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Projected National Economic and Energy Savings from Water Heater Efficiency Standards in the U.S.

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ABSTRACT

In April 2000, the U.S. Department of Energy (DOE) proposed an amended energy efficiency standard for residential water heaters. This paper presents an analysis of economic and energy savings which were used to determine the proposal.

Cumulative energy savings over the period from 2003 to 2030 is forecast by calculating national water heater consumption for several trial standard levels in comparison to the base case forecast. The key component to this calculation is a detailed projection of water heater shipments and remaining stock. The shipments model takes as input baseline efficiencies and equipment costs corresponding to a series of design options. It calculates the average unit energy consumption based on efficiency market shares with and without standards. It then uses appliance lifetimes and an accounting of stock by vintage to determine when older, less efficient water heaters will be retired and replaced by new ones that conform to standards. In addition, it tracks units shipped to newly constructed housing. The outputs of the shipments model are energy consumption and equipment cost for each year in the forecast period.

Using the output of the shipments model, the National Energy Savings (NES) model determines the total source energy savings and net present value (NPV) of each trial standard level. Net savings for each year are the difference between total operating cost savings and total equipment cost increases. Future savings are discounted to the present.

The proposed standard is expected to save 4.8 EJ (exajoules) of primary energy between 2003 and 2030. Financial benefits to consumers are estimated to be $3.3 billion during this time.

INTRODUCTION

This paper describes an analysis performed by Lawrence Berkeley National Laboratory on behalf of the U.S. Department of Energy to forecast national economic and energy savings arising from water heater efficiency standards. We consider several trial standard levels based on currently available energy efficient designs. For each, we calculate National Energy Savings (NES), which forecasts cumulative primary energy savings through the year 2030. A cost-benefit analysis on the scale of the nation is then performed. Relative cost and benefit is formulated in terms of net operating cost savings less equipment cost increases.

Appliance efficiency standards raise the minimum allowable efficiency of new units. In the case of water heaters, minimum efficiency is expressed as the energy factor (EF), which is the ratio of heat delivered as hot water to the amount of fuel energy consumed by the appliance. There are a variety of currently available technologies that improve EF, specific to fuel class. The classes considered for standards are: electric, gas (natural gas or LPG) and oil.

Assessment of potential energy savings begins with an investigation of currently available efficiency technologies. Section 2 discusses the efficiency improvement achieved by selected features, and the cost to implement each. DOE then selected a series of trial standard levels by raising minimum efficiency levels in correspondence with these features. The effects of raising minimum efficiency on stock energy consumption are forecast with a detailed shipments model, which is the subject of Section 3. Finally, Section 4 describes the NES and financial cost-benefit calculations based on output from the shipments model.

EFFICIENCY AND EQUIPMENT COST

The efficiency improvement and cost increase associated with each technology form the basis of a forecast of national energy impacts. Standard scenarios are formulated by modeling the water heater market with various minimum efficiencies.

Once these minimum efficiencies are determined, and the resulting market shares are constructed, total national energy impacts can be determined. Average unit energy consumption (UEC) and equipment prices are calculated by taking into account the full variability of water heater energy consumption in U.S. households, including the effects of variations in hot water usage patterns. We include an estimate of the spread of efficiencies after the standard is prescribed.

The various efficiency improvement technologies for water heaters were analyzed using information from computer simulations, manufacturers, utility and industry consultants. Design features were analyzed for energy consumption and feasibility to manufacture, install and maintain on a large scale. The direct inputs to NES are efficiency improvement and incremental cost of each feature.

We analyzed a hypothetical design consisting of each efficiency technology added to a water heater of typical volume and baseline efficiency. The energy factor of each case is evaluated by computer simulations (Hiller, Lowenstein et al. 1992, Paul, Whitacre et al. 1993) and verified using industry estimates (Gas Appliance Manufacturers Association 1998).

In addition, we estimate the cost of improved efficiency, i.e. the additional expense to manufacturers to include a particular feature. Incremental costs were based on estimates by an industry consultant (Minniear 1997), and calculations of incremental material and labor costs.

Base Case Scenario and Trial Standards

Once efficiency and cost results for each efficiency level are determined, individual design options are combined into sets of design options. This is done by sequentially adding design options to the baseline water heater in order of increasing payback.

DOE was presented with a series of design options for each of the three major classes of water heaters. From this list, four sets of design option combinations are chosen, each forming a trial standard level that applies to all fuels. Minimum EF for typical volume water heaters are shown in Table 1.

Table 1. Minimum Efficiencies of Trial Standard Levels

	Minimum EF for Typical Volume Water Heaters		
	Electric	**Natural Gas, LPG**	**Oil**
Base Case	0.86	0.53	0.53
Trial Standard Level 1	0.89	0.59	0.53
Trial Standard Level 2	0.90	0.60	0.53
Trial Standard Level 3	0.91	0.59	0.53
Trial Standard Level 4	0.92	0.71	0.61

The standard levels are ordered by increasing energy savings: The first saves the least amount of energy but requires small additional costs, while the fourth represents the maximum energy efficiency possible with current technology.

The national energy savings analysis compares projections of the base case with those under each trial standard level. Since standards raise the baseline efficiency, they have no effect on the portion of the market already held by high-efficiency units. We assume that no improvements will occur in the absence of a new standard. The base case is therefore a forecast with current market shares continuing into the future.

Though a precise description of the water heater market is not available, low-efficiency units are believed to dominate. We define "low-efficiency" units as the current baseline and units with the next most cost-effective efficiency feature on the market. These two models are assumed to evenly share 80% of the market for electric and oil units, 70% for natural gas and LPG units. The distribution of the remaining small share held by higher efficiency units is based on an estimate of the current market share of efficient technologies (Minniear 1997).

Each trial standard level transfers market share of low efficiency units to the new baseline. Market shares of designs that exceed the new baseline do not change. Therefore, the more stringent the trial standard level, the more the new baseline is expected to dominate the market. This determination of market shares, along with shipment projections, forms the basis for energy savings projections.

National Average Unit Energy Consumption and Equipment Cost

Calculation of national energy savings depends on how improved efficiency levels will effect energy consumption of a large and varied population of water heaters. Consumer equipment expenditures depend on how manufacturer costs translate into increased retail equipment costs. A detailed Monte Carlo analysis is used to model these effects.

Variability in UEC of a water heater depends on household hot water usage and temperatures. Usage varies significantly depending on parameters such as the number of household members, presence of a dishwasher and/or a clothes washer and water heater thermostat setting. Many of these parameters are given for a large sample of U.S. households as part of the Energy Information Administration's *Residential Energy Consumption Survey* (U.S. Department of Energy 1995). Using information from this survey, average hot water use was calculated for each sample household (Ladd and Harrison 1985). The corresponding annual household energy consumption was calculated from annual draw volume, along with tank thermostat setting, air temperatures and efficiency parameters. Mean efficiency parameters were determined from computer simulations. A distribution was then generated by combining the mean with expected variability, as estimated by an industry consultant (Minniear 1997).

To include the full variability of retail equipment prices, we compiled a sample of current retail prices of baseline units in a database. Price data was gathered by directly contacting over 130 retailers throughout the United States. Over 1100 models are included in the tabulation of consumer price, installation fees and warranty costs. The retail price data were used to determine a range of markups above manufacturer costs (U.S. Department of Energy 1999a).

Unit energy consumption for the base case and trial standard levels are the market weighted average for all design options. Results are shown in Table 2.

Table 2. Average Annual Unit Energy Consumption and Equipment Cost from Monte Carlo Analysis

Design Option	Electric		Natural Gas, LPG		Oil	
	Equipment Cost (*$*)	UEC (*GJ*)	Equipment Cost (*$*)	UEC (*GJ*)	Equipment Cost (*$*)	UEC (*GJ*)
Base Case	403	12.4	463	23.1	1188	26.5
Trial Standard Level 1	411	12.3	496	21.4	1200	26.3
Trial Standard Level 2	437	12.1	514	21.3	1200	26.3
Trial Standard Level 3	455	12.0	496	21.4	1188	26.5
Trial Standard Level 4	565	11.8	900	17.1	1768	23.1

Retail equipment costs shown in Table 2 include installation fees and sales taxes taken from the equipment price database. Trial standard level one produces a marginal reduction in energy consumption and raises equipment prices only slightly. By contrast, trial standard level four maximizes efficiency improvement, at the cost of a large price increase.

WATER HEATER SHIPMENTS FORECAST

Efficiency standards only affect water heaters shipped after the implementation date. It is therefore necessary to forecast water heater shipments due to installations in new homes and replacements of retired units. The forecast tracks how many high efficiency units enter the stock and how many inefficient ones are removed, from which we calculate average UEC and total stock size. Average UEC and stock size yield total energy and operating cost savings. In addition, the shipments forecast estimates incremental equipment cost, that is, total consumer cost of water heaters shipped minus costs in the absence of standards.

Replacements

We estimate that as much as 85% of water heater shipments are replacements. The remainder are new home installations. Due to the relatively low cost of installing a new water heater, and the limited life extension afforded by repair, repairs and the used water heater market are negligible. Therefore, the forecast of water heater replacements is modeled by the number of units that are retired in any given year.

Water heater retirements are forecast by an accounting spreadsheet that keeps track of the aging and retiring stock throughout the forecast period. The number of water heaters entering the stock in the past few decades is provided by historical shipments data going back forty years. We model retirement probability with a triangular distribution based on published most likely, minimum and maximum lifetimes (*Appliance Magazine* 1999). We forecast the composition of the stock in each year by keeping track of units entering the stock (shipments), the age (vintage) of those units remaining from previous shipments, and those which are retired.

New Construction

A smaller, but significant number of new water heater shipments are made to new housing units each year. According to survey data (U.S. Department of Energy 1995), almost every home built between 1992 and 1993 contained a water heater fueled by one of the four major fuel types. In a small fraction of units in multifamily buildings, however, water heaters are shared by more than one household. In this case, the water heater is likely to be a large capacity unit, not targeted by residential efficiency standards. A total of 96% of current new homes contain a water heater affected by standards. We assume this fraction remains constant through the forecast period.

The most significant factor in overall shipments to new housing is growth in housing construction, which is related to national economic and population trends. Housing forecasts are provided by a multi-sector partial equilibrium model of the U.S. energy sector that has been developed over several years by DOE, and is reported in *Annual Energy Outlook 1999(AEO99)* (U.S. Department of Energy 1998).

In addition to total shipments to new construction, we model shifts in fuel type market share as a result of cost shifts imposed by standards. In principle, if standards affect the different fuel types differently, market share of one type will be favored at the expense of others. We model market share response using a generalized linear econometric model. Market shifts are small, with less than a five percent shift for any scenario.

PROJECTED NATIONAL ENERGY IMPACTS

The goal of efficiency standards is to achieve the maximum energy savings that are economically justified. This section details the calculation of energy savings and financial cost-benefit. According to the standards framework, a scenario that incurs a significant net financial cost to consumers should be rejected by DOE. Assessment of energy consumption and financial costs is performed for the base case and trial standard levels defined in the previous section.

National Energy Savings

Total national energy savings follow directly from the accounting of annual energy consumption. To evaluate the savings related to each trial standard level, we aggregate energy consumption from all classes and take the difference from the base case. There are two energy quantities of interest. First, *site* energy is energy consumed in the home, in the form of electricity, natural gas, LPG or oil. Site energy consumption is directly affected by efficiency standards and directly related to consumer expenditures. Second, *primary* energy is all energy used by utilities in producing power for residential use, including energy lost during gas transmission and electricity generation.

Primary Energy Savings. National energy consumption is the average unit energy consumption multiplied by the total number of units in the stock. Since energy consumption in each standard scenario varies between fuel types, energy consumption and savings are calculated for each fuel type separately and then summed to arrive at total national energy.

According to the *AEO99,* forecasted domestic electricity in 2000 will be 53.3% coal, 14.7% gas, 2.9% petroleum, 17.7% nuclear and 11.3% renewable. On average, delivery of 1 kJ of site electricity will require 3.19 kJ of primary energy, including generation and transmission. The conversion factor between site and primary energy is called the *heat rate factor,* and is provided for each year in the forecast.

For natural gas water heaters, site and primary energy consumption differ by a smaller amount. *AEO99* estimates that 8.9% of natural gas produced at the wellhead is lost during transmission. Therefore, every unit consumed in the household corresponds to a primary energy consumption of 1/(1-.089) = 1.098 units. Since LPG and heating oil are not piped to the household, we assume that there are no transmission losses, and the difference between site and source energy arises only from the small amount of electricity consumed by some models.

To a fair approximation primary energy savings associated with efficiency is simply the difference between standard and base case primary energy consumption, as calculated by the average heat rate. In calculating energy savings, however, it is more accurate to use *marginal* heat rates. Marginal heat rates account for the fact that, if demand for electricity decreases, the power plants shutdown first will likely be the most expensive to operate, usually those burning natural gas. Since the natural gas heat rate is somewhat lower than the average, marginal heat rates are somewhat lower than average rates. Primary energy savings is summarized in Table 3.

Table 3. Primary Energy Savings in 2010, 2020 and Total Forecast Period

	Savings in 2010 (Exajoules)	Savings in 2020 (Exajoules)	Cumulative Savings 2003-2030 (Exajoules)
Trial Standard Level 1	0.09	0.15	3.4
Trial Standard Level 2	0.12	0.19	4.3
Trial Standard Level 3	0.13	0.21	4.8
Trial Standard Level 4	0.35	0.57	13.1

A projection of primary energy savings is dependent on assumptions of future economic growth, particularly through housing projections. The economic model developed by DOE (U.S. Department of Energy 1998) assumes an annual growth rate of 2.1 percent. The model also provides high (2.6 percent) and low (1.5 percent) growth scenarios, which we use to estimate the variability in our forecast. We find a 5 to 6 percent increase (decrease) in energy savings in the high (low) growth scenario, compared to the reference case.

Consumer Cost-Benefit Analysis

Assessment of financial cost-benefit to consumers as a result of standards is straightforward. The financial benefit to consumers comes from lower energy bills. The cost comes from increased equipment prices. Cumulative savings are considered for the period from 2003 to 2030.

Operating Cost Savings. The amount of money saved by consumers as a result of efficiency standards is calculated from site energy savings. Operating cost savings is the product of total site energy savings and fuel price. Energy price projections are taken from *AEO99*. Operating cost savings, calculated for each year and fuel type, is given by

$$\Delta OC_{j,n} = Fuel\ Price_{j,n} \times \Delta AEC_{j,n}$$

where:

$DOC_{j,n}$ = Energy cost savings for fuel type n in year j.
$Fuel\ Price_{j,n}$ = Marginal fuel price for fuel type n in year j.
$DAEC_{j,n}$ = Annual site energy savings for fuel type n in year j.

In this equation, the marginal price for each fuel is used. The marginal price of a fuel is the cost to the consumer of the last unit of energy used. Marginal prices differ from average prices, which are simply the entire energy bill divided by energy consumption. Marginal prices may be lower than average prices that include flat charges not related to consumption. On the other hand, utilities may charge a premium rate for energy use over a baseline, which would raise marginal relative to average prices.

A study performed by LBNL (U.S. Department of Energy 1999b) based on a survey of ratepayer bills indicates that, on average, marginal rates are lower than average rates. The scaling factors to convert from average to marginal rates are found to be 0.93 for electricity, and 0.88 for gas. No factor is applied to LPG or oil since charges for these fuels do not include flat charges.

Incremental Equipment Costs. Equipment costs for a given year equal average retail price plus installation cost, multiplied by shipments for that year. Equipment cost savings is the difference between standards and base case equipment cost for each year and class:

$$\Delta EC_{j,n} = EC_{j,n} - EC^{0}_{j,n} = S_{j,n}\, C_{n} - S^{0}_{j,n} C^{0}_{n}$$

where

$EC_{j,n}$	=	Total equipment cost in standards case
$EC^{0}_{j,n}$	=	Total equipment cost in base case
C_{n}	=	Unit equipment cost in standards case
C^{0}_{n}	=	Unit equipment cost in base case
$S_{j,n}$	=	Annual shipments in standards case
$S^{0}_{j,n}$	=	Annual shipments in base case

for each fuel type *n* and year *j*.

Net Present Value

We use Net Present Value (NPV) to evaluate the financial impacts of trial standards. The net value of efficiency standards is operating cost savings less the penalty in increased equipment costs. Financial impacts that are postponed are "discounted", that is weighted less than impacts occurring today.

Cumulative NPV is given by:

$$NPV = \sum_{n} \sum_{j=2003}^{2030} \text{Discount Factor} \times \left(\Delta OC_{j,n} - \Delta EC_{j,n}\right)$$

The discount factor applied for year *j* is given by:

$$\textit{Discount Factor}_j = (1+r)^{-(j-j_0)}$$

where r is the discount rate and j_0 is the present year. The analysis assumes a real discount rate of 7%. The resulting NPV for each trial standard is given in Table 4.

Table 4. Net Present Value in 2010, 2020 and Total Forecast Period

	NPV in 2010 (Billions $1998)	NPV in 2020 (Billions $1998)	Cumulative NPV 2003-2030 (Billions $1998)
Trial Standard Level 1	0.11	0.11	2.3
Trial Standard Level 2	0.10	0.11	1.5
Trial Standard Level 3	0.22	0.18	3.3
Trial Standard Level 4	-0.64	-0.30	-17.4

As shown in Table 4, only trial standard level 4 results in a net loss to consumers. While this scenario affords the greatest energy savings at 13.8 exajoules, utility bill savings do not justify the increase in retail prices. Trial standard level 3 maximizes economic savings with a cumulative NPV of 3.3 billion dollars. As in the case of energy savings, variability is estimated in terms of economic growth. A range of annual growth rate from 1.5 to 2.6 percent yields a range of 2.6 to 4.1 billion dollars for trial standard level 3.

CONCLUSIONS

According to the analysis of energy savings and net financial impacts, DOE selected trial standard level 3, since it maximizes energy savings while also providing a net financial benefit to consumers. We expect that this standard will be practical to implement, since it incorporates design features that are already commercially available. Furthermore, shipments of each class differ by only about 1% from the base case. Therefore, DOE concluded that the standard will not have an adverse effect on either the electric or gas utility customer base.

Over the next three decades, we estimate that the proposed standard will save between 4.5 and 5.0 exajoules of primary energy, depending on economic growth rates. We expect that consumer energy bill savings will far outweigh the cost of equipment price increases for this standard. Within the same range of economic growth rates, we expect an NPV of between 2.6 and 4.1 over the period from 2003 to 2030.

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