.15
80% RE Side Arm Heater w/	30.72	4.15	4.90	14.98	54.75	3.80	2.60	6.40	61.15

Table 8.4.23 Side Arm Heaters w/Electronic Ignition for Gas-Fired Water Heaters: Incremental Manufacturer Costs

Design	Incr. Variable Cost					Incr. Fixed Costs			Total Increm. Mfg Cost
	Material	Labor	Transp	Overhead	Total	Capital	Product Design	Total	
	$	$	$	$	$	$	$	$	$
76% RE Side Arm Heater w/ Metal Tank including IID	68.28	3.87	7.34	19.35	98.84	2.85	3.44	6.29	105.13
78% RE Side Arm Heater w/ Metal Tank	69.25	5.12	7.34	20.73	102.44	3.99	5.14	9.13	111.57
80% RE Side Arm Heater w/ Metal Tank	69.25	5.12	7.34	20.73	102.44	3.99	5.14	9.13	111.57
76% RE Side Arm Heater w/ Plastic Tank	73.53	4.67	9.74	21.15	109.09	5.85	4.04	9.89	118.98
78% RE Side Arm Heater w/ Plastic Tank	74.50	5.92	9.74	30.22	112.69	6.99	5.74	12.73	125.42
80% RE Side Arm Heater w/ Plastic Tank	74.50	5.92	9.74	30.22	112.69	6.99	5.74	12.73	125.42

8.4.4 Design Option Retail Prices

For purposes of this analysis, retail price is considered to be the cost to the consumer of the water heating equipment only. The cost to the consumer of installing the water heater is not considered to be part of the retail price and is discussed in Section 8.4.5.

The retail price for a baseline 40 gallon (150 liter) gas-fired water heater (with HCFC-141b foam insulation) was from a large number of retailers, wholesalers, plumbing contractors, and utilities. The price of a water heater is a function of the length of the manufacturer's warranty. The baseline models chosen for this analysis have up to six year warranties. The five- to six-year warranty is the shortest warranty period offered by water heater manufacturers (although a one-year warranty is offered in special cases) and is typically reserved for models produced in large volume (i.e., baseline models). A longer warranty period, in addition to raising the price, suggests the presence of a design feature not normally found in baseline models.

The retail price of the baseline model is the median of Table 8.4.27 in the list of retail prices. For each price listed, the source is also provided. All data presented in Table 8.4.27 are from the Water Heater Price Database, which includes information gathered from more than130 contacts from all regions of the U.S. The Database contains information on more than 1100 models, including retail prices, fees (installation, delivery, etc.), and warranties. Detailed information on the data base development is provided in Chapter 5 of this report.

Table 8.4.24 Gas-Fired Water Heater Retail Prices

Source	Manufacturer	Brand	WH Model	RetailPrice
Little Rock, AR	American Water Heater Company	American	G51-40T34-3NV	115.00
Salt Lake City, UT	American Water Heater Company	American	G51-40T34-3NV	118.00
Kankakee, IL	Rheem	Richmond	5V40-7	124.00
Chicago, IL	American Water Heater Company	American	G51-40T34-3NV	126.00
Minneapolis, MN	American Water Heater Company	American	G51-40T34-3NV	126.00
Waterloo, IA	American Water Heater Company	American	G51-40T34-3NV	126.00
Salem, OR	American Water Heater Company	American	G61-40T34-3N	127.00
Reno, NY	American Water Heater Company	American	G51-40T34-3NV	128.00
Portland, OR	State Industries	Reliance	5-40-NORT	128.00
Atlanta, GA	American Water Heater Company	American	G51-40T34-3NV	129.00
Sacramento, CA	American Water Heater Company	American	G51-40T34-3NV	129.00
Stockbridge, GA	American Water Heater Company	American	G51-40T34-3NV	129.00
Marietta, GA	American Water Heater Company	American	G51-40T34-3NV	129.00
Las Vegas, NV	State Industries	Reliance	5-40-NORT	129.00
Reading, PA	Rheem	Richmond	5V40-7	129.99
New Orleans, LA	American Water Heater Company	American	G51-40T34-3NV	131.00
St. Louis, MO	American Water Heater Company	American	G51-40T34-3NV	131.00
Denver, CO	State Industries	Reliance	5-40-NORT	131.00
Oklahoma City, OK	State Industries	Reliance	5-40-NORT	131.00
Phoenix, AZ	State Industries	Reliance	5-40-NORT	131.00
Dallas, TX	State Industries	Reliance	5-40-NORT	132.00
Emeryville, CA	American Water Heater Company	American	G51-40T34-3NV	133.00
Falls Church, VA	American Water Heater Company	American	G51-40T34-3NV	134.00
Orange, CA	State Industries	Reliance	5-40-NORT	134.00
Seattle, WA	State Industries	Reliance	5-40-NORT	134.00
Kilgore, TX	A.O. Smith	A.O. Smith	FSG-40	135.00
Lexington, KY	American Water Heater Company	American	G51-40T34-3NV	135.00
Nashville, TN	American Water Heater Company	American	G51-40T34-3NV	135.00
Livermore, CA	State Industries	Sears / Kenmore	33246	139.99
Salem, OR	Bradford White	Bradford White	M-I-403T6LN	140.00
Bensalem, PA	American Water Heater Company	American	G51-40T34-3NV	144.00
Reading, PA	American Water Heater Company	American	G51-40T34-3NL	144.00
Charlotte, NC	American Water Heater Company	American	G51-40T34-3NV	147.00
Cleveland, OH	GSW	John Wood	JW540SNA	158.00
Richmond, CA	State Industries	Sears / Kenmore	33246	160.00
Parkersburg, WV	A.O. Smith	A.O. Smith	FSG-40	162.88
Livermore, CA	State Industries	Sears / Kenmore	33645	164.99
Benicia, CA	RHEEM	Rheem	21V40-7N	167.00
Indianapolis, IN	State Industries	State	PRV-40-NORT	170.00
Massillon, OH	Bradford White	Bradford White	M-I-40T6LN	174.00
Bethpage, NY	Rheem	Rheem	21V40-7	178.50
Wheeling, WV	Rheem	Ruud	P40-7	179.95

Table 8.4.24 Gas-Fired Water Heater Retail Prices —*Cont.*

Source	Manufacturer	Brand	WH Model	Retail Price
Winchester, VA	Rheem	Rheem	21V40-7	184.00
Port Chester, NY	Bradford White	Bradford White	M-I-40T6EN	186.98
Marion, IN	A.O. Smith	A.O. Smith	FSG-40	187.38
Boston, MA	State Industries	Sears / Kenmore	33246	190.00
Indianapolis, IN	State Industries	State	PR6-40-NORT	193.50
Bridgeton, NJ	Bradford White	Bradford White	M-I-403T6LN	193.90
Fredericksburg, VA	State Industries	State	PRV-40-NORT	199.95
Boston, MA	State Industries	Sears / Kenmore	33246	200.00
Reading, PA	Rheem	Rheem	21V40-7	209.00
Charlottesville, VA	Rheem	Ruud	P40-7	209.00
Amarillo, TX	American Water Heater Company	American	G51-40T34-3N	220.00
Chagrin Falls, OH	Bradford White	Bradford White	M-I-403T6EN	239.20
Painesville, OH	Rheem	Ruud	P40-7	241.50
Anchorage, AK	Bradford White	Bradford White	M-I-403T6LN	245.70
Fairfax, VA	State Industries	State	PRV-40-NORT	245.70
Reading, PA	A.O. Smith	A.O. Smith	FSG-40	255.00
Reading, PA	A.O. Smith	A.O. Smith	FSG-40	255.00
Boston, MA	State Industries	Sears / Kenmore	33246	260.00
Atlanta, GA	A.O. Smith	A.O. Smith	FSG-40	264.00
Atlanta, GA	A.O. Smith	A.O. Smith	FSG-40	264.00
Fort Wayne, IN	State Industries	State	PRV-40-NORT	276.00

As shown in Table 8.4.24, the mean retail price for a baseline 40 gallon (150 liter) gas-fired storage water heater with 3" flue is $167.78 (not including tax). The manufacturer cost of an existing baseline water heater (also with 3" flue) is $130.38 [24] (see chapter 8.4.3.1 Existing Baseline Model). Dividing the mean retail price ($167.78) by the manufacturer cost ($130.38) yields a manufacturer cost-to-retail price markup of $1.29. The calculated markup is applied to the gas-fired water heaters with 4" flue diameter. Adding the average national value for tax of 5%[30] yields a retail price of $180.76.

The baseline manufacturer cost-to-retail price markup is assumed to be constant for all design options considered for this analysis. Thus, the retail price for any design is simply determined by multiplying the manufacturer cost by the derived markup of 1.29 and adding a sales tax of 5%.

8.4.5 Installation Costs

The installation cost is the cost to the consumer of installing the water heater and is not considered part of the retail price. The cost of installation covers all labor and material costs associated with the replacement of an existing water heater. Delivery, removal, and permit fees are also included. Installation cost data for the 40-gallon (150-liter) baseline gas-fired water heater came from the Water Heater Price Database. Table 8.4.25 lists these costs. The median installation cost is $159.00.

Table 8.4.25 Gas-Fired Storage Water Heater Installation Cost

Source	Manufacturer	Brand	WH Model	Installation
Berkeley, CA	Rheem	Rheem	21V40-7N	65.00
Berkeley, CA	Rheem	Rheem	21V40S-2	65.00
Berkeley, CA	Rheem	Rheem	21V40T	65.00
Falls Church, VA	American Water Heaters	American	G51-40T34-3NV	75.00
Anchorage, AK	Rheem	Rheem	21V40T	90.00
Anchorage, AK	Bradford White	Bradford White	M-I-403S6LN	90.00
Anchorage, AK	Bradford White	Bradford White	M-I-403T6LN	90.00
Anchorage, AK	Bradford White	Bradford White	M-I-MH40T6LN	90.00
Anchorage, AK	Bradford White	Bradford White	M-I-MS40T6LN	90.00
Reading, PA	State Industries	State	PRV-40-NORS	110.00
Stockbridge, GA	American Water Heaters	American	G51-40T34-3NV	119.00
Salt Lake City, UT	American Water Heaters	American	G51-40T34-3NV	125.00
Denver, CO	State Industries	Reliance	5-40-NORT	130.00
Little Rock, AR	American Water Heaters	American	G51-40S33-3NV	130.00
Little Rock, AR	American Water Heaters	American	G51-40T34-3NV	130.00
Waterloo, IA	American Water Heaters	American	G51-40T34-3NV	135.00
Phoenix, AZ	State Industries	Reliance	5-40-NORT	136.00
Atlanta, GA	American Water Heaters	American	G51-40S33-3NV	142.00
Lexington, KY	American Water Heaters	American	G51-40T34-3NV	145.00
Marietta, GA	American Water Heaters	American	G51-40T34-3NV	149.00
Reading, PA	Bradford White	Bradford White	M-I-40S6LN	150.00
Richmond, CA	State Industries	Sears / Kenmore	33246	153.99
Livermore, CA	State Industries	Sears / Kenmore	33645	153.99
Reno, NV	American Water Heaters	American	G51-40T34-3NV	154.00
Dallas, TX	State Industries	Reliance	5-40-NORT	155.00
Charlotte, NC	American Water Heaters	American	G1F-4033-S3NV	155.00
Orange, CA	State Industries	Reliance	5-40-NBRT	159.00
Orange, CA	State Industries	Reliance	5-40-NORT	159.00
St Louis, MO	American Water Heaters	American	G51-40T34-3NV	160.00
Reading, PA	A.O.Smith	A.O.Smith	FSG-40	165.00
Reading, PA	A.O.Smith	A.O.Smith	FSG-40	165.00
Dale City, VA	American Water Heaters	U.S. Craftmaster	G1F-4033-S3NV	169.00
Las Vegas, NV	State Industries	Reliance	5-40-NORT	170.00
Richmond, CA	State Industries	Sears / Kenmore	33246	174.00
Charlotte, NC	American Water Heaters	American	G51-40T34-3NV	175.00
Emeryville, CA	American Water Heaters	American	G51-40S33-3NV	176.00
Emeryville, CA	American Water Heaters	American	G51-40T34-3NV	176.00
Oklahoma City, OK	State Industries	Reliance	5-40-NORT	180.00
Reading, PA	A.O.Smith	A.O.Smith	FSGL-40	185.00
Reading, PA	A.O.Smith	A.O.Smith	FSGL-40	185.00
Lexington, KY	American Water Heaters	American	G51-40T34-3NV	200.00
Chicago, IL	American Water Heaters	American	G51-40T34-3NV	209.00
Sacramento, CA	American Water Heaters	American	G51-40T34-3NV	210.00
Billings, MT	Bradford White	Bradford White	M-I-403S6LN	210.00
Boston, MA	State Industries	State	33246	220.00
New Orleans, LA	American Water Heaters	American	G51-40T34-3NV	225.00

Table 8.4.25 Gas-Fired Storage Water Heater Installation Cost—*Cont.*

Source	Manufacturer	Brand	WH Model	Installation
Seattle, WA	State Industries	Reliance	5-40-NORT	231.00
Atlanta, GA	American Water Heaters	American	G51-40S33-3NV	234.00
Atlanta, GA	American Water Heaters	American	G51-40T34-3NV	234.00
Reading, PA	A.O.Smith	A.O.Smith	FSGL-40	235.00
Reading, PA	A.O.Smith	A.O.Smith	FSGL-40	235.00
Minneapolis, MN	American Water Heaters	American	G51-40T34-3NV	258.00
Reading, PA	Bradford White	Bradford White	M-I-40S6LN	292.09

There are four design options considered for this analysis that increase the installation cost relative to the baseline: improved flue baffle, electronic ignition, electromechanical flue damper, and side arm heater. All design options that include 2-, 2.5-, and 3-in. insulation may incur an additional installation cost either when the water heater requires a replacement drain pan of a larger size or when it requires the addition of a tempering valve. In addition, all design options that include 3-in. insulation require an additional cost to install the wider units in narrow spaces (e.g., to disassemble and reassemble doorjambs). The analysis recognizes these potential needs and incorporates the additional costs in the total installation cost for the impacted households.

Use of gas-fired water heaters with recovery efficiency of 78% or 80% in existing venting systems that are not designed for lower temperature flue gases can potentially lead to excessive corrosion and failure of the vent system in certain situations. This analysis includes costs of venting modifications (Type-B vent connectors and/or masonry chimney relining) in the total installation costs for gas-fired water heaters. We developed the installation costs for Type-B vent connectors and masonry chimney relining based on the replacement market.

A Type-B vent connector is installed when replacing an existing gas-fired water heater with a water heater with RE of 78% or 80% in some homes in climate regions exceeding 5,000 heating degree days (HDD). The average national cost is based on installations in the Northeast and the Midwest regions because the most populated areas in the West and the South have HDD less than 5,000. The calculations utilized the following five steps:

a) We determined the fraction of homes with gas-fired water heaters in Northwest and Midwest regions. An AGA survey provided data regarding regional installations of gas-fired water heaters.[39]

b) We determined that approximately 54% of water heaters are installed in conditioned spaces and the rest are installed in garages or unconditional spaces. Gas-fired water heaters installed in unconditioned spaces are already required to have Type-B vent connectors. This data is based on a review of the RECS 93 public data.

c) We determined the number of installations with an existing single-wall vent connector in Northwest and Midwest regions. Again, the AGA survey provided data regarding regional existing single-wall vent connector installations.[39]

d) We assumed that 25% of those need Type-B vent connectors.

e) Finally, the cost of installing Type-B vent connectors is based on installers' estimates.[40] These estimates of $114 ($1998) are slightly higher than the GRI estimates of $105 ($1998).[6]

The following is a generalized equation that describes the calculation of the cost when installing a Type-B vent connector:

$$VentInstallCost_{TYPE\text{-}B\ Vent\ Connector} = Fraction\ of\ GWH\ Homes\ in\ NE\ \&\ NW\ \ \mathbf{x}\ \ Fraction\ of\ Water\ Heaters\ in\ Conditioned\ Space\ \ \mathbf{x}\ \ Fraction\ of\ Homes\ With\ Single\text{-}Wall\ Vent\ Connector\ in\ NE\ \&\ NW\ \ \mathbf{x}\ \ 25\ \%\ \ \mathbf{x}\ \ Total\ Type\text{-}B\ Install\ Cost$$

We assumed that installers would reline the masonry chimneys in some homes in climate regions exceeding 5,000 heating degree days when replacing an existing gas-fired water heater with a water heater with RE of 80%. The average national cost is based on installations in the Northeast and the Midwest regions because the most populated areas in the West and the South have HDD less than 5,000. The calculations utilized the following five steps:

a) We determined the fraction of homes with gas-fired water heaters in Northwest and Midwest regions. An AGA survey provided data regarding regional installations of gas-fired water heaters.

b) We determined the fraction of homes with masonry chimneys in Northwest & Midwest regions. Again, we used the AGA survey data, cited above, to determine, by region, the number of water heaters connected to masonry chimneys.

c) We assumed that 25% of those need chimney relining.

d) Finally, using the PNNL data cited above, we determined the cost to reline masonry chimneys from discussions with chimney contractors. These estimates show that the average cost of relining is $433 ($1998). This compares with $505 ($1998) in the GRI estimates.

A generalized equation that describes the calculation of the chimney relining cost can be expressed as follows:

$$VentInstallCost_{CHIMNEY\ RELINING} = Fraction\ of\ GWH\ Homes\ in\ NE\ \&\ NW\ \ \mathbf{x}\ \ Fraction\ of\ Water\ Heaters\ in\ Conditioned\ Space\ \ \mathbf{x}\ \ Fraction\ of\ Homes\ With\ Masonry\ Chimney\ \text{in NE \& NW}\ \ \mathbf{x}\ \ 25\ \%\ \ \mathbf{x}\ \ Total\ Relining\ Cost$$

The three remaining design options (electronic ignition, electromechanical flue damper, and side arm heater) all require electricity to operate. The installation cost was increased in order to include the cost to bring electricity to the gas-fired water heater for these design options. This installation cost estimate was based on data from GRI, Table B.10 of the GRI briefing.[41] Of the added installation cost, $6.20 in 1990 dollars (or $7.73 in 1998 dollars) is required for labor and wiring of every water heater with any of these three design options. Thirty-two percent of households will also require an electrical outlet at the water heater. GRI estimated this cost at $66.15 in 1990 dollars ($82.50 in 1998 dollars).[6] Thus, the average cost for installing an outlet was determined by multiplying the $82.50 cost by 32%. This yields an average cost of $26.40 in 1998 dollars for the installation of an outlet. This value plus the wiring and labor cost of $7.73 yields a total representative added installation cost of $34.13 in 1998 dollars for the three design options that require electricity to operate. A generalized equation that describes the calculation of the cost to bring electricity to the gas-fired water heater can be expressed as follows:

ElecInstallCost = (*Wiring Labor* ***x*** *Wiring Materials*) ***x*** (*Total Elec Outlet Install Cost* ***x*** *Fraction of Homes Needing Elec Outlet*)

Some households may require replacement drain pan of a larger size when a wider water heater (due to increased insulation) is installed under the new standard. The drain pan size is a function of the water heater diameter. Manufacturers recommend that the drain pan diameter be 2 inches larger than the diameter of the water heater. We used RECS 97 to identify the huseholds that would need a drain pan. We assumed that houses would use drain pans if the house did not have a slab-on-grade floor or a garage or an unconditioned basement.

The details of the drain pan replacement approach as well as the development of the associated costs are described in Appendix E-5. In the Engineering Analysis, we use a weighted average cost for each water heater diameter from the LCC Analysis. The following average costs were applied: for water heaters with 2-in insulation, the drain pan cost is $0.61 and for 2.5- and 3-in. insulation, the drain pan cost is $1.81.

In some households, the original water heater location may be too small to accommodate a replacement water heater of the same rated volume under the new standard, specifically when the water heater insulation thickness is 2.5 or 3 inches. When such space constraints exist, some households are assumed to use the next smaller standard size water heater, and increase the water heater setpoint to compensate for the lower storage volume. If the new setpoint is too high it may require a tempering valve. We used RECS97 to identify which households would have such space constraints. We assumed that such constraints would only exist in cases where:

- the water heater is installed in a conditioned space, e.g., not in a garage or an unconditioned basement, and
- the water heater is in a small house or apartment with a floor area of less than 1,000 ft^2

For households with space constraints, we adjusted the setpoint of the smaller water heater upward so that the total energy content of the water that could be delivered is the same as could have been delivered by the original water heater at a lower temperature. If the new setpoint is > 140°F, the cost of a tempering value is added. The details of the space constraint approach as well as the tempering valve cost are described in Appendix E-5. In the Engineering Analysis, we used a weighted average cost of $15.26 for adding tempering and check valves (when ≥2.5in insulation) from the LCC Analysis.

Design options that include 3-in. insulation require an additional cost in some cases to account for the impact on installation and cost in replacement applications (e.g., to disassemble and reassemble doorjambs). We have added a $160 installation cost for removal and replacement of doorjambs for 50% of all water heaters located in a conditioned space. From the RECS 1997 data, we determined that 54% of water heaters are located in a conditioned space. In the Engineering Analysis, we used the calculated average cost of $43.19 for all design options that include 3-in. insulation.

8.4.6 Maintenance Costs

The maintenance cost is the price of regular maintenance or the price to repair a water heater when it fails ($/year). This cost covers all labor and material costs associated with the maintenance of an existing gas-fired water heater.

The electromechanical flue damper and the side arm are the only design options assumed to increase a gas-fired water heater's maintenance cost.

The maintenance cost of the electromechanical flue damper was based on a prior DOE analysis,[42] which represents the maintenance cost of the combustion box damper in direct heating equipment. The national average flue damper maintenance cost was estimated as $63.64 in 1990 dollars (or $79.37 in 1998 dollars). For this analysis, the flue damper was assumed to fail in the tenth year of operation. Using a 6% discount rate, this yields a present value of $44.32 in 1998 dollars or an annualized maintenance cost over the ten year period of $6.02.

We also included the maintenance cost to replace the side arm water heater circulation pump. In this analysis, based on contractor's estimates, we assumed that annually 10% of the installations would require a replacement of the circulation pump. We estimated this cost using contractor estimates and the 1998/99 Grainger Catalog.

The maintenance cost of the side arm water heater circulation pump is based on $82.20 pump replacement cost,[43]installation kit cost of $23.12, and labor cost of $37.00.[44] This cost is applied to 10% of the installations each year. In addition, an average of $5/year is added to cover other miscellaneous costs [45] These yield $14.73 for the annual maintenance cost associated with the side arm design option. We assumed IID maintenance cost to be equivalent to the maintenance cost of the replaced standing pilot and therefore did not assign an incremental cost to it.

With the exception of the electromechanical flue damper and the side arm circulation pump, there is virtually no maintenance of residential gas-fired water heaters. Side arm gas-fired water heater designs may incur increased maintenance costs due to fouling of the heat exchanger from hard water, but no data were identified or provided to confirm this. It should be noted that manufacturers recommend that water heaters be drained and flushed annually to minimize deposition of sediment, maintain operating efficiency and prolong equipment life.

8.4.7 Cost-Efficiency Data

The results of the design option analysis for 40-gallon (150-liter) gas-fired water heaters are presented below in Tables 8.4.25 and 8.4.26. Disaggregated manufacturer costs, retail prices, installation costs, maintenance costs, energy factor, energy use, and payback periods included in the cost and efficiency tables. Design options were added incrementally in order of shortest payback period relative to the baseline model. A full description of the labels for the analyzed design options are presented in Table 8.4.27.

The existing baseline design with HCFC-141b foam insulation is also presented in Tables 8.4.25 and 8.4.26 to show the manufacturer cost and retail price differences. For purposes of this analysis, the cost effectiveness of all design options was evaluated relative to the 2003 baseline designs. Energy costs are from national average energy prices for the year 2003 from DOE/EIA's *Annual Energy Outlook 2000.*

The results show that, using HFC-245fa as the blowing agent, the highest EF attainable is 0.715, which can be achieved by using a side arm design, electronic ignition, an efficient flue baffle, a plastic tank, 3-in. (7.6-cm) jacket insulation and heat traps. The payback period for this design is 10.51 years. Energy savings are 7.70 million Btu/year based on the DOE test procedure. Models incorporating heat traps, 2-in. insulation, and 78% RE (Improved Flue Baffle) have an EF of 0.592 and a payback of 3.38 years. This design saves 1.92 million Btu/year.

As described earlier in this report, the EF and other parameters of the water heater, such as the UA, were determined from output generated by the TANK simulation model under the conditions of the DOE water heater test procedure.

Figure 8.4.2 depicts the relationship between increased consumer cost and increased operating cost (expressed as a simple payback period) and EF for the selected design options for the 2003 baseline. One exception is the design option #4 (in Table 8.4.26b) incorporating heat traps, 2.5-in. insulation, and 78% RE (Improved Flue Baffle), which has a payback of 4.89 years. This design option is ranked before the design option #5 incorporating heat traps, 2-in. insulation, and 80% RE (Improved Flue Baffle), which has a payback of 4.26 years. The reason is that the design option #5 has a negative life-cycle cost (in LCC analysis) due to the very high relining cost encountered by some households, while the design option #4 has a positive life-cycle cost (in LCC analysis) due to the lower magnitude of the additional cost due to the introduction of the tempering valve encountered by some households.

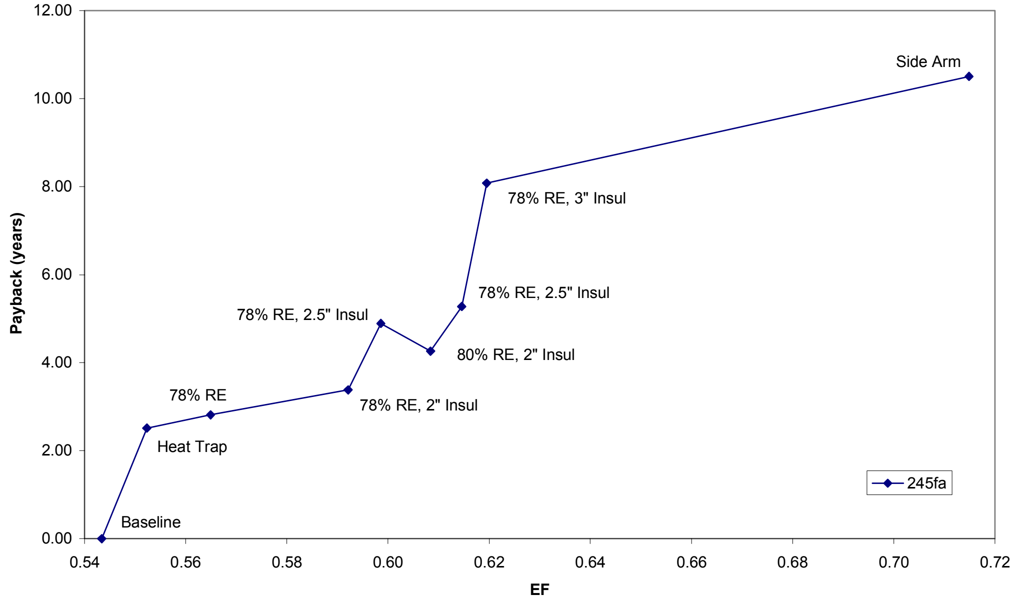

Figure 8.4.2 Payback Period vs. Energy Factor: Gas-fired Water heaters, 40-gal (150-litter)

Table 8.4.25 Cost Table for 40-gal (150-liter) Gas-Fired Water Heater

		Incremental Variable Costs [1,2]					Incr. Fixed Costs [1,2]			Total	Mfg. to			
Desig No.	Design Options	Material $	Labor $	Transp $	Overhead $	Total Variabl $	Capital $	Product Design $	Total Fixed $	Mfg. Cost $	Retail Markup	Retail Price[1,3] $	Install. Cost[1] $	Maint. Cost[1] $
00	Existing Baseline	75.02	10.74	9.67	38.35	133.78	0.00	0.00	0.00	133.78	1.35	180.76	159.00	0.00
0	2003 Baseline	1.11	0.00	0.00	15.00	16.11	0.00	20.00	20.00	169.89	1.35	229.55	159.00	0.00
1	Heat Traps	2.75	0.16	0.00	0.19	3.10	0.07	0.13	0.20	173.19	1.35	234.01	159.00	0.00
2	78% RE	3.72	1.41	0.00	1.57	6.70	-	-	3.04	179.63	1.35	242.72	165.73	0.00
3	78% RE, 2" Insulation	13.33	2.00	2.56	3.97	21.86	-	-	4.47	196.22	1.35	265.13	166.44	0.00
4	78% RE, 2.5"	18.27	2.59	5.12	6.37	32.35	-	-	5.48	207.22	1.35	280.67	176.12	0.00
5	80% RE, 2" Insulation	13.33	2.00	2.56	3.97	21.86	-	-	4.47	196.22	1.35	265.13	203.22	0.00
6	80% RE, 2.5"	18.27	2.59	5.12	6.37	32.35	-	-	5.48	207.72	1.35	280.67	212.90	0.00
7	80% RE, 3" Insulation	24.33	3.18	9.60	8.77	45.88	-	-	6.49	222.16	1.35	300.32	256.09	0.00
8	Side Arm	97.86	7.85	19.34	29.92	154.97	-	-	16.38	341.24	1.35	461.08	290.22	14.73

[1] All costs and prices in 1998$.
[2] Incremental variable and fixed costs are per unit costs.
[3] Retail prices are calculated based on the manufacturer cost-to-retail price markup of 1.2869. An additional sales tax of 5% is applied.

Table 8.4.26 Efficiency Table for 40-gal (150-liter) Gas-Fired Water Heater

Design No.	Design Options	Energy Factor	Recovery Efficiency	UA	Thermal Efficiency[2]	Fuel Energy Use Daily *Btu/day*	Fuel Energy Use Yearly *MMBtu/year*	Electrical Energy Use Daily *kWh/day*	Electrical Energy Use Yearly *kWh/year*	Payback Period [1] *years*
00	Existing Baseline	0.5440	0.7571	13.99	0.78	78558	28.67	0.00	0.00	0
0	2003 Baseline	0.5434	0.7572	14.02	0.7808	78579	28.68	0.00	0.00	0
1	Heat Traps	0.5523	0.7561	13.16	0.7808	77843	28.41	0.00	0.00	2.51
2	78% RE	0.5649	0.7717	12.79	0.798	75644	27.61	0.00	0.00	2.81
3	78% RE, 2" Insulation	0.5921	0.7799	10.91	0.7975	73297	26.75	0.00	0.00	3.38
4	78% RE, 2.5" Insulation	0.5986	0.7818	10.53	0.7974	72787	26.57	0.00	0.00	4.89
5	80% RE, 2" Insulation	0.6084	0.8002	10.59	0.8188	70809	25.85	0.00	0.00	4.26
6	80% RE, 2.5" Insulation	0.6146	0.8022	10.21	0.8187	70320	25.67	0.00	0.00	5.28
7	80% RE, 3" Insulation	0.6195	0.8027	9.94	0.8187	69956	25.53	0.00	0.00	8.08
8	Side Arm	0.7149	0.8000	3.99	-	57210	20.88	0.080	29.32	10.51

[1] Annual operating cost for Payback Period calculation established with a gas price of $6.60 /MMBtu and an electricity price of $0.0756 /kWh in 1998$.
[2] Thermal Efficiency is used to determine the risk of venting system corrosion.

Table 8.4.27 Definition of Design Options—Gas-Fired Water Heaters

Short Name		Full Description
00	Existing Baseline	Baseline (141b)
0	2003 Baseline	Baseline (245fa)
1	Heat Traps	2003 Baseline + Heat Traps
2	78% RE	2003 Baseline + Heat Traps + 78% RE
3	78% RE, 2" Insul	2003 Baseline + Heat Traps + 78% RE + 2" Insulation
4	78% RE, 2.5" Insul	2003 Baseline + Heat Traps + 78% RE + 2.5" Insulation
5	80% RE, 2" Insul	2003 Baseline + Heat Traps + 80% RE + 2" Insulation
6	80% RE, 2.5" Insul	2003 Baseline + Heat Traps + 80% RE + 2.5" Insulation
7	80% RE, 3" Insul	2003 Baseline + Heat Traps + 80% RE + 3" Insulation
8	Side Arm	2003 Baseline + Heat Traps + 80% RE + 3" Insulation + Side Arm + Electronic Ignition + Plastic Tank

8.5 OIL-FIRED WATER HEATERS

Oil-fired water heaters are typically constructed with 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). Both use an oil burner consisting of oil pump, blower, ignition device, and controls. In a center-flue design, combustion products are vented through a flue that goes up the middle of the storage tank. Rear-flue designs allow combustion gases to travel around the outside of the storage tank. Rear-flue oil-fired water heaters have significantly more heat exchange area between the storage tank and flue gases, and thus, typically have higher RE and input ratings than center-flue designs of similar storage volumes. However, there is also more heat transfer area for off-cycle losses to the flue. Because center-flue designs are much more common in residential use, the DOE analysis for oil-fired water heaters only considers center-flue designs.

The pump and blower of an oil-fired water heater are powered by a single motor. The blower provides for proper mixing of oil and combustion air. The oil and air mixture is electrically ignited with a high-voltage spark. In most burners, this spark operates continuously as long as the burner is firing. Because the spark does not operate when the burner is off, the ignition system is referred to as an intermittent ignition.

Oil-fired water heaters have higher input ratings and thus higher recovery rates than similar sized gas-fired water heaters. Because of the relatively high recovery rates, storage tank volumes are slightly smaller than those of gas-fired or electric water heaters. The two common tank volumes for oil-fired water heaters are 32 gallons (120 liter) with an input rating between 85,000 and 95,000 Btu/hr (24,905 to 27,835 watts) or 50 gallons (189 liter) with an input rating between 100,000 and 110,000 Btu/hr (29,300 to 32,230 watts). Discussions with installers and manufacturers indicate that the bulk of the residential market uses 32-gallon oil-fired water heaters and this is the size of the baseline model in our engineering analysis.

8.5.1 Existing Baseline Model

The first step in analyzing energy-efficiency design options is to characterize existing models. The existing oil-fired water heater used in this analysis has an EF of 0.529, an RE of 75% and an input of 90,962 Btu/hr (90,000 Btu/hr of fuel oil and 282 W, i.e.962 Btu/hr, for the pump and blower motor) during firing.

Table 8.5.1 summarizes characteristics of the baseline oil-fired water heater. Jacket insulation is assumed to be 1 in. of HCFC-141b foam, which is characteristic of water heater models known to closely match the current minimum efficiency standards. Many existing oil-fired water heater models use fiberglass insulation; however they typically have more than 1 in. of insulation. Our analysis did not model the water heater's combustion chamber. The values in Table 8.5.1 describe the water heater in engineering terms as they are used in heat transfer calculations.

Table 8.5.1 Oil-Fired Water Heater Baseline Model Characteristics

Descriptive parameter	Value
Input Rating (oil)	90,000 Btu/hr (26,377 W)
On-cycle power consumption	282 W
Off-cycle power consumption	0.0 W
Tank	
Inside Diameter	17.892 in. (40.366 cm)
Steel Wall Thickness	0.054 in. (0.1372 cm)
Height	32.7 in. (83.1 cm)
Volume	32.0 gallons (120 liter)
Jacket	
Foam insulation thickness	0.981 in. (2.492 cm)
Sheet metal thickness	0.019 in. (0.0483 cm)
Thermal conductivity of foamed assembly	0.0140 Btu/hr·ft·°F (0.0242 W/m·K)
Outer Jacket Emissivity	0.87
Flue	
Internal Diameter	6.00 in. (15.24 cm)

In order to determine the water heater's daily energy consumption, we first determine its hours of operation, using the following equation:

$$BOH = \frac{Q_{draw}}{EF \cdot P_{on}} \quad \textbf{(Eq. 8.5.1)}$$

where:

- *BOH* = burner operating hours, the number of hours per day the burner is on (hrs/day),
- Q_{draw} = the amount of heat added to the water in the daily draw under the DOE test procedure, (41,094 Btu/day or 43,346 kJ/day),
- P_{on} = the total energy consumption rate (both electrical and fuel oil) when the burner is firing (Btu/hr)

For the existing model, this calculation results in 0.854 burner operating hours per day. Using the DOE test procedure as a guideline, daily energy consumption is calculated from the electrical and oil input rates multiplied by the number of operating hours per day. This results in an oil consumption of 76,860 Btu/day (81,072 kJ/day) and an electrical energy consumption of 241 Wh/day.

The standby heat loss coefficient (UA) from the DOE test procedure was estimated using the following equation:

$$UA = \frac{\frac{1}{EF} - \frac{1}{P_{on}}}{(T_{tank} - T_{amb}) \cdot \left| \frac{24}{Q_{draw}} - \frac{1}{RE \cdot P_{on}} \right|} \quad \textbf{(Eq. 8.5.2)}$$

Plugging in the appropriate values for EF, RE, and P_{on} results in a UA of 14.494 Btu/hr-°F (7.64 W/°C) for the existing model. By definition, UA consists of standby heat losses through the tank shell, fittings, and the flue during the off-cycle. It is the amount of input energy necessary to maintain the hot water at a constant temperature. Table 8.5.2 summarizes the performance characteristics of the existing baseline model.

Table 8.5.2 Performance Characteristics for Existing Baseline Oil-Fired Water Heater

Description	UA		RE	EF	Oil Use		Electrical Use
	Btu/hr - °F	(W/°C)	*(%)*		*Btu/day*	*(kJ/day)*	*Wh/day*
Existing Baseline	14.494	(7.64)	75%	0.529	76,860	(81,072)	241

Continuous losses, on-cycle flue losses, and off-cycle flue losses are determined from two equations. The first equation states that the sum of the rates of heat loss multiplied by the hours of each type of loss equals the total consumption minus delivered energy. The second equation is based on the definition of RE, i.e., total on-cycle losses equal the energy input minus the hot water energy removed from the tank during the recovery portion of the DOE test procedure. The two equations can be written as follows:

$$24 \cdot Loss\_continuous + (24\text{-}BOH) \cdot Loss\_Flue\_off + BOH \cdot Loss\_flue\_on = Q_{draw} / EF - Q_{draw} \quad \textbf{(Eq. 8.5.3)}$$

$$Loss\_continuous + Loss\_flue\_on = Input \cdot (1 - RE) \quad \textbf{(Eq. 8.5.4)}$$

where:

Loss_continuous = continuous losses through the jacket insulation and out the fittings, (Btu/hr) or (Watts),
Loss_flue_on = on-cycle losses up the flue, (Btu/hr) or (Watts),
Loss_flue_off = off-cycle losses up the flue as well as other off-cycle non-continuous losses, (Btu/hr) or (Watts)

These losses are not used for calculating energy consumption, but as the basis for determining heat loss rates for the energy-efficiency design options.

8.5.2 Modeling Design Options

8.5.2.1 2003 Baseline

As discussed in Chapter 3.4, the blowing agent HFC-245fa has a 3.0% higher conductivity than HCFC-141b, which is currently used. To compensate for increased conductivity, we increased the thickness of the HFC-245fa insulation. Thus, the conductivity value of the foam insulation in the baseline model listed in Table 8.5.3 was increased to a value of 0.0144 Btu/hr·ft·°F (0.0249 W/m·K) to match the conductivity of HFC-245fa insulation. In addition, the thickness of the foam insulation surrounding the tank was increased from 0.981 in. (2.492 cm) to 1.01 in. (2.56 cm) to compensate for the HFC-245fa based insulation's increased conductivity. This increase in insulation thickness resulted in an increase in sheet metal for the jacket.

Table 8.5.3 summarizes the changes to the existing baseline model with HCFC-141b in order to match its performance with the other blowing agents. All other design options are analyzed using HFC-245fa as the blowing agent for the tank insulation. Table 8.5.4 summarizes the results for the performance characteristics of the 2003 baseline model.

Table 8.5.3 Jacket Insulation Characteristics for Oil-fired Baseline Water Heaters

Descriptive Parameter	Baseline w/ HFC-141b	Baseline w/ 245fa
Insulation thickness	0.981 in. (2.492 cm)	1.01 in. (2.56 cm)
Insulation conductivity	0.0140 Btu/hr·ft·°F (0.0242 W/m·K)	0.0144 Btu/hr·ft·°F (0.0249 W/m·K)

Table 8.5.4 Performance Characteristics for 2003 Baseline Oil-Fired Water Heater

Description	UA		RE	EF	Oil Use		Electrical Use
	Btu/hr ˚F	W/˚C	*(%)*		*Btu/day*	*kJ/day*	*Wh/day*
2003 Baseline w/ 245fa	14.49	(7.64)	75	0.529	76,860	(81,072)	241

8.5.2.2 Heat Traps

Heat traps were analyzed for oil-fired water heaters. Heat traps prevent the losses associated with the convective circulation of hot water into the piping when hot water is not being used.

An estimate of the efficiency impact of heat traps is based on test data reported by the industry.[46] These data indicates that EF savings from heat traps on oil fired units are 0.06. Modeling a 32-gallon oil-fired water heater with heat traps using this assumption yields energy savings of approximately 860 Btu/day. The UA increase to 13.94 Btu/hr of the performance parameters to achieve the heat traps' efficiency impact are shown in Table 8.5.5.

Table 8.5.5 Analysis Results for Heat Traps Design Option

Design Option	UA		RE %	EF	Oil Use		Electrical Use
	Btu/hr ˚F	*(W/˚C)*			*Btu/day*	*(kJ/day)*	*W-h/day*
Heat Trap	13.94	(7.35)	75	0.535	76,001	(80,166)	238

The energy savings estimated for heat traps installed in oil-fired water heaters are less than on gas-fired products.

Heat traps on the inlet water side use a ball that is lighter than water to prevent the water circulation when hot water is not being used. There are small slots cut into the seat that the ball floats against. These slots allow a small flow of water from the tank up the inlet piping to relieve pressure in the tank. The slots on the inlet seat are designed to provide more flow area in oil-fired water heaters than in gas-fired water heaters. The required rate of water flow through the slots is determined by the rate of temperature rise in the tank. The rate of temperature rise is a function of heat input. Since the heat input for an oil-fired water heater is more than twice that of a gas-fired water heater, a well designed heat trap requires twice as much by-pass area as slots in the seat of heat traps for gas-fired water heaters. Hence, for the time during standby, the oil-fired water heater heat trap performance is lower.

8.5.2.3 Increased Jacket Insulation

Most oil-fired water heaters on the market today have at least 1-in. (2.5 cm) thick jacket (sides and top) insulation. The analysis assumes that polyurethane foam insulation is used on the baseline performance model. Although increasing the insulation thickness reduces the standby loss, it does affect manufacturing costs and shipping costs, and may present installation problems. Because of these potential problems, the maximum insulation thicknesses were limited to 3 in. (7.6 cm). This appears to be the maximum thickness of insulation used by any manufacturer of current residential electric, gas, or oil water heaters. We estimated the performance of an oil-fired water heater with 2, 2.5, and 3-in. (5.1 cm, 6.4 cm, and 7.6 cm) insulation.

This design option increases the diameter and the total height of the water heater. The only other change is to enlarge the entire water heater jacket to accommodate the increased thickness of insulation.

A water heater designer will either increase the fiberglass insulation thickness around the combustion chamber or increase the internal dimensions of the combustion chamber to maintain a smooth cylindrical jacket on the water heater. Either approach increases costs. The addition of insulation may require that the burner be recessed or that the length of the burner blast tube be increased to maintain proper placement of the nozzle in the combustion chamber. This analysis does not account for any resulting changes in heat loss from the combustion chamber.

Jacket heat losses are calculated as conductive losses through jacket insulation as well as convective and radiative heat transfer from the jacket to the surrounding air and environment. Side insulation is modeled as a hollow cylinder with an inner diameter equal to the tank diameter (18 in. or 45.7 cm) and the same height as the tank (32.7 in. or 83.1 cm). Top insulation is modeled as a disk (18 in. diameter 45.7 cm) with a hole for the flue in the center (6 in. diameter 15.2 cm). Details of the calculation for total conductive heat loss from the top and sides of the storage tank are provided in Appendix D-4.

Both RE and UA are changed by the reduction in total jacket heat loss as it occurs continuously during water heater use. Because jacket losses are continuous losses, they are related to the RE through equation (8.5.5):

$$Loss\_continuous + Loss\_flue\_on = P_{on} \cdot (1 - RE) \qquad \textbf{(Eq. 8.5.5)}$$

Thus,

$$RE = 1 - (Loss\_continuous + Loss\_flue\_on) / P_{on} \quad \textbf{(Eq. 8.5.6)}$$

And subtracting the RE for two different levels of jacket losses when all other losses are held constant gives

$$RE_2 - RE_1 = (Loss\_continuous_1 - Loss\_continuous_2) / P_{on} \quad \textbf{(Eq. 8.5.7)}$$

or

$$RE_2 - RE_1 = (Jacket\_loss_1 - Jacket\_loss_2) / P_{on} \quad \textbf{(Eq. 8.5.8)}$$

In the DOE test procedure, the UA represents the average rate of tank energy input needed to maintain the water in the tank at a constant temperature during standby. The standby heat loss rate is calculated as:

$$Standby\ heat\ loss\ rate = UA\ (T_{tank} - T_{amb}) \quad \textbf{(Eq. 8.5.9)}$$

This standby heat loss rate includes continuous losses, flue losses when firing, and flue losses and piping losses during the off-cycle. An overall energy balance for the standby period yields:

$$UA \cdot (T_{tank} - T_{amb}) \cdot (24 - BOH_{draw}) = (Loss\_continuous + Loss\_flue\_off) \cdot (24 - BOH) + BOH_{st} \cdot P_{on} \cdot (1 - RE) \quad \textbf{(Eq. 8.5.10)}$$

where:
BOH_{draw} = Burner operating time to make up for hot water drawn from the tank (hr),
BOH_{st} = Burner operating time to make up for standby losses (hr).

BOH_{st} can be calculated from the total energy required during the standby period divided by the energy input during firing. The energy required to make up for losses during the standby period is equal to the energy input for the whole DOE test minus the energy that is actually used to heat water removed from the tank. In equation form, BOH_{st} is:

$$BOH_{st} = Q_{draw} \cdot (1/EF - 1/RE) / P_{on} \quad \textbf{(Eq. 8.5.11)}$$

And by default

$$BOH_{draw} = BOH - BOH_{st} \quad \textbf{(Eq. 8.5.12)}$$

Inserting equation (8.5.11) into equation (8.5.10) and solving for the loss components gives:

$$Loss_{continuous} + Loss_{flue\_off} = \frac{UA \cdot (T_{tank} - T_{amb}) \cdot (24 - BOH + BOH_{st}) - Q_{draw} \cdot (1 - RE) \cdot \left| \frac{1}{EF} - \frac{1}{RE} \right|}{24 - BOH} \quad \textbf{(Eq. 8.5.13)}$$

Plugging in the known parameters for the 2003 Baseline oil-fired model water heater and the same water heater with increased insulation gives combined *Loss_continuous* + *Loss_flue_off* values.

When insulation is added, continuous losses are reduced by the difference in jacket losses between the design with the increased insulation and the 2003 baseline. By solving the equations (8.5.1), (8.5.2), (8.5.11), and (8.5.13), we find UA and EF values that give the new combined Loss_continuous +Loss_flue_off value for the water heater with the increased insulation. Table 8.5.6 shows the results of this procedure for both 2003 models.

Table 8.5.6 HFC-245fa 2003 Models with 2-, 2.5-, & 3- in. Foam Insulation

Design Option	Insulation Thickness	UA *Btu/hr-°F*	RE (%)	EF -	Oil Use	Electrical Use *(W-h/day)*
with 2-in. foam insulation	2.00 in. (5.08 cm)	13.15	75.1	0.544	74703	234
with 2.5-in. foam insulation	2.50 in. (6.35 cm)	12.85	75.1	0.548	74218	233
with 3-in. foam insulation	3.00 in. (7.62 cm)	12.64	75.1	0.550	73888	232

8.5.2.4 Improved Flue Baffle

As described for gas-fired water heaters, improved flue baffle designs allow the extraction of more heat from the exhaust gases and increase the recovery efficiency of a water heater.

The energy savings for this design option are calculated by assuming that modification of the flue baffle will provide more efficient heat transfer to the storage tank. This design option will allow the water heater to achieve an RE of 0.78 by reducing *Flue_loss_on* only. No modifications to *Flue_loss_off* or *Loss_continuous* are assumed for this design option.

Concerns with condensing flue products do not appear to be a problem at an RE of 0.78. The references for existing rear-flue oil-fired water heaters report REs in this range, and the premium water heater products sold by Bock Water Heaters all exceed this RE.[47]

Improving only the RE from 0.75 to 0.78, while maintaining the sum of *Flue_loss_off* and *Loss_continuous* as for 2003 baseline model gives an EF of 0.550 as shown in Table 8.5.7.

Table 8.5.7 Improved Flue Baffle Design Option

Design Option	UA, *Btu/hr-°F*	RE %	EF -	Oil Use *Btu/day*	Electrical Use
Improved Flue Baffle	13.94	78.0	0.550	73934	232

8.5.2.5 Increased Heat Exchanger Surface Area

Several design options make up the category referred to as Increased Heat Exchange Surface Area. The design option we chose to analyze uses small projections from the inner flue surface to increase the heat-transfer area and increase turbulence along the inner flue wall.

This design option is used as one of a number of possible design modifications that would increase the surface area for heat exchange between the flue gases and water. These could include increased flue diameter with improved baffling, multiple flues, or internally finned flues. The Bock turboflue design uses many small rectangular fins welded in a helical pattern on the inside of the flue. The fins provide increased surface area for heat exchange with the flue gases and they create turbulence in the flue. Variations of this model have the highest efficiency rating listed in the GAMA directory for oil-fired water heaters. This type of internally finned flue is assumed to preclude the use of improved flue baffles; thus the "increased heat exchanger surface area" design option is really an alternative to the improved flue baffle design option.

The energy performance of the increased heat exchanger surface area design option is modeled by increasing the RE of the 2003 baseline model to 0.82. Several water heater models that include the Turboflue in their design have listed REs of 0.82. No modifications to *Flue_loss_off* or *Loss_continuous* are assumed with this design option.

Improving the RE alone, from 0.75 to 0.82, while maintaining the sum of *Flue_loss_off* and *Loss_continuous* as for the 2003 baseline model gives an energy factor of 0.578. Table 8.5.8 shows the performance for Increased Heat Exchanger Area Design Option.

Table 8.5.8 Increased Heat Exchanger Area Design Option

Design Option	**UA,** ***Btu/hr-°F***	**RE** **%**	**EF** **-**	**Oil Use** ***Btu/day***	**Electrical Use**
Increased Heat Exchanger Area	13.27	82.0	0.578	70363	220

The energy factor estimate above may be conservative. An examination of the energy performance parameters of several water heater models that use the Turboflue design suggests that much better energy performance can be achieved. For example, a 32-gallon (120 liter) water heater model 32PP (Bock) using the internally finned Turboflue design and 1" jacket insulation reports an energy factor of 0.66 and an RE of 0.82. Bock's standard design model 32E, also incorporating the Turboflue design, has a reported energy factor of 0.63 and an RE of 0.82.

Energy losses for Bock's model 32PP were partitioned as for the 2003 model. Using the EF (0.66), RE (0.82) and rated input (30,472 W) of the 32PP model from the GAMA directory in equation (B) gives a UA value of 7.652 Btu/hr (4.036 W/°C). Note, however, that it should actually be easier to achieve the RE of 0.82 on a water heater when the rated input is the same as that of the 2003 model. If losses are partitioned using the EF of 0.66, RE of 0.82, and rated input of 90,962 Btu/hr (26,652 W), the UA is 7.676 Btu/hr-°F (4.052 W/°C). Both of these examples suggest a considerable reduction in UA beyond what has been assumed for the increased heat exchanger surface area design option. Standby losses for the Bock 32PP model are reduced significantly from those estimated for the increased heat exchanger surface area design option. It is not clear how much of this reduction in standby loss can be attributed to the Turboflue design (which may restrict air movement during the off-cycle) and how much is achieved by other means. Note that the Bock 32PP model was used only as a comparison to our design option for achieving 82% RE. We represented the performance impact of a design option that would simply raise thermal efficiency to 82% using the WHAM equation.

8.5.2.6 Interrupted Ignition

Interrupted ignition turns off the ignition spark after a flame has been established and saves electrical energy by reducing the time the spark is operating. Interrupted ignition systems may also increase the life of the spark electrodes somewhat and thus may reduce maintenance costs.

Interrupted ignition saves electrical energy by shutting off the transformer that makes sparks. A typical intermittent ignition system with an iron-core transformer may draw approximately 1.7 Amps at 110 V during all hours that the burner operates. Thus, ignition system electrical energy for the increased heat exchanger surface area design option (the most efficient of the previous design options) would be calculated as:

$$Intermittent\_Ignition\_Energy = (1.7\ Amps)\cdot(110\ V)\cdot BOH \qquad \textbf{(Eq. 8.5.14)}$$

For the increased heat exchanger surface area design option, BOH is 0.746 hrs/day from equation (8.5.1).

Equation (8.5.14) ignores any power factor relationships in the transformer or electronic circuitry. The *Intermittent_Ignition_Energy* for the increased heat exchanger surface area design option is calculated to be 140 wh/day.

An interrupted ignition system fires for approximately 20 seconds each time the burner is ignited. The duration of each water-heater on-cycle is a function of household usage patterns. The DOE test procedure, with six 10.3-gallon draws per day, is the basis for this analysis. For most water heater designs, there is a single recovery for each draw, with the length of each recovery period given by $1/6^{th}$ of BOH_{draw} (see equation 8.5.12). For the increased heat exchanger surface area design option water heater, BOH_{draw} equals 0.551 hrs, and the recovery period after each draw is thus 0.092 hrs.

During standby periods the burner will fire on one or more occasions to make up for standby losses. Our working assumption is that the average tank temperature drops 20°F below the set point before firing is initiated, as dictated by the typical water-heater thermostat deadband. The energy required for each recovery is then the product of the actual storage volume of the water heater (estimated at 95% of the rated volume), the density and heat capacity of the water, and the water temperature rise during firing. The time for each individual recovery during standby can then be estimated as:

$$BOH_{recovery\_standby} = (Vol_{tank} \cdot dens \cdot C_p) \cdot (T_{rise}) / (P_{on} \cdot RE) \quad \textbf{(Eq. 8.5.15)}$$

where:

$BOH_{recovery\_standby}$ = the average time for **each** recovery during standby (hr)
Vol_{tank} = 0.95 * rated tank volume (gal)
T_{rise} = the difference between the average tank temperature before and after recovery (°F).

Solving the above equation yields an average $BOH_{recovery\_standby}$ equal to 0.0676 hr/day.

The number of firings during standby equals BOHst / $BOH_{recovery\_standby}$. Using the increased heat exchanger surface area design option gives 2.125 firings during the standby period. Thus, on average, the DOE test procedure would require the burner to fire an average of 8.125 times per day. At 20 seconds of igniter operation per firing, this requires the ignition to operate for 0.045 hours per day.

The difference between intermittent ignition and interrupted ignition operating time is thus 0.701 hrs per day (0.746 hr - 0.045 hr), saving 131 wh/day of electrical energy. This represents 447 Btu/day reduction in the *Loss_burner_on* losses. If these energy savings are averaged over the total burner operating hours of 0.749 hrs/day for the increased heat exchanger surface area design option, there is an average reduction in electrical power draw of 176 W (602 Btu/hr).

Because the P_{on} is reduced by 602 Btu/hr (176 W) and the output of the water heater is unaffected, the definition of RE can be used to construct an equation for the RE that will result if interrupted ignition is added.

$$RE\_interrupted = (RE\_intermittent \cdot P_{on}\_intermittent) / (P_{on}\_interrupted) \quad \textbf{(Eq. 8.5.16)}$$

For the water heater described by the increased heat exchanger surface area design option, the change from an intermittent to an interrupted ignition results in an increase in RE from 0.820 to 0.825.

The UA is also affected, because the burner operates periodically during standby periods. Because the energy input to the tank during the standby period (represented by UA) is changed while the heat energy to the water during standby does not change, the ratio of the UA of the intermittent ignition system to the UA of the interrupted ignition system is equal to the ratio of the input (P_{on}) for the intermittent system to the input of the interrupted ignition system. Hence,

$$UA\_interrupted = UA\_intermittent \cdot (P_{on}\_interrupted / P_{on}\_intermittent) \quad \textbf{(Eq.8.5.17)}$$

The result is *UA_interrupted* = 11.142 Btu/hr-°F (5.88 W/°C). This UA, in combination with a calculated RE of 0.825 results in a EF of 0.610 from equation (8.5.2).

The same interrupted ignition analysis can be performed on the Improved Flue Baffle Design Option. The resulting performance parameters are: RE of 0.785, UA of 11.72 Btu/hr-°F (6.17 W/°C), and EF of 0.580. Table 8.5.9 shows the performance for the Interrupted Ignition Design Option.

Table 8.5.9 Interrupted Ignition Design (HFC-245fa 2003 Model)

Design Option	**UA**	**RE** *(%)*	**EF** -	**Oil Use** ***Btu/day***	**Electrical Use**
Interrupted Ignition + Improved Flue Baffle	13.32	78.5	0.560	73108	86
Interrupted Ignition + Increased Heat Exchanger Area	12.68	82.50	0.588	69577	82

NOTE: The savings from the interrupted ignition design option are based on use of a conventional magnetic transformer to provide high ignition system voltages. High-voltage generators used in electronic igniter circuitry typically use about 0.5 Amps, or less than a third the current draw of magnetic igniter circuitry.[48,49] Assuming the same hours of burner operation as for the increased heat exchange design option, the transition from magnetic to electronic ignition circuitry in an intermittent ignition system would save 90 Wh/day. This is 70% of the energy saved from going to an interrupted ignition system. Therefore, the adoption of an interrupted ignition system in a water heater with electronic ignition circuitry would result in net energy savings of only 51 Wh/day (176 Btu/day) as compared with intermittent electronic-ignition circuitry. Discussions with oil-fired water heater manufacturers indicate that electronic ignition circuitry is not commonly used in residential water heater burners but is available.

8.5.3 Manufacturer Costs

Manufacturing cost estimates for oil-fired water heater design options are broken down into variable and fixed costs. These cost estimates are shown in Table 8.5.10 and Table 8.5.11, and the assumptions and sources behind the estimates are discussed below. All fixed conversion costs have been amortized over a five year period and an assumed shipment volume of 5,000 units annually, unless otherwise noted.

8.5.3.1 Existing Baseline

Baseline cost for the oil-fired water heater tank (without burner) was estimated based on data provided by a consultant under contract to LBNL. Manufacturers of oil-fired water heaters use both fiberglass and foam insulation in their baseline models; for the purposes of this analysis, baseline costs are assumed to be equivalent for models with fiberglass or foam. A calculation of the volume of foam and shell material for the baseline model was made independently of the data supplied by the consultant. For a 32-gallon baseline model, the total mass of the insulation was estimated at 2.77 lbs of HCFC-141b foam. The unit price for HCFC-141b based insulation was estimated at $1.00/lb, yielding a total insulation cost for the 32-gallon water heater of $2.77/unit. Total jacket material is 16.87 lbs of steel at $0.30/lb, resulting in a manufacturer cost of $5.06. Total material cost for insulation and jacket is $7.83. This cost information was used in determining the cost impact of increasing insulation thickness on oil fired water heaters.

8.5.3.2 2003 Baseline

The 2003 model assumed 1.01 in. of HFC-245fa-based insulation on the top and sides of tank. For 32-gallon tank the total mass of the insulation was estimated at 2.86 lbs. Assuming a cost of $1.32/lb for HFC-245fa-based insulation, total insulation cost was estimated at $3.77. Total shell material was estimated to be 16.93 lbs of steel at $0.30/lb for a total shell cost of $5.08. Total materials cost for foam and shell is $8.85, $1.02 more than for the baseline model. Because the year 2003 phase-out of HCFC141b as a foaming agent is unrelated to the DOE's energy-efficiency mandate and its cost will be borne by the manufacturers regardless of mandated efficiency improvements, fixed costs for the 2003 design option have not been estimated.

Additional labor costs of $0.29/unit and additional overhead burdens of $0.99/unit were provided by the same source for the nominal 1 to 2-in. size increase. These costs were also assumed to vary linearly over the thickness change and, through interpolation, were estimated to cause a $0.13/unit labor cost increase and a $0.43/unit overhead burden increase for the 2003 design option. These were incorporated into the variable cost.

Finally, the addition of insulation can affect shipping costs for water heaters. An estimate of the impact on shipping cost was made based on GAMA's estimated increase in shipping costs of $2.56 for an increase of 1-in. of insulation on gas-fired water heaters (see GAMA Cost Data cited above). Linear interpolation was used to estimate this value for the 2003 oil-fired water heater design, resulting in an increase in shipping cost of $1.11. The GAMA data were reported to have included all additional shipping costs including carton size increase. The estimated carton costs provided by Eugene West and cited above were subtracted from the estimated increase in shipping costs based on the GAMA data. That revised shipping cost increase (not including the increase in carton size) was then estimated at $0.98.

8.5.3.3 Heat Traps

Variable cost estimates for heat traps are based on data gathered by two independent consultants. Both estimates were very similar. The estimates from the first reference are used here because they are slightly higher and therefore conservative, and were broken down into variable material, labor, and overhead costs. Fixed conversion costs to incorporate heat traps were developed from product design cost estimates. For a small manufacturer, the capital cost to incorporate heat traps was deemed negligible.

8.5.3.4 2-Inch Jacket Insulation

Variable costs to increase insulation from 1 to 2 in. (1.01 to 1.981 in. actual thickness) of HFC-245fa-based insulation were estimated based on a 0.98 inches increase in foam on both the top and side walls of the tank. Total foam mass for the 2-in. design was estimated at 6.01 lbs. At $1.32/lb for HFC-245fa-based insulation, the total foam cost is estimated at $7.93. The corresponding increase in tank jacket size increased the total mass of jacket steel to 19.16 lbs. Assuming an estimated $0.30/lb for jacket metal gives a jacket cost of $5.75. Total materials cost for foam and shell is $13.68. An additional cost of $0.76 for miscellaneous items such as foam stop blocks, paint, and larger shipping cartons was incorporated into the material costs based on data provided by E. West. Additional labor costs of $0.29/unit and additional overhead burdens of $0.99/unit, provided by the same source, were also incorporated into the variable cost. An estimate of the impact on shipping cost was made based on GAMA's estimated increase in shipping costs of $2.56 for an increase of 1-in. of insulation on gas-fired water heaters (GAMA Cost Data). The shipping carton cost ($0.30) was subtracted out of the GAMA estimate to yield a net shipping cost of $2.26. This value was added to the variable cost overhead, resulting in a net variable cost increase of $9.13 over that calculated for the 2003 model.

Fixed conversion costs for the 2-inch jacket insulation design option were based on data provided by E. West. These data assumed a small manufacturer, using spin forming to shape the top and bottom pans for the water heater, would incur an estimated $18,000 in engineering costs, and $20,000 in capital expenses to modify the production line. A manufacturer who used die stamping to produce the top and bottom pans could expect approximately $100,000 in new die costs alone. However, for a large manufacturer the cost for dies to cut and form the top and bottom pans would likely be amortized over an existing gas product line of similar diameter so that final per unit costs would likely be similar or less than experienced by the small manufacturer. The per unit costs were estimated assuming a production volume of 5,000 units per year over a 5 year amortization period. Estimated amortized fixed costs were $1.52/unit.

Discussions with manufacturers and installers of oil-fired water heaters have indicated that at least one-half of all installations of oil-fired water heaters are retrofits of new water heaters to existing oil burners. Oil burner life is typically at least twice that of the typical water heater tank; however, in some cases, if a new model or brand of water-heater is installed it may be impossible or costly to fit to an existing burner, and a complete installation of tank and new burner will be undertaken.

Because the cost of a new burner is a significant fraction of the cost of the water heater tank on most models, it is desirable to attach an existing burner to a new water heater. This would pose a significant problem with added jacket insulation, which would affect burner placement and thus the combustion characteristics of the water heater. The solution, suggested by several industry members, was for manufacturers to provide a kit that allows replacement of the nozzle and blast tube on the existing burner with a nozzle and blast tube that would be suitable for a new, more insulated model. The estimated cost for manufacturing and stocking this kit was between $20 and $40 . The midpoint of that range plus a labor charge of $6.50 (20 minutes of service at $19.50/hour) are added when tanks using the 2-inch jacket insulation design are retrofit to existing burners.

8.5.3.5 2.5- and 3-Inch Jacket Insulation

Costs for 2.5 inches and for 3 inches of insulation (nominal) were estimated in a similar fashion to those calculated for 2-in. insulation models. The cost increases for foam and metal were calculated based on the increase in foam thickness and exposed shell of these proposed models, using the foam and steel costs shown previously. Cost increases for paint, foam stop blocks, labor, overhead burdens, and shipping were based on linear extrapolation of the cost increase in going from the existing baseline to 2-in. insulation thickness models. No costs were provided for longer blast tube extension kits for 2.5 or 3 in. of insulation (nominal thickness). For this analysis, the costs for the kit were assumed to be essentially independent of the length of the extension.

With regard to fixed costs, engineering costs to design water heaters with different thickness of insulation would be relatively constant for a small manufacturer regardless of insulation thickness (basically these are thought to be for design of manufacturing equipment and for testing requirements). However other costs, such as actual modifications to equipment, would likely increase with different thickness. The estimates for fixed cost for 2.5-in. and for 3-in. insulation levels are based on assuming design costs equivalent to that assumed for 2 inches of insulation, but assuming capital costs for conversion vary linearly with total insulation thickness.

8.5.3.6 Improved Flue Baffles

Variable costs for improved flue baffles were estimated as $3.75 for material, $0.55 for labor, and $1.00 per unit for overhead costs based on reference data. Fixed costs for improving the flue baffle design are estimated at $300,000 for production improvements and $500,000 for product design.

8.5.3.7 Increased Heat Exchanger Surface

Variable costs for increasing heat exchanger surface area were estimated at $17.25/unit for material costs, $1.75/unit for labor costs, and $4.25/unit in overhead. Fixed conversion costs for this design option were estimated at $1,500,000 for production improvements and $500,000 for product design.

The fixed costs reflect estimated product design and retooling necessary to achieve the necessary 82% recovery efficiency rating through modification of the heat transfer characteristics of a 32 gallon oil-fired water heater. No particular design is being emulated; however, the only products on the market, that presently achieve this performance are based on the Bock Turboflue design. This design uses a large number of fins welded to the inner flue surface in a helical pattern. Other options to improve the recovery efficiency include multiple flue designs, new baffle designs, or extruded fins on the flue and possibly combustion chamber surfaces.

8.5.3.8 Interrupted Ignition

Variable costs to incorporate interrupted ignition circuitry in oil burners was estimated at $16.50 materials costs. Discussions with a burner manufacturer indicated that the manufacturers' cost differential for interrupted versus intermittent controls was presently between $10 and $15, and that typically ignition controls are installed by burner manufacturers. The burner units with controls are then sent to the water heater manufacturer, who subsequently ships the burner to a distributer or equipment dealer. No additional overhead or labor costs were anticipated if interrupted ignition controls replace intermittent ignition controls. The manufacturer offered the opinion that in the near future, interrupted controls would likely be the most common control option offered on all burners. However, no attempt was made to indicate the effect of this change on the interrupted ignition control cost.

No fixed capital costs are anticipated for interrupted ignition. Design costs for water heater manufacturers are mostly for water heater testing and certification. These costs are estimated at $25,000, based on similar product testing costs for increased insulation and heat traps. These costs are assumed to be amortized over a five-year period.

8.5.4 Design Options' Retail Prices, Installation, and Maintenance Costs

Residential oil-fired water heaters are typically sold and installed by local residential heating oil dealers. Thus, it is difficult to separate installation cost from purchase price. Calls to 29 companies dealing in oil-fired water heating equipment were made; thirteen companies provided some consumer price data to PNNL. Based on this information as well as discussions with water heater and oil-burner manufacturers and two oil-heating associations, the following costs were established for the Engineering Analysis:

Typical consumer cost for a base performance oil-fired water heater without burner:	$446
Typical consumer cost for an oil burner for an oil-fired water heater:	$285
Typical installation cost for a new oil-fired water heater	$300-700

We found a very wide range of installation costs. Costs are much higher in small markets in some areas of the country. The installation cost for a typical oil-fired water heater was estimated at $491 based on data provided by seven dealers in the northeastern U.S.

At least 50% of oil-fired water heater installations involve fitting a new water heater tank to an existing burner. Thus, for this analysis, we assumed that 50% of oil-fired water heaters sold are retrofit to existing burners. Therefore, 50% of the installations of water heaters with 2-in. of insulation would require an oil burner modification kit. On average, the installation cost would rise to $509.25.

A typical manufacturer-to-consumer markup of 320% was used for all design options based on the $446 figure for the existing baseline oil-fired water heater cost (without burner). The estimated manufacturing cost of $139.25 is shown in Table 8.5.10 and Table 8.5.11.

A typical maintenance contract cost of $97.14/yr was included in Table 8.5.10. It is based on the data described above. This varies widely, depending on the presence of other oil-fired equipment in the residence. Because none of the design options is anticipated to significantly affect maintenance, this charge has no bearing on the final engineering analysis of the design options. It may, however, impact the economic analysis of possible fuel switching.

8.5.5 Cost-Efficiency Data

Table 8.5.10 and Table 8.5.11 present the relative first cost, performance and annual energy use predicted for HFC-245fa based design options considered for this analysis. The tables also show the annual energy cost and estimated simple payback for each design option. Annual energy costs were based on residential energy rates of $7.522/MMBtu for oil and $0.0788/kWh for electricity. Design options were selected based on cumulative payback. Note that there is a difference in the order of the selected design options between HFC-245fa and water-blown insulation based models. Design option #1 is "Heat Traps" followed by the "2" insulation + Heat Traps".

The results of the design option analysis for 32-gallon oil-fired water heaters are presented below. Disaggregated manufacturer costs, retail prices, installation costs, maintenance costs, energy factor, energy use, and payback periods are included in the cost-efficiency tables. Design options were added incrementally in order of shortest payback period relative to the 2003 baseline model. A full description of the labels for the analyzed design options is presented in Table 8.5.12.

The results show that, using HFC-245fa as the blowing agent, the highest EF attainable is 0.614, which can be achieved by using an intermittent ignition, 82%RE increased HX area, 3-in. (7.6-cm) jacket insulation and heat traps. The payback period for this design is 15.5 years. Energy savings are 3.6 million Btu/year, based on the DOE best procedure. The first selected design option combination is the 2003 Baseline plus Heat Traps, which has the shortest payback period of 6.1 years and has an EF of 0.535. This design saves 0.31 million Btu/year.

Figure 8.5.1 depicts the relationship between increased consumer cost and increased operating cost (expressed as a simple payback period) and EF for the selected design options for the 2003 baseline.

As described earlier in this report, the EF and other parameters of the water heater, such as the UA, were determined from engineering calculations under conditions of the DOE water heater test procedure.

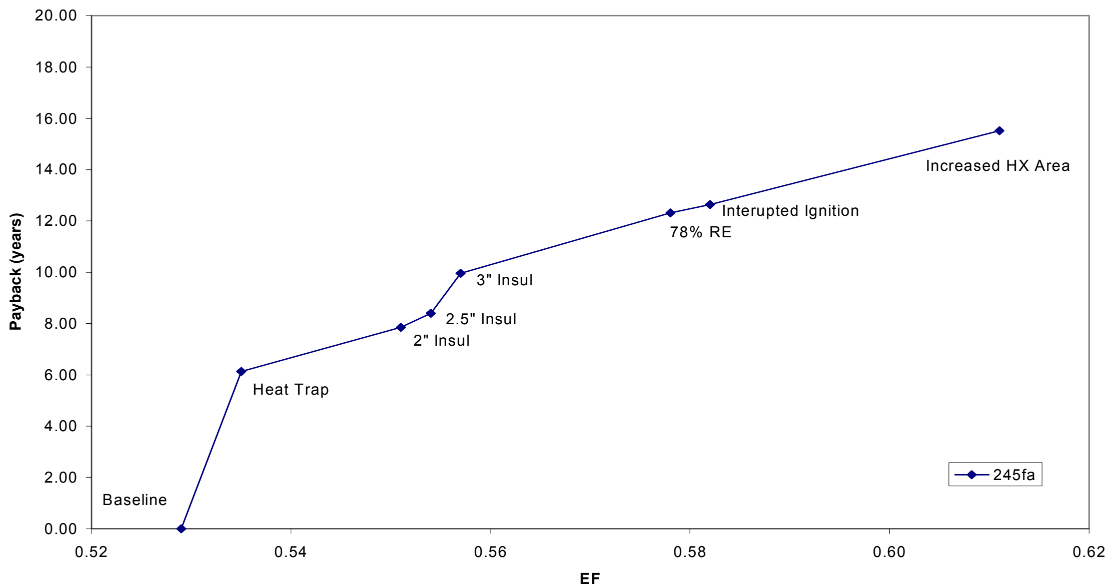

Figure 8.5.1 Payback Period vs. Energy Factor: Oil-Fired Water Heaters, 32-gal (120-liter)

Table 8.5.10 Cost Table for 32-gal (150-liter) Oil-Fired Water Heater—HFC-245fa 2003 Baseline

Design No.	Design Options	Incremental Variable Costs Material $	Labor $	Overhead $	Total Variable $	Total Fixed $	Total Mfg Cost $	Mfg. to Retail Markup	Retail Price $	Install. Cost $	Maint. Cost $
00	Existing Baseline	85.00	18.25	36.00	139.25	0.00	139.25	3.20	445.60	491.00	97.14
0	2003 Baseline	1.02	0.00	0.00	1.02	0.00	140.27	3.20	448.86	491.00	97.14
1	Heat Traps	3.97	0.15	0.05	4.17	1.52	144.94	3.20	463.81	491.00	97.14
2	2" Insulation	10.59	0.44	3.24	13.29	3.04	155.58	3.20	497.86	509.25	97.14
3	2.5" Insulation	13.69	0.59	4.86	18.16	3.24	160.65	3.20	514.08	509.25	97.14
4	3" Insulation	16.96	0.73	6.47	23.18	3.44	165.87	3.20	530.78	517.25	97.14
5	78% RE	20.71	1.28	7.47	28.48	35.44	203.17	3.20	650.14	517.25	97.14
6	Interrupted Ignition	37.21	1.28	4.49	44.98	36.44	220.67	3.20	706.14	517.25	97.14
7	Increased HX Area	54.46	3.03	11.72	62.93	84.44	286.62	3.20	917.18	517.25	97.14

Note: Annual energy costs are based on residential energy rates of $7.522/MMBtu of oil and $0.0787/kWh of electricity.

Table 8.5.11 Efficiency Table for 32-gal (150-liter) Oil-Fired Water Heater—HFC-245fa 2003 Baseline

Design No.	Design Options	Energy Factor	Recovery Efficiency	UA	Fuel Energy Use Daily *Btu/day*	Fuel Energy Use Yearly *MMBtu/year*	Electrical Energy Use Daily *Wh/day*	Electrical Energy Use Yearly *kWh/year*	Payback Period *years*
00	Existing Baseline	0.529	75.00	14.49	76860	28.05	240.8	217.94	NA
0	"2003" Baseline	0.529	75.00	14.49	76860	28.05	240.8	217.94	NA
1	Heat Traps	0.535	75.00	13.94	76001	27.74	238.1	215.50	6.14
2	2" Insulation	0.551	75.08	12.60	73844	26.95	231.4	209.39	7.86
3	2.5" Insulation	0.554	75.09	12.30	73358	26.78	229.9	208.01	8.40
4	3" Insulation	0.557	75.10	12.09	73028	26.66	228.8	207.07	9.96
5	78% RE	0.578	78.00	11.64	70340	25.67	220.4	199.45	12.31
6	Interrupted Ignition	0.582	78.52	11.57	70341	25.67	82.7	195.50	12.63
7	Increased HX Area	0.611	82.54	11.01	66939	24.43	79.1	186.06	15.51

Table 8.5.12 Definition of Design Options—Oil-Fired Water Heaters: HFC-245fa

	Short Name	Full Description
00	Existing Baseline	Baseline (141b)
0	2003 Baseline	Baseline (245fa)
1	Heat Traps	2003 Baseline + Heat Traps
2	2" Insulation	2003 Baseline + Heat Traps + 2" Insulation
3	2.5" Insulation	2003 Baseline + Heat Traps + 2.5" Insulation
4	3" Insulation	2003 Baseline + Heat Traps + 3" Insulation
5	78% RE	2003 Baseline + Heat Traps + 3" Insulation + 78% RE
6	Interrupted Ignition	2003 Baseline + Heat Traps + 3" Insulation + 78% RE + Interrupted Ignition
7	Increased HX Area	2003 Baseline + Heat Traps + 3" Insulation + Interrupted Ignition + Increased Heat Exchanger Area (82% RE)

8.6 ADDITIONAL BLOWING AGENTS

In addition to HFC-245fa, there are two other blowing agents besides water-blown insulation which have been approved by EPA as acceptable substitutes for HCFC-141b. These blowing agents are HFC-134a and cyclopentane. To evaluate their suitability for water heater applications, we conducted engineering cost analyses with each of them as the blowing agent in the insulation.

On April 7, 2000, Bayer Corporation issued a press release which states that most appliance manufacturers in North America are considering either HFC-245fa or HFC-134a.[50] Cyclopentane is not considered favorably because of the capital investment required to handle it safely (cyclopentane is highly flammable). Another factor contributing to the high costs are the manufacturing losses due to the fact that a factory must cease production while converting equipment to a cyclopentane system. However, appliance manufacturers are independently deciding which blowing agent to select. Switching to HFC-134a also involves capital costs, but significantly less than switching to cyclopentane. According to industry and Bayer research, HFC-134a demonstrates an insulation value approximately 10% lower than HCFC-141b, but has a lower per-pound cost than HFC-245fa.

We examined the impact on costs and product design of using HFC-134a and cyclopentane blowing agents to achieve a similar energy factor as the proposed levels for HFC-245fa (see Table 8.6.1 and Table 8.6.2 below). We included the 10% performance reduction for HFC-134a and an estimate of $7 per unit for the capitalization costs of cyclopentane in our engineering analyses. These analyses show that energy factors for all three blowing agents are within 1% of each other. Costs for all design options are within a few dollars for HFC-245fa (see Tables 8.3.18 and 8.4.25), HFC-134a, and cyclopentane. The test results and costs of using HFC-134a and cyclopentane-blown foam to evaluate design options can be found in Chapter 3.4.1 of this T.S.D.

Tables 8.6.1 and 8.6.2 show the trial standard levels, design options, energy factors, and installed costs for the two alternative blowing agents, HFC-134a and cyclopentane, respectively. Note that the energy factors are the same for blowing agents and for all trial standard levels. There are small differences in costs; HFC-245fa is the cheapest blowing agent, HFC-134a costs about \$2/unit more than HFC-245fa, while cyclopentane is the most expensive blowing agent, costing about \$7/unit more per installed water heater.

While we have not examined every possible blowing agent option (there are no currently no other blowing agents approved by EPA), we conclude that at least these two additional options can be used to achieve similar performance for comparable cost.

Table 8.6.1 Engineering Results for HFC-134a Blowing Agent

Trial Standard Level	Design Options	Energy Factor	Installed Costs ($)
1	Electric: Heat Traps +Tank Bottom Insulation	0.87	363.06
	Natural Gas: Heat Traps + Flue Baffles (78% RE) + 2 Inch Insulation	0.59	428.65
2	Electric: Heat Traps +Tank Bottom Insulation + 2 Inch Insulation	0.89	391.60
	Gas: Heat Traps + Flue Baffles (78% RE) + 2.5 Inch Insulation	0.60	454.39
3	Electric: Heat Traps + Tank Bottom Insulation + 2.5 Inch Insulation	0.90	428.01
	Gas: Heat Traps + Flue Baffles (78% RE) + 2 Inch Insulation	0.59	428.65
4	Electric: Heat Traps + 3 Inch Insulation + Plastic Tank	0.91	531.45
	Gas: Heat Traps +Flue Baffles (80% RE) + 3 Inch Insulation + Side Arm Heater + Plastic Tank + IID	0.71	749.41

Table 8.6.2 Engineering Results for Cyclopentane Blowing Agent

Trial Standard Level	Design Options	Energy Factor	Installed Costs ($)
1	Electric: Heat Traps +Tank Bottom Insulation	0.88	368.11
	Natural Gas: Heat Traps + Flue Baffles (78% RE) + 2 Inch Insulation	0.59	432.14
2	Electric: Heat Traps +Tank Bottom Insulation + 2 Inch Insulation	0.89	394.70
	Gas: Heat Traps + Flue Baffles (78% RE) + 2.5 Inch Insulation	0.60	445.56
3	Electric: Heat Traps + Tank Bottom Insulation + 2.5 Inch Insulation	0.90	428.79
	Gas: Heat Traps + Flue Baffles (78% RE) + 2 Inch Insulation	0.59	432.14
4	Electric: Heat Traps + 3 Inch Insulation + Plastic Tank	0.91	529.79
	Gas: Heat Traps +Flue Baffles (80% RE) + 3 Inch Insulation + Side Arm Heater + Plastic Tank + IID	0.72	749.25

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