Demonstrating Economic Justification: Updating Water Heater Efficiency Standards

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ABSTRACT

This paper summarizes the analyses that allowed Department of Energy (DOE) to select a revised standard for residential water heaters to produce the maximum improvement in energy efficiency that is technologically feasible and economically justified.

Designs that are not technically feasible, practicable to manufacture, safe, or that reduce consumer utility are screened out. Detailed computer simulations of the remaining designs predict energy consumption and simple payback. These results are used to calculate consumer life-cycle costs (LCC). The LCC calculations are repeated thousands of times to account for the variability and uncertainty of input variables driving water heater energy consumption. These calculations show average change in LCC and percent of population benefitting from different designs for a representative sample of U.S. households. From these results DOE chose trial standards to examine further.

Impacts on water heater shipments from changes in operating and first costs due to standards are estimated using a modified logit model. Forecasted shipments are used to estimate the affect on manufacturers. A computer-based, energy-economy modeling system of U.S. energy markets estimates the impact on utilities and emissions of applied end-use energy savings. A special-purpose national input-output model is used to assess job creation.

Introduction

Water heating is the third largest energy end use in the residential sector in the U.S. after space heating and "miscellaneous" other uses, see Figure 1. Water heating consumes about 2.53 quadrillion Btus (2.53 quads) of primary energy per year.(DOE 1995) Roughly comparable amounts of primary energy are consumed by electric and gas water heaters, which, together, account for about 90% of primary energy consumption for residential sector water heating.

This report describes the assessment of economic impacts of potential standards for residential water heaters.(DOE 2000b) The assessment includes analysis of: the water heater market; retail prices, manufacturing costs, and markups for water heaters; design options to improve water heater energy efficiency; and costs and benefits of efficiency standards to consumers, manufacturers, utilities, and the nation as a whole, including effects on employment.

Overview

The framework diagram, Figure 2, shows how DOE determined an appropriate standard.

Market and Technology Assessment. The *Market and Technology Assessment* defines baseline models and lists potential design options for each of the water heater product categories from information about the water heater market in the U.S.

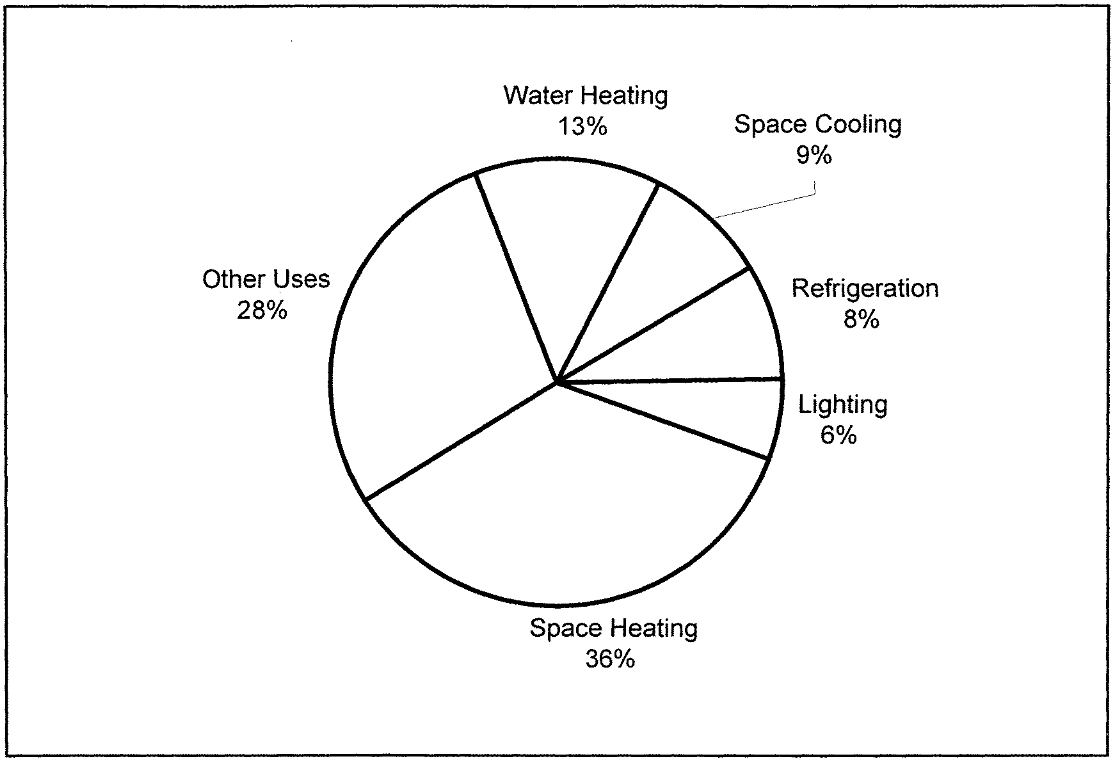

Figure 1. Primary Energy Consumption in the Residential Sector (1998)

Conventional storage type electric and gas-fired water heaters account for the vast majority of the installed base and current sales of water heaters in the U.S. A conventional, residential electric storage water heater consists of an insulated, glass-lined, steel hot water storage tank. It has a 0.86 energy factor (EF), the minimum allowed under the current standards. A typical gas-fired residential water heater is also an insulated, glass-lined, steel hot water storage tank. It has an EF of at least 0.54, the minimum allowed for the most common size tank.

Screening of Design Options. The first step in the rulemaking process is to identify those design options that will be considered for the analysis. The factors DOE uses for screening design options are: (DOE 1996)

- Technological feasibility.
- Practicability to manufacture, install, and service.
- Adverse impacts on product utility or product availability.
- Adverse impacts on health and/or safety.

DOE used the following design options in the analyses because they are currently (or have recently been) applied to commercial or residential water heaters and pass all of the screening criteria.

- Heat Traps
- Plastic Tank
- Increased Jacket Insulation
- Insulating the Tank Bottom (Electric Only)
- Improved Flue Baffle/Forced Draft

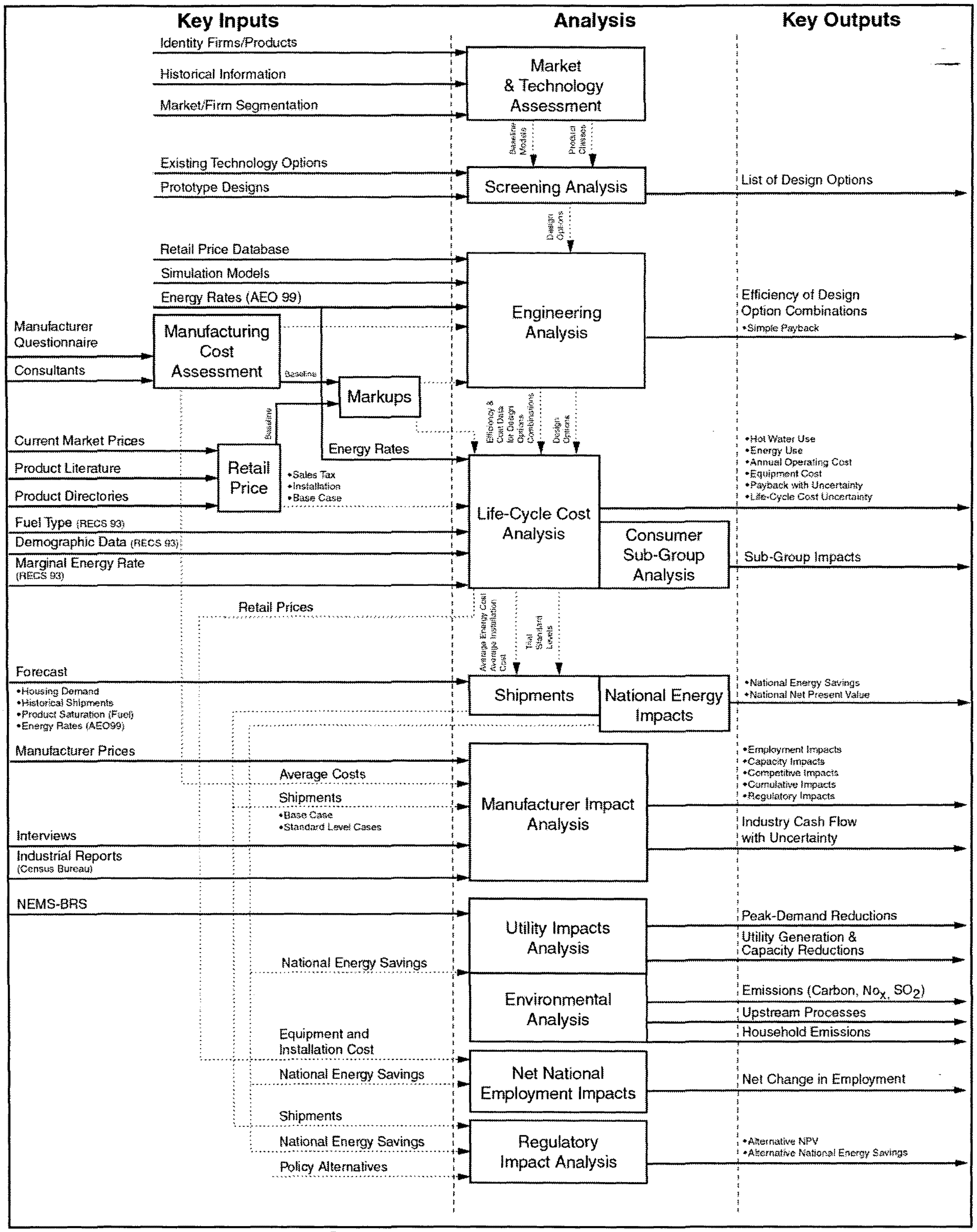

Figure 2. Impact Assessment Flowchart

- Increased Heat Exchanger Surface Area
- Flue Damper (Electromechanical)
- Side Arm Heater

- Electronic (or Interrupted) Ignition.

Engineering Analysis

The *Engineering Analysis* determines the increased efficiency from the design options and combinations of the design options using computer simulation models. The analytical methods are based on DOE's test procedure for residential water heaters. All prices for this analysis, including AEO99 (DOE 1998) energy prices, are national averages. We obtained manufacturers' cost data for design options from Gas Appliance Manufacturers Association (GAMA) and industry consultants. Also, we questioned retailers and installers around the country to obtain retail prices and installation costs of water heaters. The results of the *Engineering Analysis* are used to select and order the combination of design options for the *Life-Cycle Cost Analysis*. Energy consumption of EWH is modeled with WATSIM, a simulation model developed by EPRI.(Hiller, Lowenstein, and Merriam 1992)

EF and standby heat loss coefficient (UA) were determined from output generated by the WATSIM simulation model and DOE test procedure equations. Figure 3 shows the relationship between simple payback period (calculated from increased consumer cost and decreased operating cost) and EF for the selected design options.

Energy consumption for gas-fired water heaters is modeled with TANK, a computer simulation model developed for the Gas Research Intitute (GRI).(Paul et al. 1993) EF, UA, and recovery efficiency (RE) were determined under the conditions of the DOE water heater test procedure.

Figure 4 depicts the relationship between simple payback period and EF for the selected design options for gas-fired water heaters.

Life-cycle Cost (LCC) Analysis

The *LCC Analysis* determines life-cycle cost and cumulative payback compared to the baseline for consumers for design options on residential water heaters. Life-cycle cost represents the present value of the consumer's cost of purchasing and installing a water heater and operating it for its lifetime. To account for all the variability and uncertainty among consumers, the analysis is done 10,000 times drawing from a weighted sampling of 5,222 households with individual water heaters from RECS. (DOE 1995) Other inputs for the analysis are also represented as samples drawn from a range of values. In this way, the analysis accounts for the full range of variability and uncertainty of characteristics related to residential hot water use.

Much of the input for this analysis comes from the *Engineering Analysis*. The factory cost for the baseline models and the range of incremental cost of design options were supplied by the GAMA. For a few design options, where GAMA was unable to supply estimates of manufacturer costs, consultants familiar with the water heater industry were used.

The price of baseline models was from the LBNL Water Heater Price Database.(DOE 1999) Baseline models were defined as models with six-years or less of manufacturer warranties. To obtain markups, the retail prices were divided by the GAMA-supplied manufacturing costs for existing baseline models. A different markup was calculated for each sampled house, but was kept the same for all design options applied to the water heater in that house.

Installation costs were also taken from the database and included delivery, removal, and permit fees. Costs for miscellaneous parts used in installing a water heater, such as pipe fittings,

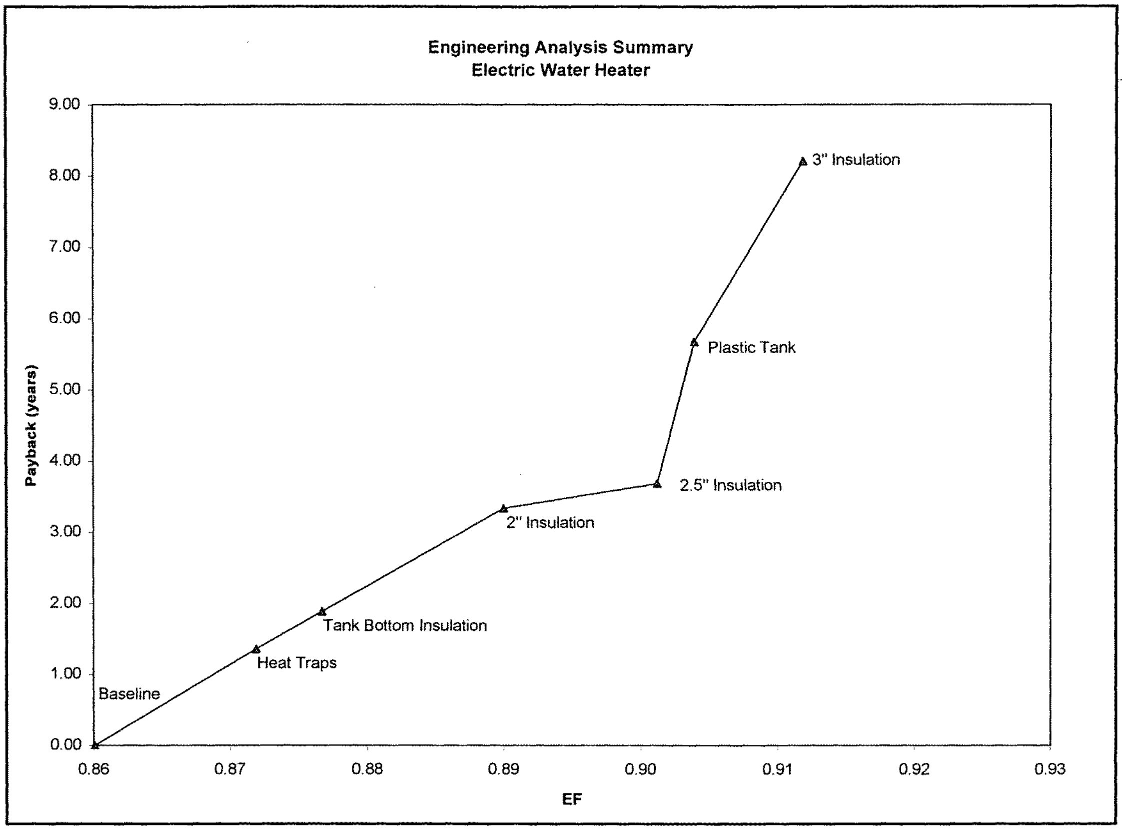

Figure 3. Payback Period vs. Energy Factor: Electric Water Heaters

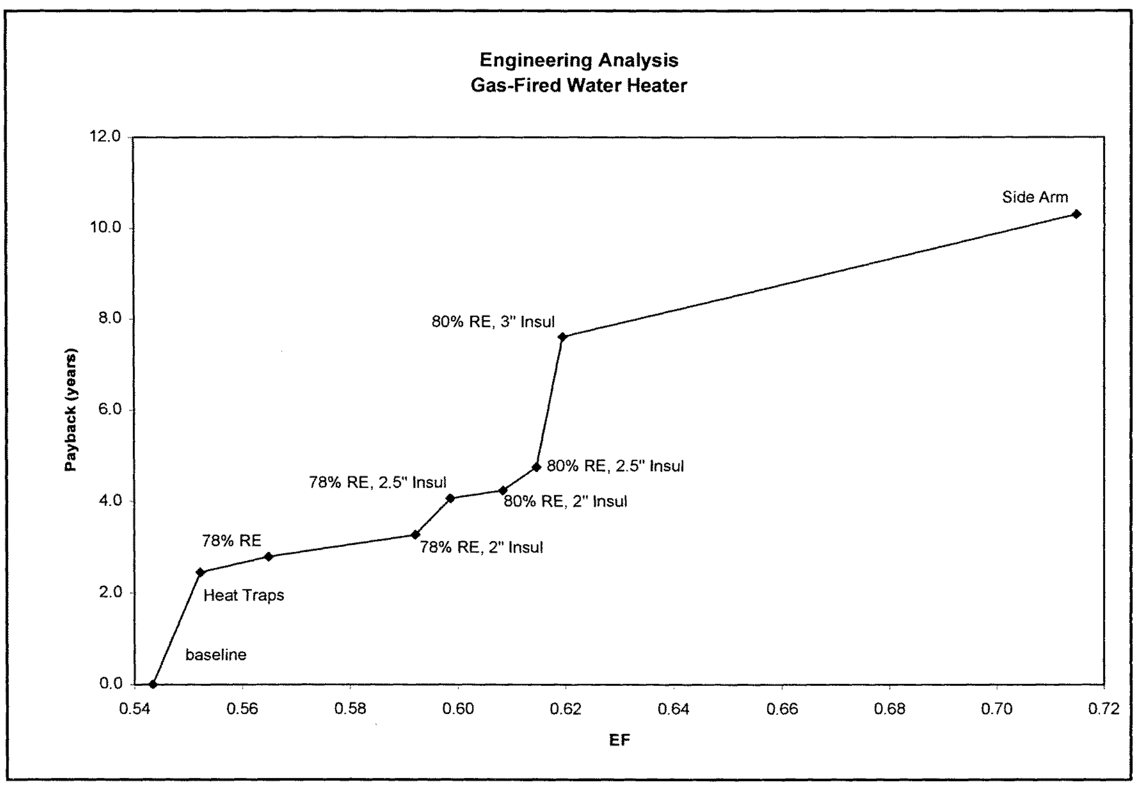

Figure 4. Payback vs. Energy Factor: Gas-Fired Water Heaters

were also added.

Energy consumption in the *LCC Analysis* was calculated using the Water Heater Analysis Model (WHAM)(Lutz et al. 1998). The energy parameters used by WHAM are from the simulation models used in the *Engineering Analysis*. Daily hot water use was calculated for individual households. Data from RECS was used to calculate marginal energy prices for residential appliance owners. We estimated consumer marginal energy prices directly for each RECS household by calculating the slopes of the regression lines relating customer bills to customer usage. For electricity, the slopes of the regression lines for four summer months (June-September) and, separately, for the remaining ("winter") months, were calculated. For natural gas we did not calculate seasonal rates.

The results of the *LCC Analysis* are used to choose the trial standard levels used in the later stages of analysis and decision-making. Outputs are also used by the *National Energy Impacts Analysis* and the *Utility* and *Environmental Analyses*. Results for electric water heaters are shown in Table 1 which lists the portion of the population benefitting in terms of reduced life-cycle cost, from each design option. An average LCC savings and median payback are also shown.

Table 1. Life-Cycle Cost and Payback for Electric Water Heaters

Design Option	Fraction of Population Benefitting (*%*)	Average LCC Savings (*$*)	Median Payback (*yrs*)
Heat Traps	93	27.3	1.4
Tank Bottom Insulation	91	32.2	2.5
2" Insulation	79	36.0	4.8
2.5" Insulation	74	40.1	5.4
Plastic Tank	46	1.0	8.5
3" Insulation	31	-55.3	11.7

For gas-fired water heaters, Table 2 lists the portion of the population that benefits, in terms of reduced life-cycle cost, from each design option. The average LCC savings and median payback are also shown.

Consumer Sub-group Analysis

The *Consumer Sub-Group Analysis* examines the economic impacts of possible water heater energy-efficiency standards on different groups of consumers. Of particular interest is the effect of standards on households with low-income levels and on senior-only residences—two consumer sub-groups identified by stakeholders. Households belonging to these two consumer sub-groups are identified from RECS and the entire LCC analysis is repeated for each sub-sample Inputs, analysis method, and assumptions are the same as those in the *LCC* analysis.

For all but the most stringent trial standard levels both senior-only and low-income households benefit at substantially the same rate as the general population.

Table 2. Life-Cycle Cost and Payback for Gas-Fired Water Heaters

Design Option	Fraction of Population Benefitting (%)	Average LCC Savings ($)	Median Payback (yrs)
Heat Traps	97	15.9	1.3
78% RE	82	13.0	3.0
78% RE, 2" Insulation	87	43.1	2.9
78% RE, 2.5" Insulation	79	34.4	3.9
80% RE, 2" Insulation	83	-2.9	2.5
80% RE, 2.5" Insulation	77	-12.1	3.5
80% RE, 3" Insulation	55	-69.2	5.7
Side Arm	20	-214	11.3

Shipments Analysis

The output from the *Shipments Analysis* allows a national energy savings analysis to be performed for each proposed trial standard level. Water heater shipment forecasts by fuel type are used primarily as input in the *National Energy Impacts Analysis*. Shipment forecasts are also used by the *Manufacturing Impacts* analysis. Summary results of the shipments analysis are shown in Table 3.

The *Shipments Analysis* produces two quantities: (1) the total number of water heaters purchased in a year and (2) the market share by fuel type. A different market share distribution is expected for each trial standard level.

The only drivers we use for total water heater shipments are housing starts and water heater lifetimes. We assume when a water heater is retired, it is always replaced with a water heater of the same fuel type; therefore, changes in market share for different fuel types are affected only by fuel choice in new housing. We also assume there is no market for used water heaters.

The market share by fuel type of water heaters to new housing units is affected by three factors: fuel price, equipment cost, and household income. The equipment costs are from the *LCC* analysis. The fuel price projections are from *Annual Energy Outlook 1999* (*AEO99)* (DOE 1998) and GRI. (GRI 1998) Equipment cost elasticities are derived from operating cost elasticities, water heater lifetime, and fuel-dependent implicit discount rates. Household income comes from average forecast national household income

National Energy Impacts (NES) Analysis

The *NES* predicts primary energy savings and cost savings of trial standard levels. Total national energy consumption, as well as costs and savings from proposed water heater standards are projected to 2030. From this, net present value and source energy savings are calculated for each trial standard level. Energy and cost savings predictions serve as input to other impact assessment analyses (*Environmental Analysis*, *Net National Employment Impacts*, *Utilities Impacts Analysis*).

Table 3. Total Shipments During 2003-2030 by Fuel Type and Trial Standard Level

Total Shipments 2003-2030 *Millions*				
Scenario	**Electricity**	**Gas**	**Oil**	**LPG**
Baseline	193.3	199.4	2.8	17.1
Trial Standard Level 1	195.2	197.3	2.7	17.0
Trial Standard Level 2	194.8	197.6	2.8	17.0
Trial Standard Level 3	190.7	202.1	3.0	17.3
Trial Standard Level 4	187.9	207.6	1.7	16.4

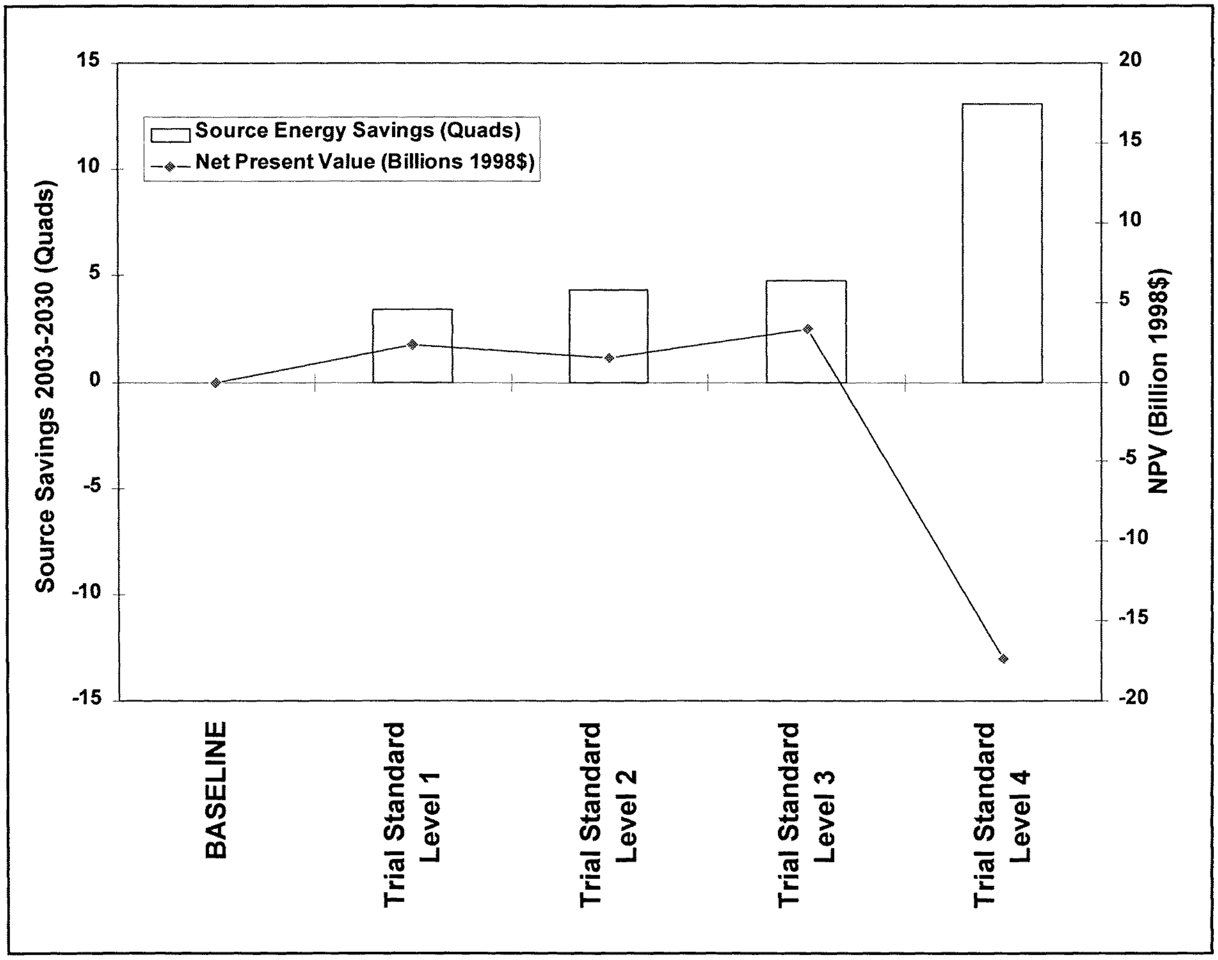

Figure 5. Source Savings and Net Present Value

The *NES* uses a discount rate of 7% for calculating societal net present value. Marginal energy prices follow the average energy price forecast; retail prices and installation costs come from the LCC analysis. Energy price projections and yearly electricity source to site conversion factors are from the *AEO99* forecast. Average annual unit energy consumption is calculated from weighted average unit energy consumption (UEC) of the water heater stock

Source energy savings, together with NPV, form the basic criterion for assessing each particular trial standard level. The optimum standard is the one which maximizes energy savings while causing no net negative economic impact on the consumer. The relative merits of the trial standard levels can be seen at a glance, in Figure 5.

Manufacturer Impacts Analysis (MIA)

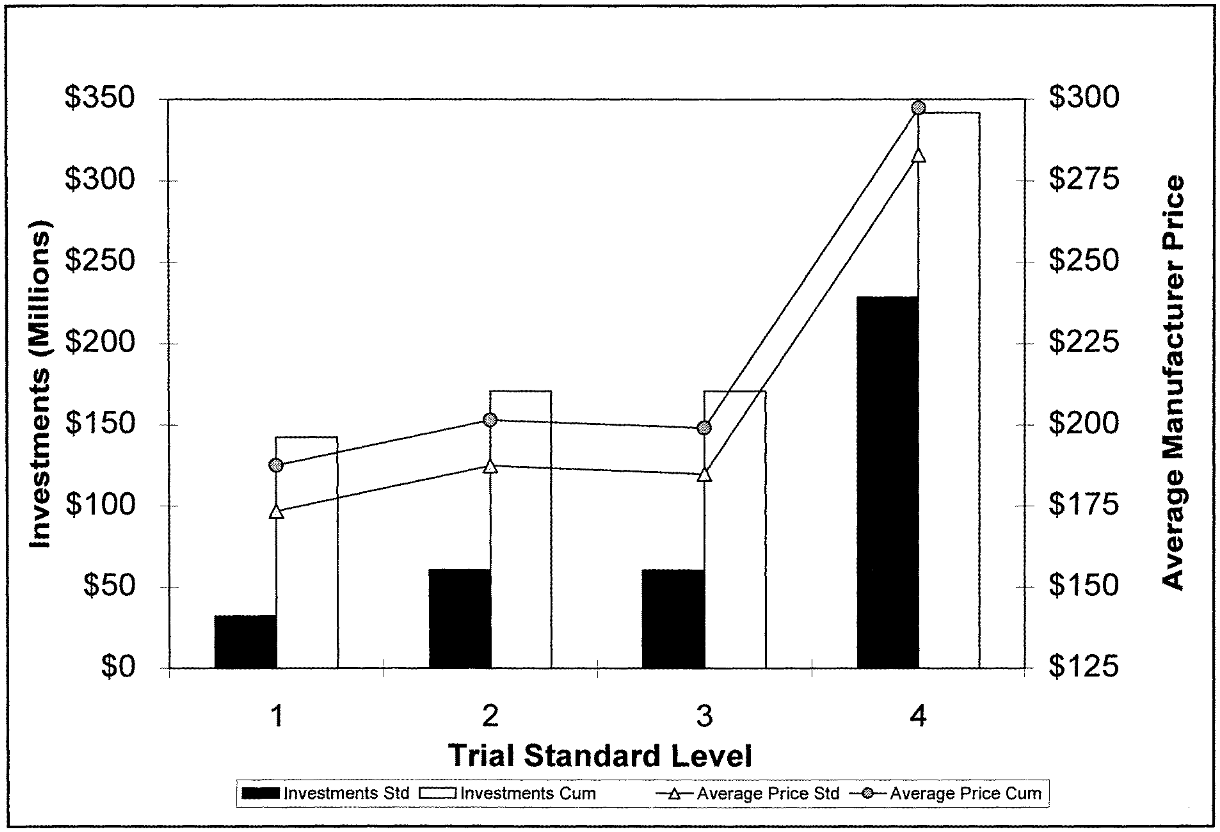

Figure 6. Manufacturer Prices and Investments

The *MIA* focuses on impacts of the trial standard levels on water heater manufacturers. An annual cash flow analysis is used as a measure of potential investment acceptability by determining a total present value of future cash flows, implicitly including the cost of capital. The financial analysis was conducted using estimated manufacturer costs and investments from GAMA and independent consultants' data and financial information obtained from SEC 10-K statements, other publicly available industry statistics and manufacturer interviews. Future shipments come from the *Shipments Analysis*. The necessary level of investments and average manufacturer price for each standard level are shown in Figure 6.

Utility Impacts Analysis

The effects of proposed standards on the electricity and gas industries are analyzed using a variant of U.S. DOE/EIA's National Energy Modeling System (NEMS–BRS). The energy savings associated with each proposed trial standard level from the *NES* model are input into

NEMS-BRS.

The utility analysis uses the assumptions of *AEO99* and treats water heater efficiency standards as variations in policy. None of the trial standard levels reduces demand by more than 1% of total U.S. electricity generation and gas consumption in any given year

For each trial standard level residential energy sales fall compared to the *AEO99* Reference Case. The decrease in sales is proportional to the energy that the NES model predicts will be saved by each standard level, ranging from just under 0.1% to just under 1.2% of total residential electricity sales and up to 6.0% of total residential gas sales in the peak savings year.

Environmental Assessment

The environmental analysis uses NEMS-BRS to provide information about the effect that new standards would have on pollutants and other emissions. For each trial standard level, total power sector carbon and NO_x emissions and estimated household emissions for carbon, NO_x, and SO_2 are reported. The assumptions and inputs to the analysis are similar to the utility analysis.

Cumulative emissions savings for the combined power and residential sectors (excluding upstream emissions) are shown Table 4.

Table 4. Cumulative Emissions Reductions to 2030: Power and Household Sectors

	Trial Standard Level			
Emission	**1**	**2**	**3**	**4**
Carbon (Mt)	47.6	73.9	83.0	219.1
NO_x (kt)	141.4	207.7	228.6	599.1
SO_2 (kt)	3.9 [1]	0.1 [1]	-5.8 [1]	53.6 [1]

Net National Employment Analysis

Net national employment impacts from water heater standards are defined as net jobs created or lost in the general economy as a consequence of five factors: (1) reduced spending by end-users on energy; (2) reduced spending on new equipment by the energy companies; (3) increased spending on new water heaters; (4) increased spending on the installation of new water heaters; and (5) the associated indirect effects of those four factors throughout the national economy.

Figure 7 shows, for any given year, the estimated net national employment impacts of the four different trial standard levels as the change in the number of jobs in the economy relative to the number of jobs if the standards were not revised.

The water heater manufacturing industry is more capital-intensive than average, so an increase in spending flows to it will initially tend to reduce the employment level in the overall economy.

During the first few years of a new standard, the increased costs of buying more efficient

[1] Results include only household emissions reductions because the power sector emissions cap implies that savings from electricity generation will be negligible.

water heaters are greater than the dollar savings in energy. In Figure 7, this is reflected as a net decrease in jobs between 2002 and 2003 at all of the trial standard levels.

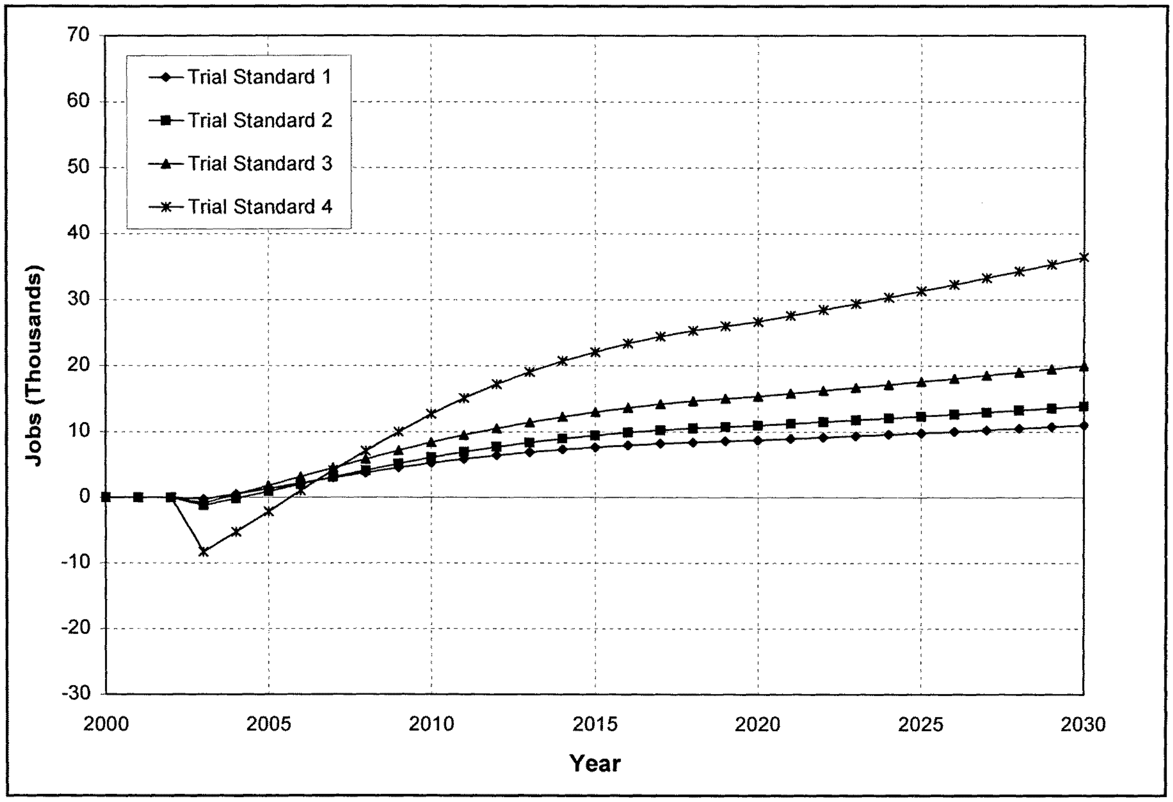

Figure 7. Net National Employment Impacts

Once the initial costs are recovered through energy savings, the dollars saved in expenditures on energy are available to buy other goods in the economy, thereby increasing jobs. The net national employment curve is steepest for the first dozen years (the lifetime of a water heater), during which time there is both a growth in the total stock of water heaters as well as an increase in the saturation of water heaters of higher efficiency.

After 2015, even though the total stock of water heaters continues to increase, the growth in net employment stabilizes because at that point all of the water heaters being replaced in the standards case are water heaters that are already high-efficiency (instead of replacing baseline water heaters with high-efficiency ones).

Conclusion

Supported by the results of this analysis, DOE has issued a proposed rule (DOE 2000a) to increase the efficiency standard levels for residential water heaters to a level represented by trial standard 3. This is a .05 increase in EF for gas-fired water heaters and .04 increase in EF for electric water heaters.

Acknowledgements

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