CHAPTER 2. ANALYTIC FRAMEWORK

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CHAPTER 2. ANALYTIC FRAMEWORK

2.1 OVERVIEW

In the water heater rulemaking, DOE has used the following steps and analyses. These are summarized in the framework diagram shown in Figure 2.1 below. The numbers in the lower right-hand corner of the boxes refer to the relevant chapter in this Technical Support Document. Solid lines in the flowchart indicate inputs and outputs; dotted lines, on the other hand, follow the path of intermediate results from one part of the analysis to another. The steps involved in the process in a roughly sequential order are:

- Market and Technology Characterization
- Identification and Screening of Design Options
- Engineering Analysis
- Life-Cycle Cost Analysis
- Consumer Sub-Group Analysis
- Shipments Analysis
- National Energy Impacts (NES) Analysis
- Manufacturer Impacts Analysis (MIA)
- Utility Impacts Analysis
- Environmental Analysis
- Net National Employment Analysis
- Regulatory Impact Analysis

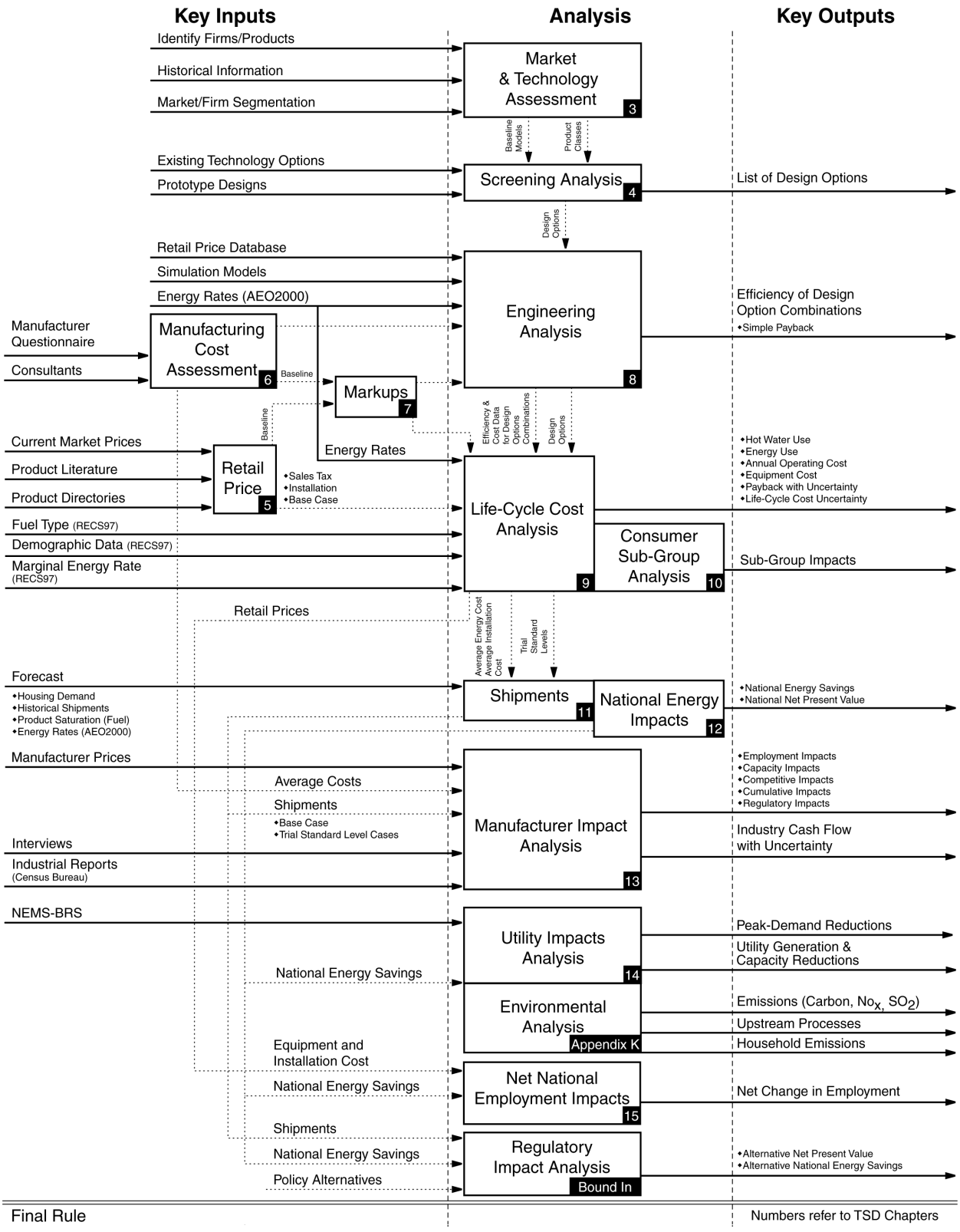

Figure 2.1 Framework Flowchart for Water Heater Energy Efficiency Analysis

2.2 MARKET AND TECHNOLOGY ASSESSMENT

The objective of the *Market and Technology Assessment* is to develop baseline models and the list of potential design options for each of the electric, gas-, and oil-fired water heater product classes. The choice of baseline models and design options is from information and analysis regarding the market situation of water heaters in the U.S. The gas-fired product class includes water heaters fueled by both natural gas and liquified petroleum gas (LPG) because they are constructed almost identically. With respect to costs, however, they are treated separately, having different manufacturing costs, markups, retail prices, and fuel price structures. The general characteristics of the baseline model for each of the three primary product classes of water heaters analyzed are provided in Table 2.1 below.

Table 2.1 Summary Characteristics of the Baseline Models for Three Water Heater Product Classes

	Electric	Natural Gas & LPG	Oil-Fired
Tank Volume	50-gallon (190-liter)	40-gallon (150-liter)	32-gallon (120-liter)
Tank Type	Glass-lined steel	Glass-lined steel	Glass-lined steel
Insulation	1.5-inch (3.8 cm) polyurethane foam insulation blown with HCFC-141b	1-inch (2.5 cm) polyurethane foam insulation blown with HCFC-141b	1-inch (2.5 cm) polyurethane foam insulation blown with HCFC-141b
Input Rating	4500 W	40,000 Btu/hr (11,700 W)	0.65 gallons per hour (2.5 liters/hr) or 90,000 Btu/hr (26,000 W)
Recovery Efficiency (RE)	0.98	0.76	0.75
Energy Factor	0.86	0.54	0.53
Analysis Tools	WATSIM, a computer simulation model of electric water heaters	TANK, a computer simulation model of gas-fired water heaters	A simplified water heater analysis model (WHAM), based on the DOE 24-hour test procedure, is an equation to calculate average daily energy consumption using the RE, stand-by heat loss coefficient (UA), and rated input (Pon).
Other	Two interlocked heating elements	Bottom-fired with center flue	Bottom-fired with center flue. The baseline model uses an intermittent ignition system. The burner motor, which powers both the blower and oil pump, is rated at 282W.

2.3 IDENTIFICATION & SCREENING OF DESIGN OPTIONS

The first step in the rulemaking process is screening of design options. The purpose of screening is to identify those design options that the Department will consider for the engineering analysis. The screening analysis also discusses the criteria for eliminating certain design options from further consideration. On July 15, 1996, the Department issued the Process Improvement (Interpretive) Rule[1] which establishes the factors DOE uses for screening design options. The factors are as follows:

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

2.4 ENGINEERING ANALYSIS (PRICE EFFICIENCY RESULTS)

The results of the *Engineering Analysis*, termed "price efficiency results", demonstrate the increased cost and efficiency due to design options and combinations of design options within each product class of water heaters. To arrive at the price efficiency results, the *Engineering Analysis* uses computer simulation models and other analytical methods (see Table 2.1 under "Analysis Tools") to investigate the efficiency improvements of a design option and combinations of design options. The models and analytical methods are based on DOE's test procedure for residential water heaters. All prices, including *Annual Energy Outlook 2000*[2] (*AEO2000*) energy prices, are national averages. For this analysis, we obtained manufacturers' cost data for the design options from Gas Appliance Manufacturers Association (GAMA) and industry consultants. Additionally, 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.

The design options are listed in ascending order by payback period. The payback period measures the amount of time needed to recover the additional consumer investment in increased efficiency through lower operating costs. DOE test procedure conditions and the 1998 national average energy price are used in the payback calculation.

The following technological changes are included in the 2003 baseline model:

- Insulation blowing agent: The U.S. EPA is phasing out HCFC-141b on January 1, 2003. As a result, water heater manufacturers will have to use an alternative foam insulation blowing agent. One of the leading alternative blowing agents, HFC-245fa, was chosen for analysis by DOE.

- Flammable-Vapor Ignition Prevention Design: The Consumer Product Safety Commission initiated a safety design program for natural gas and LPG water heaters[a] to prevent ignition of flammable vapors. The water heater industry and the Gas Research Institute (GRI) established a voluntary program to develop a test procedure and burner designs resistant to ignition of flammable vapors. Several manufacturers joined the Water Heater Consortium to pool design and developmental resources. As a result of discussions with this consortium, DOE used a placeholder value of $35 as additional cost for designs to prevent ignition of flammable vapors. In this analysis, the extra $35 is applied to the manufacturer cost of all design options for natural gas and LPG water heaters, including the 2003 baseline design.

For high-efficiency natural gas and LPG water heaters, venting may pose problems. We assumed Type-B vent connectors may be required in 25% of homes with heating degree days (HDD) above 5000 when recovery efficiency (RE) is 78% or above. Additional modifications, including the relining of masonry chimneys, may be needed in 25% of homes with masonry chimneys and HDD above 5000 when an 80% RE is reached.

2.5 LIFE-CYCLE COST (LCC) ANALYSIS

The *LCC* analysis determines the life-cycle cost and the cumulative payback for consumers for a variety of 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 from a weighted sampling of 3,911 households with individual water heaters from the *Residential Energy Consumption Survey* (RECS) database.[3] In addition to the variety of consumers, 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 and variability of characteristics related to residential hot water use.

- To account for uncertainty and variability, the *LCC* model uses Monte Carlo simulations to perform the analysis. The uncertainty and variability in the model's inputs are specified using probability distributions. The Monte Carlo simulation then randomly samples from the probability distribution for each input within the model to calculate the outputs. This is done 10,000 times for each fuel. The distribution of the values calculated for the model outcome therefore reflects the probability that those values would occur in the general population. This technique provides insight into the likelihood of possible outcomes.
- An importance analysis is also conducted which shows the relative contribution of each of the inputs to the total range of outputs.

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

Much of the input for this analysis comes from the *Engineering Analysis* (or the Price Efficiency Results). Other major input is from a database of water heater specifications and costs and from distributions of manufacturing costs from GAMA and consultants. The results of the *LCC Analysis* are used by the Department to select the trial standard levels used in the later stages of analysis and decision-making. The outputs are used by the *National Energy Impacts Forecast* analysis and the *Utility* and *Environmental* analyses. Assumptions made in the *LCC* analysis are:

- The combinations of design options are taken directly from the *Engineering Analysis*.
- The estimate of factory cost for the baseline models and the range of incremental cost of design options were supplied by GAMA. For a few design options, GAMA was unable to supply estimates of manufacturer costs; consultants familiar with the water heater industry were, therefore, hired to supply the data.
- To obtain markups, the retail prices for existing baseline models were divided by GAMA-supplied manufacturing costs. 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. Average markup varies by fuel type and tank size.
- GAMA-supplied estimates of factory costs were for typical size tanks only. The range of factory costs was estimated for water heaters with other size tanks by adding or subtracting the material costs for different amounts of steel, for both the jacket and the tank, and for different amounts of foam insulation.
- The energy consumption in the *LCC* analysis was calculated using the Water Heater Analysis Model (WHAM). The energy parameters used by WHAM—RE, UA, and Pon—are from the simulation models used in the *Engineering Analysis*. The temperatures and average daily hot water use were calculated for individual households in the analysis according to algorithms explained in the TSD.
- For this analysis, the price of baseline models was taken from the LBNL Water Heater Price Database. The baseline models were defined as those with six-year manufacturer warranties or less.
- Installation of larger diameter water heaters under new standards may not be possible in all circumstances. To account for this, in households of less than 1,000 ft^2 in which the water heater is in a conditioned space, we assigned the next smaller standard size water heater and then adjusted the setpoint to ensure delivery of an equal amount of hot water.
- Installation costs were also taken from the LBNL Water Heater Price Database. In addition to the actual costs of installing water heaters, delivery, removal, and permit fees were also included. Typical costs for miscellaneous parts used in installing a water heater, such as pipe fittings, were also added.
- Four fuels were analyzed: electricity, natural gas, LPG, and oil.
- The household characteristics remained constant over time.

Previous analyses of the life-cycle costs of consumer energy savings possible from appliance energy-efficiency standards were based on *average* energy prices.[a] Using *marginal* energy prices in

[a] *Average* energy prices for a consumer are derived by dividing annual energy costs by annual energy consumption.

these analyses is more theoretically sound.[a] In April 1998, the Advisory Committee on Appliance Energy Efficiency Standards delivered a letter to the Secretary of Energy recommending, among other things, that DOE should replace the use of national average energy prices with the full range of consumer marginal energy rates in its life-cycle cost analyses. Because neither published nor readily available data existed for consumer marginal energy prices, a major research effort was required to derive consumer marginal energy prices.[4, 5]

Data from DOE's Energy Information Administration's (EIA) 1997 RECS are used to calculate marginal energy prices for residential appliance owners. We estimated consumer marginal energy prices directly for each RECS household used in the *LCC* and *Consumer Sub-Group* analyses by calculating the slopes of the regression lines relating customer bills to customer usage. For electricity, the slopes of the regressions for four summer months (June-September) and, separately, for the remaining ("non-summer") months, were calculated. For natural gas, the data were split into seasons in a manner parallel to electricity data. The "peak" winter season was defined as those billing periods whose midpoint fell in any of the following four months: November, December, January, February. The remaining eight months constitute the non-winter season.

2.6 CONSUMER SUB-GROUP ANALYSIS

The *Consumer Sub-Group Analysis* examines the economic impacts from possible revisions to water heater energy-efficiency standards on different population groups of consumers. The analysis determines whether or not a particular segment of consumers would be adversely affected from different trial standard levels in terms of increased life-cycle cost. The fraction of population that would benefit is calculated. The mean life-cycle cost change is also estimated. Of particular interest is the potential effect of standards on households with low-income levels and on seniors-only residences—two consumer sub-groups of interest identified by stakeholders. These two consumer sub-groups are identified from the RECS public use database. Inputs, analysis method, and assumptions are the same as those used in the *LCC* analysis.

2.7 SHIPMENTS ANALYSIS

The *Shipments Analysis* produces two quantities: (1) the total number of water heaters of all fuel types that are purchased in a year and (2) the market share by fuel type for water heater shipments. A different market share distribution is expected for each of the trial standard levels. The output from the *Shipments Analysis* allows a national cost/savings analysis to be performed for each proposed trial standard level (see *National Energy Impacts*).

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[a] *Marginal* prices as discussed here are those prices consumers pay (or save) for their last units of energy used (or saved). Marginal prices reflect a change in a consumer's bill (that might be associated with new energy efficiency standards) divided by the corresponding change in the amount of energy the consumer used.

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. The assumptions for the analysis are:

- Equipment costs are from the *LCC* analysis.
- Fuel price projections are from *Annual Energy Outlook 2000* (*AEO2000*)[2] and the *2000 Edition of the GRI Baseline Projection* (*GRI2000*).[6]
- The only two drivers for total water heater shipments are housing starts and water heater lifetimes.
- Water heater retirement functions are triangular in form. Electric water heater lifetimes range from 6 to 21 years, with a likeliest of 14 years. Natural gas water heater lifetimes range from 5 to 13 years, with a likeliest of 9 years. We assumed the lifetimes of LPG and oil water heaters were equal to the lifetime of natural gas water heaters.
- 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 fraction of new housing units with shared water heaters remains constant over time.
- Market share of water heaters to new housing units is affected by three factors: fuel price, equipment price, and household income.
- Equipment cost elasticities are derived from operating cost elasticities, water heater lifetime, and fuel-dependent implicit discount rates.
- Household income affects market share via average forecast national household income (*AEO2000*) and income elasticities.
- Most water heaters installed in new homes just meet the minimum efficiency levels.

2.8 NATIONAL ENERGY IMPACTS (NES) ANALYSIS

The implementation of a particular standard (or the decision not to implement a standard) will have direct consequences for future fuel consumption and consumer expenditures. The *NES* summarizes these consequences for each trial standard level. The net present value of an option represents a single figure of merit for evaluation of its desirability.

The *NES* predicts the 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 result, 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 Impact*s, *Utilities Impacts Analysis*). Assumptions for the *NES* are:

- The discount rate for calculating societal net present value is 7%.
- Energy savings are based on source consumption. Cost savings use site consumption.
- To calculate a projected marginal energy price for each year, we adjusted the projected energy price as follows. For each fuel, we calculated the average marginal price for all households using that fuel for water heating. We divided this by the average price for

that fuel for the same households, giving us the ratio of marginal to average price. We then projected the marginal price in future years by multiplying the projected fuel price in each of those years by this ratio.

- Retail prices of water heater units are the average retail price from the LCC analysis.
- Energy price projections are from *AEO2000* and *GRI2000*.
- Electricity source to site conversion factors vary over time — yearly values are from the *AEO2000* forecast.
- Gas source to site conversion factor is assumed to be 0.9.
- Average annual unit energy consumption is calculated from weighted average unit energy consumption (UEC) of the water heater stock.
- Average installation costs are average installation costs from the LCC analysis.

2.9 MANUFACTURER IMPACTS ANALYSIS (MIA)

The *MIA* focuses on financial and non-financial impacts of the trial standard levels on water heater manufacturers. The financial analysis is based on expected future cash flows. An annual cash flow analysis is used as a measure of potential investment acceptability by determining a total value today of the future cash flows, implicitly including the cost of capital. The financial analysis was conducted using the Government Regulatory Impact Model (GRIM). GRIM used the following inputs:

- Estimated manufacturer costs and investments from the GAMA data submittal and from independent consultants' data;
- Financial information (e.g., tax rate, working capital, depreciation) is obtained from SEC 10-K statements, other publicly available industry statistics (e.g., Robert Morris Associates), and manufacturer interviews; and
- Future shipments from the *Shipments Analysis*.

In addition to financial impacts, a wide range of quantitative and qualitative effects may occur following adoption of a standard that may require major changes to water heater manufacturing practices. Many of these qualitative effects were identified through interviews with the water heater manufacturers.

2.10 UTILITY IMPACTS ANALYSIS

The effects of proposed water heater energy-efficiency standards on the electricity and gas industries are analyzed using a variant of U.S. DOE/EIA's NEMS,[a] called NEMS-BRS, which stands for National Energy Modeling System–Building Research and Standards. The analysis presents the impacts of standards on utilities by reporting several key industry parameters, notably energy sales,

[a] For further explanation about NEMS, please refer to the U.S. Department of Energy, Energy Information Administration documentation. A useful summary is *National Energy Modeling System: An Overview 1998.* DOE/EIA-0581(98), February 1998.

electricity generation, and electrical generation capacity. Analysis of the effects of standards on the natural gas sector includes reports of residential consumption of natural gas and the change in natural gas used to generate electricity. The energy savings associated with each proposed trial standard level from the *NES* model become input into NEMS-BRS. We show results from the reference case as well as scenarios for high and low economic growth.

The utility analysis uses the assumptions of the *AEO2000* and treats water heater efficiency standards as variations in policy. Because 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, its effect cannot be detected directly by NEMS-BRS. Therefore, simulation runs are done for larger reductions in demand and results are interpolated between the *AEO2000* reference case and these runs. We assumed that the measured effects are linear.

2.11 ENVIRONMENTAL ANALYSIS

The environmental analysis uses NEMS-BRS to provide information about the effect that new water heater standards would have on the quantity of 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 outcome of the analysis for each trial standard level is reported as a variation from the *AEO2000* results. The assumptions and inputs to the analysis are similar to the utility analysis.

2.12 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 (electricity, natural gas, LPG, and oil); (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.

To develop these results, an input/output model (ImBuild) of the U.S. economy was used to estimate the effects on different major sectors of the U.S. economy most relevant to buildings and their net impact on employment.[7, 8] The model was developed by Pacific Northwest National Laboratory to estimate the employment and income effects of building energy technologies and is itself a special-purpose version of the Impact Analysis for Planning (IMPLAN), a national input-output model, originally developed by the U.S. Forest Service in cooperation with the Federal Emergency Management Agency and the Bureau of Land Management. The IMPLAN model was developed by the Minnesota IMPLAN Group.[9]

An input/output model analyzes the interrelationships within an economy among businesses, and between businesses and consumers (including government entities), and captures all monetary market transactions for consumption for a given time period. These interrelationships between the various sectors of the economy are summarized as mathematical formulas and allow one to analyze

the effects of a change in one or more economic activities on an entire economy (e.g., changes in investment, monetary or tax policy).

In comparison with simple economic multiplier approaches, ImBuild allows for more complete and automated analysis of the economic impacts of energy-efficiency standards in buildings. The model takes user-supplied inputs to estimate employment effects at the national level. It uses a 35-sector model of the national economy to model the economic impacts of residential and commercial building technologies.

The assumptions made for this analysis are:

- The economy is considered "closed" and 100% of the investment in energy-efficiency technology has an opportunity cost in the U.S. economy's current activity. Funds necessary to finance investment are drawn proportionately from all sectors of the economy (i.e., personal/household consumption represents 70% of total spending; gross private fixed investment, 10%; federal defense spending, 2%; federal non-defense spending, 6%; and state and local government spending, 12%. These percentages are close to the actual distribution of final demand among these sectors as noted in M.J. Scott[7]).
- 100% of the capital cost premium associated with the new energy efficiency technology is purchased directly from the Household Appliances sector of the model.
- Cost savings to end users and saved utility investment funds are recycled back into the economy.

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