TECHNICAL SUPPORT DOCUMENT: ENERGY CONSERVATION STANDARDS FOR CONSUMER PRODUCTS: COOKING PRODUCTS

September 1998

U.S. Department of Energy
Assistant Secretary, Energy Efficiency
and Renewable Energy
Office of Codes and Standards

PREFACE

In accordance with the Energy Policy and Conservation Act, the Department of Energy (DOE) has wide-ranging statutory authority to promote appliance and equipment energy efficiency. Federal energy conservation standards set minimum levels or mandatory performance levels for certain products according to statutorily required economic and technical criteria.

As part of DOE's overall regulatory reform effort, the Department initiated a comprehensive review of the appliance energy efficiency rulemaking process. Throughout this process improvement, DOE has solicited comments from stakeholders through a series of public meetings. A constant "theme" has been the need for DOE to seek early stakeholder input into the rulemaking process, including early review of technical and economic analyses.

This Technical Support Document (TSD) was produced for DOE's Office of Energy Efficiency and Renewable Energy by the Energy Analysis Program at the Lawrence Berkeley National Laboratory. It is an extensively revised version of the Technical Support Document published in November 1993, upon which DOE's Notice of Proposed Rulemaking (NOPR) on March 4, 1994 for residential cooking equipment was based. This final TSD relies heavily on data, much of it from industry sources, supplied to DOE through comments made in response to the NOPR. An earlier version of this TSD was issued as a draft report by the DOE in April 1996 for the purpose of obtaining comments on the input data, methodology and results of the analyses. The General Methodology volume of this earlier draft report pertained to room air conditioners in addition to residential cooking equipment as DOE issued accompanying product specific volumes along with the General Methodology volume. Volumes 1 & 2 pertain only to residential cooking products, and they incorporates only minor revisions from the April 1996 draft report.

Volume 1 outlines the general methodology used to analyze several alternative efficiency levels for the residential cooking market in the United States. It contains the methodologies for conducting engineering analyses and determining life-cycle costs, energy savings potential, energy and economic impacts for residential buildings, impacts on manufacturer profitability, environmental impacts on air-borne emissions, and utility impacts for several energy efficiency levels.

Volume 2 contains an analysis of the energy savings and economic impacts of reaching differing energy efficiency levels on the U.S. residential cooking market. The final technical report contains engineering analyses, residential cooking life-cycle costs, energy savings potential, energy and economic impacts for residential buildings, impacts on manufacturer profitability, environmental impacts on air-borne emissions, and utility impacts for several energy efficiency levels.

The Supplemental Analysis contains more current information concerning venting and insulating non-self-cleaning ovens like self-cleaning ovens, and the penetration of gas cooking products without pilot lights. Additionally, two more recent fuel price forecasts (AEO (Annual Energy Outlook) 97 and GRI (Gas Research Institute) 97) have been employed in the revised analysis. Supplemental Chapter 3 contains the revised projected national impacts of several trial standard levels. Supplemental Chapter 4 contains the revised life-cycle cost (LCC) and payback period analyses. Supplemental Chapter 7 shows the impacts of one trial standard level (level 3A).

TECHNICAL SUPPORT DOCUMENT FOR RESIDENTIAL COOKING PRODUCTS

(Docket Number EE-RM-S-97-700)

VOLUME 1: GENERAL METHODOLGY

LAWRENCE BERKELEY NATIONAL LABORATORY
Environmental Energy Technologies Division
Technology and Market Assessment Group
Berkeley, CA 94720

Prepared for

U.S. DEPARTMENT OF ENERGY
Office of Codes and Standards

TABLE OF CONTENTS
VOLUME 1 - GENERAL METHODOLOGY

CHAPTER 1. INTRODUCTION

The Energy Policy and Conservation Act (P.L. 94-163), as amended, establishes energy conservation standards for 12 of the 13 types of consumer products specifically covered by the Act. The legislation requires the Department of Energy (DOE) to consider new or amended standards for these and other types of products at specified times. DOE is currently analyzing alternative energy efficiency levels for kitchen ranges and ovens (including microwave ovens). This Technical Support Document (TSD) presents the methodology, data, and results from the analysis of the energy and economic impacts of the efficiency levels.

The economic impact analysis is performed in four major areas:

- An *Engineering Analysis*, which establishes technical feasibility and product attributes, including energy performance and costs of alternative design options, which improve appliance efficiency.

- A *Consumer Analysis*, which forecasts appliance sales, efficiencies, energy use, and consumer expenditures.

- A *Manufacturer Analysis*, which provides an estimate of manufacturers' responses to the alternative efficiency levels. Their responses are quantified by changes in several financial performance measures for a prototypical firm.

- An *Impact Analysis*, which provides an integrated framework for assessing the costs and benefits of implementing new appliance efficiency levels. The Impact Analysis includes: 1) an *Industry Impact Analysis* that shows the financial and competitive impacts on the respective appliance manufacturing industry; 2) a *Life-Cycle Cost Analysis* that evaluates the savings in operating expense relative to an increase in purchase price for individual consumers; 3) a *Utility Analysis* that measures the impacts of the altered energy-consumption patterns on electric utilities; 4) a *Cost-Benefit Analysis* that collects the results of all the analyses into the net benefits and costs from a national perspective; and 5) an *Environmental Assessment* that presents the results of the associated environmental impacts from a range of alternative efficiency levels.

The Engineering Analysis segregates product types into separate classes to which different efficiency levels apply. For each appliance class, baseline units are chosen representing relatively low-efficiency units currently being manufactured. The analysis identifies a series of design options to improve energy efficiency and estimates the factory costs to produce them. Design options are added individually or in combination to the baseline unit to evaluate units that might be produced in response to having new efficiency levels implemented. Factory costs are then marked up to consumer

CHAPTER 2. DOCUMENT STRUCTURE

2.1 PURPOSE AND SCOPE

The Energy Policy and Conservation Act (P.L.94-163), as amended by the National Appliance Energy Conservation Act of 1987 (P.L. 100-12) and by the National Appliance Energy Conservation Amendments of 1988 (P.L. 100-357), provides energy conservation standards for 12 of the 13 types of consumer products[1] covered by the Act, and authorizes the Secretary of Energy to prescribe amended or new energy standards for each type (or class) of covered product.

The assessment of the alternative energy efficiency levels for kitchen ranges and ovens is designed to evaluate their economic impacts according to the criteria in the Act. It includes an engineering analysis of the cost and performance of design options to improve the efficiency of the products; forecasts of the number and average efficiency of products sold, the amount of energy the products will consume, and their prices and operating expenses; a determination of change in investment, revenues, and costs to manufacturers of the products; a calculation of the costs and benefits to consumers, electric utilities, and the nation as a whole; and an assessment of the environmental impacts of the alternative efficiency levels.

2.2 STRUCTURE OF THE DOCUMENT

This Technical Support Document (TSD) consists of two volumes. Volume 1, General Methodology, provides a general description of the analytic approach, including the structure of the major models. Volume 2 is specific to kitchen ranges and ovens and contains the data, documentation, and results specific to the analysis of kitchen ranges and ovens.

[1] The 13 products covered in the legislation are: 1) refrigerators, refrigerator-freezers, and freezers; 2) room air conditioners; 3) central air conditioners and central air-conditioning heat pumps; 4) water heaters; 5) furnaces; 6) dishwashers; 7) clothes washers; 8) clothes dryers; 9) direct heating equipment; 10) kitchen ranges and ovens; 11) pool heaters; 12) television sets; and 13) fluorescent lamp ballasts.

CHAPTER 3. ANALYTIC APPROACH

3.1 INTRODUCTION

The economic impacts of alternative energy efficiency levels depend largely on the relationship between the cost of a consumer product and its energy efficiency. The cost-efficiency relationships are determined for each product class based on engineering analyses. DOE has segregated product types into classes to which different energy efficiency levels might apply. The product types and the number of classes of ranges and ovens are shown in Table 3.1. Within each class, the energy-conserving designs are ordered by cost-effectiveness; then combinations of energy-saving design options are used to generate the relationships that are inputs to the other analyses of the impacts of setting new energy efficiency levels at various levels.

Identification of product classes, baseline units, design options, and maximum technologically feasible efficiencies is based on information gathered from the trade associations, manufacturers, discussions with researchers, a literature survey, and comments on the Advance Notice of Proposed Rulemaking (ANOPR) and the Notice of Proposed Rulemaking (NOPR). Energy use data have been obtained from AHAM (Association of Home Appliance Manufacturers), GAMA (Gas Appliance Manufacturers Association), FTC (Federal Trade Commission), manufacturers, and simulation models. Sources of factory cost data include manufacturers, suppliers, and the ANOPR and NOPR comments. The cost estimates are combined with the efficiency estimates to generate the cost-efficiency relationships.

The relationships between manufacturer costs and efficiency that are presented in this chapter are used throughout the other parts of the analysis. The engineering analysis also includes determination of maintenance and installation costs for each of the design options studied (see Chapter 1 of Volume 2 of this Technical Support Document). The manufacturer analysis uses manufacturer costs to produce retail prices. Retail prices, installation costs, and maintenance costs in conjunction with the corresponding efficiencies are used in the forecasting models to forecast sales and efficiencies and to calculate life-cycle costs and payback periods.

Table 3.1 Product Types and Number of Product Classes

Product Type	Number of Classes
Kitchen Ranges and Ovens	8

CHAPTER 4. INDUSTRY PROFILE FOR LAWRENCE BERKELEY NATIONAL LABORATORY MANUFACTURER IMPACT ANALYSIS

This section begins by examining housing starts and appliance saturation rates, with the primary focus on annual unit shipments for each of the analyzed products. It then presents a brief description of market shares followed by a discussion of mergers and acquisitions in these industries, and finally a comparison of consumer and producer price indices.

4.1 DEMAND

Units Shipped and Housing Starts

One of the primary components driving the demand of most appliances is housing starts. Although the changes in shipments of appliances are not entirely the result of changes in housing starts, housing starts can be used to predict shipments of most appliances for two reasons. First, almost every new house requires a new set of appliances, so fluctuations in housing starts cause fluctuations in shipments of most common appliances. (In fact, most of the fluctuation in shipments of products being analyzed can be attributed to the fluctuations in housing starts.) Second, housing starts are a good indicator of the strength of the economy as a whole. A healthy new-housing market is likely to correspond to a healthy economy, and a healthy economy encourages replacement and discretionary purchases of appliances. Therefore, there is generally a strong correlation between new-housing starts and appliance shipments.

Figures 4.1 and 4.2 [1] show annual shipments compared to housing starts for kitchen ranges and ovens. Other factors such as age of the current stock of appliances, purchase prices, fuel costs, consumer incomes, and climate conditions have varying degrees of importance in determining shipments of the various products covered by the National Appliance Energy Conservation Act of 1987 (NAECA). Further, some appliances have strong demand in the replacement market or in the aftermarket, and thus would be less correlated with new housing starts. Examples of such a product would be microwave ovens. Some of these factors are used by the Lawrence Berkeley National Laboratory-Residential Energy Model (LBNL-REM) in predicting appliance shipments in the base and alternative efficiency level cases. The manufacturers impact analysis uses the LBNL-REM estimates in its analysis of financial impacts on manufacturers.

The explosive growth in microwave ovens is displayed in Figure 4.2. After a slow period of growth in the late 1960s to early 1970s, the popularity of microwave ovens increased steeply in the 1980s, probably due to their greater convenience, improved technology, and lower prices. According to an industry trade source, the saturation rate of microwave ovens rose from 1.2% in 1973 to over 85% in 1993 (1).

---

[1] Housing starts data are from "Table No. 1202. New Privately-Owned Housing Units Started–Selected Characteristics: 1970-1993," *Statistical Abstract of the United States 1994*, U.S. Department of Commerce, 1994, p. 730. Shipments data for most products are from "Statistical Review," *Appliance*, April 1980, April 1990, and April 1993.

CHAPTER 5. DEVELOPMENT OF BASE CASE FORECASTS

Analyzing impacts of federal alternative energy efficiency levels requires comparing projected U.S. residential energy consumption with and without the efficiency levels. The cases without efficiency levels are referred to as *base case projections*. These base case projections are compared to projections of conditions that would be likely to prevail if alternative efficiency levels were enacted (see Volume 1, Chapter 3). The difference between the two projections is defined as the impact of implementing new efficiency levels.

Projections are made for a number of demographic, economic, and energy variables, including energy prices, household income, housing stock, housing starts, mix of house types (single-family, multi-family, mobile homes), building shell thermal characteristics, appliance purchases, equipment prices, unit energy consumption, and aggregate residential energy consumption by fuel type.

5.1 ECONOMIC AND DEMOGRAPHIC DATA: RESIDENTIAL

The LBNL-REM (described in Appendix B) is used to derive projections of residential energy demand. These projections are dependent on assumptions about future years, including occupied households, number of annual housing starts, disposable personal income, and energy prices. These data are described in Tables 5.1 through 5.5. (Economic data specific to ranges and ovens, such as equipment price, initial market shares, elasticities for market shares, efficiency choices, and usage behaviors are described in Appendix C of the product-specific discussion of ranges and ovens (Volume 2).)

5.1.1 Occupied Households

The number and type of occupied households for the base year (1980) are from the 0.1% Public Use MicroSample (PUMS) of the 1980 Decennial Census. The occupied households projection from 1992 to 2010 is obtained from DOE/EIA's *Annual Energy Outlook 1995*. (1). The stock of households is interpolated in years 1981 to 1991.

APPENDIX A. UNCERTAINTY ANALYSIS FOR ENERGY EFFICIENCY

Many of the inputs to the calculations of energy savings for each design option have some degree of uncertainty associated with them. This uncertainty of the inputs affects the level of confidence in the estimate of energy savings for design options. As design options are combined, the effects of the uncertainty on the inputs are also combined, so that the uncertainty in the energy savings becomes larger and larger.

In order to understand the effects that the uncertainty of input values had on the calculation of energy savings, a risk-analysis program (1) was used to quantify the uncertainty. The risk-analysis program (See Figure A.1.) was an add-in to the spreadsheets used to generate the cost/efficiency tables shown in this Technical Support Document. It allowed the inputs to the calculations to be specified by an assumed distribution of values with associated probabilities. After the probabilities were specified, the energy-savings spreadsheet was recalculated several hundred times, randomly choosing a value from each distribution. The selection was done in such a way that the distribution of input values chosen matched the probabilities specified in the input distribution.

The baseline was assumed to be exact for purposes of this study, therefore no distribution was applied to any of the inputs on the baseline models. The uncertainty of the inputs for combined or stacked design options included (i.e., were applied on top of) the uncertainties of previous design options. Often different design options affected different parts of the energy consumption calculations. An example of this would be applying heat traps to a gas-fired storage water heater and then applying a submerged combustion chamber. The heat traps reduce the standby loss, while the submerged combustion chamber increases the recovery efficiency. In these cases, the uncertainties from previous design options were used in the calculations, even though that part of the calculation was not being changed by the current design option.

The results of the uncertainty analysis were reported only for the maximum technologically feasible design options. These results include the uncertainties of all the design options that were applied before the maximum technologically feasible design option. The upper and lower values reported for the uncertainty of the efficiency indicator span the middle 95% of all values resulting from the uncertainty analysis.

For room air conditioners, the method was modified slightly to accommodate the use of a simulation model. An input file to the simulation model was constructed for the baseline and each design option. The data in the input files specified the properties and operating conditions of a room air conditioner. The risk-analysis program was used to generate several hundred simulation model input files. The distribution of values in the input files that were used to specify changes from the baseline by the design options reflected the probability distribution entered into the risk-analysis program. The combined results of all the simulation runs thus reflected the impact of uncertainty on the inputs.

Most of the input values were assumed to have a normal distribution, with the selected value being the mean of the distribution. The standard deviation of the distribution was then specified as the difference between the largest and/or the smallest values considered possible and the mean. The

APPENDIX B. FORECASTING MODELS

B.1 LBNL RESIDENTIAL ENERGY MODEL

B.1.1 Overview

The LBNL Residential Energy Model (LBNL-REM) provides projections of the important characteristics of the residential appliance market. The LBNL-REM utilizes a database of significant determinants of the current residential appliance market, as well as parameters characterizing market decisions that will affect the energy consumption of future appliances. This appendix describes the LBNL-REM, the types of data it uses, the calculations it performs, and the results the LBNL-REM provides.

The LBNL-REM projects numbers of households by house type, energy-related building shell characteristics, average energy efficiency of appliances, fraction of households owning each appliance, usage behavior, and turnover of appliances. These characteristics are projected for each year from 1980 to 2030.

The LBNL-REM combines these factors to project energy consumption and expenditures by fuel type for each end use, and monetary expenditures for equipment (both replacement and new installations) and for fuels. The results are reported in several formats, for convenience, including: annual energy consumption and expenditures, annual equipment shipments, cumulative energy consumption and expenditures over a period (e.g., from policy implementation date to the end of the projection period), and net present values of equipment and energy expenditures, discounted and summed over time.

The basic equation in the simulation model that defines residential use of fuel *i* for end use *k* in housing type *m* during year *t* is:

$$Q_t^{ikm} = STOKC_t^{m} \cdot C_t^{ikm} \cdot EU_t^{ikm} \cdot U_t^{ik} \cdot TI_t^{i} \qquad \textbf{(B.1)}$$

where *STOKC* is the stock of occupied housing units, *C* is the saturation (percent of households with this equipment), *EU* is the unit energy consumption, *U* is the usage behavior factor, and *TI* is the thermal integrity factor (for space conditioning only).

Households respond to changes in operating expenses in three different ways. In the short run (see B.1.6, "Usage Behavior"), they change the way they operate existing equipment and structures (e.g., lower winter thermostat settings). In the long run, they also change equipment by switching from one fuel to another (see B.1.5, "Market Shares"), by improving the efficiency of their equipment (e.g., purchasing a water heater with more jacket insulation (see B.1.4, "Equipment Efficiency"), or both. Thus, the elasticity of demand for a particular fuel with respect to the price of that fuel can be separated into three elements—a usage elasticity (E_u), a technical efficiency elasticity (E_e), and an equipment/fuel

APPENDIX C. LAWRENCE BERKELEY NATIONAL LABORATORY - MANUFACTURER ANALYSIS MODEL

C.1 OVERVIEW OF THE LAWRENCE BERKELEY NATIONAL LABORATORY - MANUFACTURER ANALYSIS MODEL

C.1.1 Purpose

The Lawrence Berkeley National Laboratory Manufacturer Analysis Model (LBNL-MAM) collects into one spreadsheet all the calculations necessary to determine the impact of a change in appliance efficiency levels on an industry's profitability and scale of operation. The spreadsheet design makes it possible to quickly analyze the effects of uncertainties in input values and to efficiently incorporate new data into the calculations. The model has a control panel, which makes the analysis of uncertainty particularly straightforward for nine of the model's crucial inputs. Through this panel, the model provides the user not only with the best estimates of financial impacts, but also with the uncertainty of these estimates and a sensitivity analysis attributing that uncertainty to certain input variables.

C.1.2 The Economic Approach

The impact of implementing new efficiency levels on manufacturers depend on the interaction of four factors: 1) the costs imposed by the change in implementing new efficiency levels, 2) the price elasticity of a single typical firm, 3) the industry's price elasticity of demand, and 4) the consumer market discount rate for energy savings for a product (which are used to obtain industry operating cost elasticity). The LBNL-MAM integrates and analyzes these four factors as they apply to a single typical firm.

A change in imposed efficiency levels will generally create three types of costs for a firm. First, variable costs of goods sold (VCGS) will be affected by new parts and labor requirements. Second, some engineering will be required to design, test, and plan the manufacturing of new products. And third, new products often require re-tooling and new equipment (capital) costs. The incorporation of VCGS is straightforward, but engineering and capital costs must be amortized to be converted from one-time costs to annual costs for a typical-year model.

Markups from manufacturing costs to ex-factory prices depend on the single-firm price elasticity. Because it is difficult to find data on single-firm price elasticities, the LBNL-MAM infers them from the firm's fixed costs and return on equity (ROE). The markup is over variable cost and not fixed; hence it must be greater than one if a firm with fixed costs is to recover its fixed costs and turn a profit.

The industry has two elasticities of interest: its price elasticity and its operating cost elasticity.

APPENDIX D. MAINTENANCE COSTS FOR INTERMITTENT IGNITION DEVICES IN GAS RANGES AND OVENS

This appendix describes the analysis used to characterize the maintenance costs for intermittent ignition devices (IIDs) for gas cooktops and ovens.

D.1 ANALYSIS APPROACH

Maintenance costs have been characterized for this analysis as an annual incremental cost, referred to here as the annualized maintenance cost, MC_a, to be added to the annual fuel cost for the gas cooktop or oven. In order to derive MC_a, the present value of the maintenance cost, MC_{pv}, is first derived. The value of MC_{pv} is based on an assumed probability distribution of maintenance costs over the appliance lifetime. Given the present value MC_{pv} , the annualized maintenance cost is calculated using the so-called capital recovery factor, CRF, as $MC_a = CRF \cdot MC_{pv}$. The capital recovery factor is calculated as

$$CRF = \frac{d}{1 - (1+d)^{-n}}$$

National Appliance Energy Conservation Act (NAECA), Public Law 100-12, March 17, 1987. where *n* is the appliance lifetime, and *d* is the discount rate.

D.2 GENERAL DESCRIPTION OF INTERMITTENT IGNITION DEVICES (IIDs)

The cost analysis here was generated specifically for two types of pilotless ignition systems; direct spark and spark-to-pilot IIDs. IIDs are common to gas-fired furnaces, water heaters, direct heating equipment, clothes dryers, and cooktops. With regard to ovens, most use electric glo-bar ignition systems rather than IIDs. Although electric glo-bar ignition devices are a type of hot surface ignition (HSI) device, their control systems differ considerably from those used by typical HSI devices. Electric glo-bar ignition systems are designed to draw electrical power for as long as the burner remains in operation while almost all other HSI systems draw power only to light the burner. Although the glo-bar's control system uses a considerable amount of electrical energy, it is a relatively simple design which, unlike most IIDs and HSI systems, does not require the use of electronics. Therefore, the maintenance costs for gas ovens using electric glo-bar ignition devices are not treated in this Appendix. The cost analysis generated here is not directly applicable to typical HSI devices either. The main difference between HSI and IID devices is the actual ignitor element itself; control modules, gas valves, and ignition sensors appear to be similar in function and maintenance across all systems. Therefore, the assumption is made here that HSI and spark ignitors have the same maintenance costs. While HSI ignitor breakage rates were probably substantially higher than spark ignitor failure rates in the recent past, the assumption in this analysis is that HSI ignitor breakage rates will have been significantly reduced

APPENDIX E. ELECTRIC UTILITY IMPACT MODELING

E.1 INTRODUCTION

This appendix summarizes the methods used to calculate utility avoided costs for the energy savings that result from the imposition of appliance energy efficiency levels. Usually, the appliance being analyzed is electrically fueled; however, efficiency levels imposed on gas or oil-fired appliances may also indirectly affect electricity demand. The conventions and background information used in the analysis, and the basis for valuing the energy and capacity savings of the efficiency levels are explained. The goal of this analysis is to calculate the peak and capacity savings and the avoided costs, in dollars per million Btu ($/MMBtu) of electricity saved, where the energy is expressed as primary energy. Avoided costs contain both the marginal fuel and marginal capacity value of each kWh saved by the alternative efficiency levels in each year of the period analyzed.

E.2 AVOIDED COST: BACKGROUND AND CONVENTIONS

The analysis adopts the standard utility convention that the value of electricity savings, commonly called *avoided cost*, can be broadly separated into *energy* or variable cost savings, and *capacity* or fixed cost savings. The variable impact measures the production costs avoided by reduced electrical generation. The largest variable component by far is the cost of the fuel not burned, but there are also avoided labor and variable operation and maintenance costs to be considered. The fixed component is intended to measure the benefit of reduced system load during peak periods. Since electricity cannot normally be stored on the large scale associated with utilities, all electricity must be generated at the same moment it is consumed. One way to measure the cost avoided by a lower peak demand is to estimate the lowest possible cost of maintaining the cheapest generator available on hand year-around simply to generate the last kW demanded at the peak hour. By convention, this hypothetical generator is a low-cost gas turbine, and its capital cost per kW is called the *gas turbine proxy*. In addition to the generating capacity itself, lowering peak demand will also deliver a saving in the need for peak transmission and distribution (T&D) capacity, which should be included in the capacity savings.

An appliance alternative efficiency level analysis typically relies on disaggregation by National Electric Reliability Council (NERC) region of capacity savings and energy savings, followed by re-aggregation to the national level. Disaggregation is necessary because different regions need capacity at different times, and the relative energy savings attributable to each region for heating, cooling, and all other appliances vary substantially. For the purposes of calculating electric utility avoided costs, *heating appliances* are defined as electric heat pumps in heating mode and electric resistance heat, *cooling appliances* are defined as room and central air-conditioning plus heat pumps in cooling mode, and *baseload appliances* are defined as all other appliances affected by new efficiency levels, including all residential refrigeration.

E.3 ENERGY COST SAVINGS

ENVIRONMENTAL ASSESSMENT FOR ALTERNATIVE EFFICIENCY LEVELS FOR KITCHEN RANGES AND OVENS

1. INTRODUCTION AND NEED FOR PROPOSED ACTION

This Environmental Assessment (EA) on the candidate alternative efficiency levels for kitchen ranges and ovens was prepared pursuant to the National Environmental Policy Act of 1969 (NEPA), regulations of the Council on Environmental Quality, and Title 40, Code of Federal Regulations, Parts 1500 through 1508. The candidate alternative efficiency levels are being analyzed pursuant to the Energy Policy and Conservation Act, as amended by the National Energy Conservation Policy Act and the National Appliance Energy Conservation Act (1).

The EA presents the results of the associated environmental impacts from new candidate alternative efficiency levels for kitchen ranges and ovens. Each measure of possible environmental change is an alternative action, and it is compared to what is expected to happen if no new efficiency levels for these products were implemented, i.e., the "no action" alternative.

The primary environmental concern addressed is atmospheric emissions both from fossil-fueled electricity generation and from combustion in the home. The design options for kitchen ranges and ovens result in decreased electricity use and, therefore, a reduction in power plant emissions. The alternative efficiency levels will generally decrease air pollution by decreasing future energy demand. A major benefit of lower energy use is the reduced need to emit sulfur dioxide, SO_2. However, the Clean Air Act Amendments (1990) placed a national ceiling on emissions of this acid rain precursor. In this report, reductions in SO_2 are reported; however, these should be interpreted as a reduced need to pollute, rather than reduced physical emissions. Reductions of nitrogen oxides (NO_x) and carbon dioxide emissions (CO_2) will actually occur as a result of the new efficiency levels and are listed by weight of NO_x and CO_2, respectively. NO_x also contributes to acid deposition and is a precursor to urban photochemical smog, as well as being directly harmful if breathed. CO_2 emissions from fossil-fuel burning is considered an environmental hazard because it contributes to the “greenhouse effect” by trapping heat energy from the earth that is emitted as infrared radiation. The greenhouse effect is expected to gradually raise the mean global temperature.

Although the quantity of raw materials used per appliance will remain relatively constant, in most scenarios increased initial cost is expected to slightly decrease the number of appliances sold, resulting in small decreases in raw materials used. The main effect of the appliance production decrease is reduced SO_2 emitted in steel production. That reduction is small, however, in comparison to the SO_2 decreases from avoided fuel-burning at power plants. The contribution from steel production is not included in the estimates for net SO_2 decreases resulting from design changes in these products.

The focus of the environmental analysis is on just two air pollutants, SO_2 and NO_x, because the effects of changes in total electric power generation are primarily seen in emissions of these pollutants. In-house combustion is an important source of NO_x. Additionally, since the greenhouse effect is of such major international concern, the effect on emissions of CO_2 is also reported.

Of the six criteria pollutants, power generation contributes major shares (70% and 32%, respectively) of total U.S. SO_2 and NO_x emissions, but only 2% of lead emissions, and insignificant amounts of particulate[1], carbon monoxide (CO), and volatile organic compounds (VOCs) (2). In-house combustion is an important contributor to overall NO_x emissions in urban areas, which can be important during smog episodes, but is an insignificant source of SO_2 and the other criteria pollutants. Power generation contributes 34% of all U.S. CO_2 emissions, and in-house combustion 19% (3).

Reductions in particulate emissions accompanied by decreases in SO_2 and NO_x would have other beneficial effects on the environment. The resultant improvement to air quality and the decreased potential of acid rain formation would help improve the quality of wetlands and fish and wildlife as well as aid in the preservation of historical and archaeological sites. Reductions in NO_x emissions within warm urban areas is particularly beneficial because it is an urban smog precursor as well as an acid rain precursor, and an air pollutant in its own right.

Reduced in-house fuel consumption will decrease the amount of gas or oil burned within some homes, thereby decreasing the impact of combustion on indoor air quality. Indoor air problems are usually due to a combination of factors, including a tight house envelope, insufficient ventilation for cooking appliances, presence of sources such as cigarette smokers or formaldehyde-containing products, and radon diffusion from soil. In comparison to the above factors, and because fuel-burning appliances are normally vented to the outside, the projected changes in in-house fuel-burning appliance use is expected to have little effect on indoor air quality.

2. METHODS OF ESTIMATING ENVIRONMENTAL IMPACTS

The greatest impacts of implementing the new efficiency levels would be a reduction in electricity demand growth. The main environmental effects of power plants on air and water quality result from emissions of SO_2, NO_x, and CO_2. With the alternative efficiency levels lessening the need for electricity generation, power plant emissions would be reduced. A second source of these pollutants is fuel-burning household appliances. Pollutants from fuel-burning household appliances will be termed “in-house” emissions, and are reported below.

Note that the effect of implementing new efficiency levels will not be to reduce emissions in all cases. There are two major ways in which emissions can rise as the result of an imposed efficiency level. First, the changing economics of appliances may cause consumers to fuel-switch or appliance-switch. For example, higher room air conditioner prices could prompt a switch to central air conditioning, raising both overall energy use and emissions. Second, the efficency level may also change the thermodynamics of

---

[1] Based on the PM-10 plus PM-10 fugitive dust definition.

the home. For example, more efficient cooking appliances could lower the heat released in-house, increasing the load on the heating system. If the home is heated with oil, the effect would be to raise SO_2 emissions.

2.1 Baseline Emissions

In the Service Report that accompanies the 1991 National Energy Strategy (NES), the impact on power plant emissions as a result of revisions to Title V of the 1990 Clean Air Act Amendments, P. L. 101-549, are estimated (4). The emission forecast that appears in that report is presented below as Table 1.

NO_x emissions are required to be reduced by 1.8 Mt (2 million short tons) by the year 2000 under the legislation. However, no emissions cap exists for NO_x, and the goals of the legislation are implemented through command-and-control emissions rates that vary by fuel burned and type of boiler. Therefore, while NO_x emissions per kWh generated are expected to fall, they will fall less than emissions of SO_2. Also, it is less clear whether the Act's emissions reduction target will be met because enforcement is indirect, through various performance standards. In this case, it is reasonable to report predicted reductions in physical NO_x emissions as a result of the appliance efficiency levels, and that approach is adopted here.

The case of SO_2 emissions is more complex. The legislation calls for SO_2 emissions reductions in two phases. In the first phase of the planned reductions (beginning December 31, 1995, and carrying through the year 2000), electric utilities will have several options for reducing their SO_2 emissions to comply with the allowance constraints imposed by the provisions of the Clean Air Act. The major options are 1) to decrease their use of high-emission units and increase the use of their clean units, 2) to switch units using high-sulfur coal to low-sulfur coal, 3) to retrofit plants emitting at a high rate with emissions-reduction technologies (e.g., scrubbers), 4) to purchase allowances from other utilities who reduce their emissions below their permitted levels, and 5) to purchase power rather than generate it. Most utilities will make use of a combination of these options to minimize the cost of complying with the allowance constraints. Total SO_2 emissions by utilities cannot exceed 8.1 Mt (8.9 million short tons) after December 31, 2000.

In the second phase of the planned reductions (beginning December 31, 2000), the options available to electric utilities for maintaining the 8.1 Mt SO_2 emissions cap will broaden with the expected introduction of new, advanced generating technologies. However, during this period utilities are less able to reduce emissions by changing the way they utilize their plants. Since most plants will be fully utilized, there will be few opportunities for reducing emissions by decreasing the use of a high-emission plant or for further fuel switching.

The adoption or non-adoption of the efficiency level for kitchen ranges and ovens will likely not affect the physical emissions of SO_2, which will hover near the ceiling. This is not to say that there is no SO_2 emissions benefit to be derived from the lowered electricity demand implied by appliance efficiency levels. Actual physical emissions will not be lowered, but the demand for SO_2 allowances by electricity generators will be reduced, resulting in lower allowance prices, and lower electric utility compliance costs. In other words, lowered generation is a costless contribution towards the SO_2 clean-up required by the Act. Estimating these effects as they reverberate through SO_2 allowance trading, however, is too ambitious for this analysis. Here, therefore, emissions reductions by weight are simply estimated and reported, as if the allowance trading market did not exist. Further, no effort is made to estimate the reduced compliance cost, which may ultimately benefit utility companies, their stockholders, or their ratepayers. The actual distribution of benefits depends upon the regulatory regime.

In the Service Report accompanying the 1991 NES, two possible outcomes are presented, a flexible case and a restricted case, so that the effect of different levels of permitted trading of emission allowances can be evaluated. (The report does not go beyond this explanation in defining the differences between the two cases.) As presented in the report, the results for the two cases are virtually identical. Because the two cases are so similar, only the U.S. power plant emission projections for the three effluents under the assumptions made in the flexible case are presented.

Table EA-1. U.S. CO_2, SO_2, and NO_x Power Plant Emissions

Year	CO_2 *10^6 short tons*	SO_2 *10^6 short tons*	NO_x *10^6 short tons*
1995	2233	13.8	8.4
2000	2506	9.0	6.7
2010	3219	8.4	7.3
2020	3964	6.7	6.7
2030	4804	4.8	5.9

2.2 Sulfur Dioxide and Nitrogen Oxide Emissions

In order to capture the effects of cleaner-burning power plants in future years, emission rates (tons/Quad) for power plant fuel-burning are calculated from projected emissions and electrical generation data. The electrical generation data is translated below into energy use (Quads) by assuming a 30% overall energy conversion efficiency. The source of these projected emissions and electrical generation data is the Service Report. Table 2 presents these data and the calculated emission rates for SO_2 and NO_x.

Table EA-2. Electricity Generation, Emissions Data, and Emissions Rates for SO_2 and NO_x at Fossil Fuel-Burning Power Plants

	Electricity Generation			Energy Use	Emissions		Emissions Rates (primary)	
Year	Coal *10^9 kWh*	Oil *10^9 kWh*	Gas *10^9 kWh*	Total *Quads*	SO_2 *10^6 short tons*	NO_x *10^6 short tons*	SO_2 *10^3 tons/ Quad*	NO_x *10^3 tons/ Quad*
1995	1602.2	193.7	442.0	25.74	13.8	8.4	536.1	326.3
2000	1814.0	179.8	605.0	29.89	9.0	6.7	301.1	224.1
2010	2660.6	149.9	482.5	37.88	8.4	7.3	221.8	192.7
2020	3727.8	67.2	292.3	47.01	6.7	6.7	142.5	142.5
2030	4837.3	29.0	179.2	58.03	4.8	5.9	82.7	101.7

The calculated emissions rate data listed in Table 2 represents the average SO_2 and NO_x emissions rates for all fossil fuel-burning power plants in the United States. Emissions rates were not calculated for each fuel-burning source because the emissions data supplied by the Service Report were not disaggregated according to power plant type (i.e., coal, oil, gas). To obtain emission rate values, the amount of emissions was divided by the total energy use of fossil fuel-burning power plants. The total energy use by fossil fuel-burning power plants was calculated from the electrical generation data supplied by the Service Report. The electrical generation data was disaggregated by fuel source. To obtain the total energy use (input), the electrical generation data from each fossil fuel source was summed and then divided by the assumed efficiency of fossil fuel-burning power plants (30%), which includes transmission and distribution losses. This fossil fuel-burning power plant efficiency is consistent with that used by the LBNL Residential Energy Model (LBNL-REM).

The amount of SO_2 and NO_x emissions abated for any particular year is determined by multiplying the estimates of energy saved through reduced electricity generation in that year by the emission rate for that particular year. For years not covered in the Service Report, linear interpolation was used to derive emission rates and, in turn, the corresponding abated emissions.

Table 3 presents the emission factors (rates) that were used for SO_2 and NO_x for in-house gas and oil combustion. The values for reduction of SO_2 and NO_x emissions from in-house gas and oil combustion are produced by multiplying in-house fuel savings for gas and oil by the corresponding emission rates. Emission factors that appear in Table 3 are from a Lawrence Berkeley National Laboratory report (5). Emission factors for gas in-house combustion were assumed to equal the average of those for residential gas space heaters and water heaters. Emission factors for oil in-house combustion were assumed to equal those associated with a residential #2 oil boiler.

Table EA-3. Emission Rates for SO_2 and NO_x from In-House Combustion

SO_2 Gas Emission *10^3 tons/Quad*	SO_2 Oil Emission *10^3 tons/Quad*	NO_x Gas Emission *10^3 tons/Quad*	NO_x Oil Emission *10^3 tons/Quad*
0.0	156.5	52.5	65.0

2.3 Carbon Dioxide Emissions

Emission rates for CO_2 were derived in the same manner as those derived for SO_2 and NO_x. As presented in Table 1, the Service Report accompanying the 1991 NES also provided emissions data with regard to CO_2.[2] Table 4 presents the CO_2 emission rate data as derived from the electrical generation data and emissions data supplied by the report.

Table EA-4. Electricity Generation Data, Emissions Data, and Emissions Rates for CO_2 at Fossil Fuel-Burning Power Plants

Year	Electricity Generation			Energy Use Total *Quads*	Emission CO_2 *10^6 short tons*	Emission Rate CO_2 *10^6 tons/Quad*
	Coal *10^9 kWh*	Oil *10^9 kWh*	Gas *10^9 kWh*			
1995	1602.2	193.7	442.0	25.74	2232.5	86.37
2000	1814.0	179.8	605.0	29.89	2506.2	83.85
2010	2660.6	149.9	482.5	37.88	3219.3	85.00
2020	3727.8	67.2	292.3	47.01	3964.2	84.32
2030	4837.3	29.0	179.2	58.03	4804.4	82.79

As with the SO_2 and NO_x emissions, the amount of CO_2 emissions abated for any particular year is determined by multiplying the estimates of energy saved through reduced electricity generation by the emission rate for that particular year. For years not covered in the Service Report, linear interpolation was used to derive emission rates and, in turn, the corresponding abated emissions.

Table 5 presents the emission factors (rates) that were used for CO_2 for in-house gas and oil combustion. The values for the reduction of CO_2 emissions from in-house gas and oil combustion are

[2] From phone conversations with David Streets at Argonne National Laboratory (February 1992), it was determined that the carbon emissions data provided in the Service Report accompanying the 1991 NES were mistakenly reported as tons of *carbon* emitted. David Streets was one of authors at Argonne who contributed to the report.

produced by multiplying in-house fuel savings for gas and oil by the corresponding emission rates. Emission factors that appear in Table 5 are from a Lawrence Berkeley National Laboratory report (6). The emission factor for gas in-house combustion was assumed to equal the average of those for residential gas space heaters and water heaters. The emission factor for oil in-house combustion was assumed to equal the one associated with a residential #2 oil boiler.

Table EA-5. Emission Rates for CO_2 from In-House Combustion

CO_2 Gas Emission *10^3 tons/Quad*	CO_2 Oil Emission *10^3 tons/Quad*
55,000	84,300

3. RESULTS

The following results in Tables 6 through 20 indicate the potential changes in amounts of emitted CO_2, SO_2, and NO_x resulting from new efficiency levels for kitchen ranges and ovens. A table is presented for each of the alternative efficiency levels. Each table details the changes that occur to each of the three emissions (i.e., CO_2, SO_2, and NO_x) through the imposition of a new efficiency level for this type of appliance. Each table shows, for a specific year between 2000 and 2030, the amount of emission abated from power plant generation, the amount abated from in-house generation, the net change in the emission, and the percent the net change comprises of total U.S. residential emissions. Also included are the cumulative changes of each pollutant (between the years 2000 and 2030).

For each section that follows, only the results from the highest efficiency level are discussed for each appliance. In order to view the results for each efficiency level, tables for each level are provided after the discussion.

It should be noted that the alterantive efficiency levels studied are not consistent between the two appliances. The number of efficiency levels that are analyzed for a particular appliance depends on the number and type of technologies that were considered for it. For a detailed explanation of the specific technologies considered for kitchen ranges and ovens, please refer to the appropriate sections and appendices of the product-specific discussion of kitchen ranges and ovens (Volume 2) in this report.

3.1 RANGES AND OVENS

Decreases in the amounts of CO_2, SO_2, and NO_x are presented for cooktops, conventional ovens, and microwave ovens. Alternative efficiency levels 1 through 5 for cooktops are summarized in Tables 6 through 10, alternative efficiency levels 1 through 5 for conventional ovens are summarized in Tables 11 through 15, and alternative efficiency levels 1 through 5 for microwave ovens are summarized in Tables 16 through 20.

3.1.1 Sulfur Dioxide and Nitrogen Oxide Emissions

Cooktops

Need for sulfur dioxide emissions would be decreased by a cumulative total of up to 67 kt (73 thousand short tons) between 2000 and 2030 in the level 5 scenario. In the year 2000, decreases in sulfur dioxide will represent about 0.02% of the SO_2 emissions estimated to come from the residential sector in that year. In the year 2030, decreases in SO_2 emissions will represent about 0.10% of the SO_2 emissions estimated to come from the residential sector in that year. As discussed earlier, the possible reductions of SO_2 emissions caused by new efficiency levels can be earned as excess allowances. To the extent these allowances are used for future emissions, the efficiency levels' net effect on those SO_2 emissions would be only a postponement.

Level 5 design changes to cooktops would result in an estimated decrease in NO_x emissions of 65 kt (72 thousand short tons) between 2000 and 2030. NO_x decreases would represent 0.02% and 0.10% of the NO_x emissions estimated to come from the residential sector in the years 2000 and 2030, respectively.

Conventional Ovens

Sulfur dioxide emissions would be decreased by a cumulative total of up to 241 kt (266 thousand short tons) between 2000 and 2030 in the level 5 scenario. In the year 2000, decreases in sulfur dioxide will represent about 0.05% of the SO_2 emissions estimated to come from the residential sector in that year. In the year 2030, decreases in SO_2 emissions will represent about 0.43% of the SO_2 emissions estimated to come from the residential sector in that year. As discussed above, the possible reductions of SO_2 emissions caused by new efficiency levels can be earned as excess allowances. To the extent these allowances are used for future emissions, the efficiency levels' net effect on those SO_2 emissions would be only a postponement.

Level 5 design changes to conventional ovens would result in an estimated decrease in NO_x emissions of 239 kt (263 thousand short tons) between 2000 and 2030. NO_x decreases would represent 0.05% and 0.41% of the NO_x emissions estimated to come from the residential sector in the years 2000 and 2030, respectively.

Microwave Ovens

Sulfur dioxide emissions would be decreased by a cumulative total of up to 53 kt (58 thousand short tons) between 2000 and 2030 in the level 5 scenario. In the year 2000, decreases in sulfur dioxide will represent about 0.02% of the SO_2 emissions estimated to come from the residential sector in that year. In the year 2030, decreases in SO_2 emissions will represent about 0.08% of the SO_2 emissions estimated to come from the residential sector in that year. As discussed above, the possible reductions of SO_2 emissions caused by new efficiency levels can be earned as excess allowances. To the extent these allowances are used for future emissions, the efficiency levels' net effect on those SO_2 emissions would be only a postponement.

Level 5 design changes to microwave ovens would result in an estimated decrease in NO_x emissions of 48 kt (53 thousand short tons) between 2000 and 2030. NO_x decreases would represent 0.02% and 0.07% of the NO_x emissions estimated to come from the residential sector in the years 2000 and 2030, respectively.

3.1.2 Carbon Dioxide Emissions

Cooktops

The cumulative reduction in CO_2 emissions from level 5 design changes is 36 Mt (39 million short tons) of CO_2. For the year 2000, the estimated CO_2 reduction is 0.16 Mt of CO_2 or about 0.01% of estimated U.S. power plant CO_2 emissions in 2000. For the year 2030, the estimated CO_2 reduction is 1.47 Mt of CO_2 or about 0.09% of estimated U.S. power plant CO_2 emissions in 2030.

Conventional Ovens

The cumulative reduction in CO_2 emissions from level 5 design changes is 133 Mt (47 million short tons) of CO_2. For the year 2000, the estimated CO_2 reduction is 0.52 Mt of CO_2 or about 0.04% of estimated U.S. power plant CO_2 emissions in 2000. For the year 2030, the estimated CO_2 reduction is 6.77 Mt of CO_2 or about 0.38% of estimated U.S. power plant CO_2 emissions in 2030.

Microwave Ovens

The cumulative reduction in CO_2 emissions from level 5 design changes is 25 Mt (28 million short tons) of CO_2. For the year 2000, the estimated CO_2 reduction is 0.16 Mt of CO_2 or about 0.01% of estimated U.S. power plant CO_2 emissions in 2000. For the year 2030, the estimated CO_2 reduction is 1.02 Mt of CO_2 or about 0.06% of estimated U.S. power plant CO_2 emissions in 2030.

Table EA-6. Reduction of Pollutants for Cooktops, Level One

SO_2

Year	Abated from Power Plants		Abated from In House		Total Reduction in Emissions		Reduction as a % of Total Residential Emissions
	kt	thousand short tons	kt	thousand short tons	kt	thousand short tons	
2000	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2005	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2010	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2015	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2020	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2025	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2030	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Cumulative SO_2 reduction (kt): 0 (short tons): 0 000

NOx

Year	Abated from Power Plants		Abated from In House		Total Reduction in Emissions		Reduction as a % of Total Residential Emissions
	kt	thousand short tons	kt	thousand short tons	kt	thousand short tons	
2000	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2005	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2010	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2015	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2020	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2025	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2030	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Cumulative NOx reduction (kt): 0 (short tons): 0 000

CO_2

Year	Abated from Power Plants		Abated from In House		Total Reduction in Emissions		Reduction as a % of Total Residential Emissions
	Mt	million short tons	Mt	million short tons	Mt	million short tons	
2000	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2005	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2010	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2015	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2020	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2025	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2030	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Cumulative CO_2 reduction (Mt): 0 (short tons): 0 000 000

Table EA-7. Reduction of Pollutants for Cooktops, Level Two

SO_2

Year	Abated from Power Plants		Abated from In House		Total Reduction in Emissions		Reduction as a % of Total Residential Emissions
	kt	thousand short tons	kt	thousand short tons	kt	thousand short tons	
2000	0.14	0.16	-0.01	-0.01	0.13	0.14	0.00
2005	0.51	0.56	0.00	0.00	0.51	0.56	0.02
2010	0.63	0.69	0.00	0.00	0.63	0.69	0.02
2015	0.52	0.58	-0.01	-0.01	0.51	0.56	0.02
2020	0.26	0.28	-0.01	-0.01	0.24	0.27	0.01
2025	0.04	0.05	0.00	0.00	0.04	0.05	0.00
2030	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Cumulative SO_2 reduction (kt): 11 (short tons): 12 000

NOx

Year	Abated from Power Plants		Abated from In House		Total Reduction in Emissions		Reduction as a % of Total Residential Emissions
	kt	thousand short tons	kt	thousand short tons	kt	thousand short tons	
2000	0.11	0.12	-0.01	-0.01	0.10	0.11	0.00
2005	0.41	0.45	-0.01	-0.01	0.40	0.44	0.01
2010	0.55	0.60	-0.01	-0.01	0.53	0.59	0.02
2015	0.48	0.53	-0.02	-0.02	0.47	0.51	0.02
2020	0.26	0.28	-0.01	-0.02	0.24	0.27	0.01
2025	0.05	0.05	0.00	0.00	0.04	0.05	0.00
2030	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Cumulative NOx reduction (kt): 9 (short tons): 10 000

CO_2

Year	Abated from Power Plants		Abated from In House		Total Reduction in Emissions		Reduction as a % of Total Residential Emissions
	Mt	million short tons	Mt	million short tons	Mt	million short tons	
2000	0.04	0.04	-0.01	-0.01	0.03	0.04	0.00
2005	0.17	0.19	-0.01	-0.01	0.16	0.17	0.01
2010	0.24	0.27	-0.01	-0.02	0.23	0.25	0.02
2015	0.25	0.27	-0.02	-0.02	0.23	0.25	0.02
2020	0.15	0.17	-0.02	-0.02	0.14	0.15	0.01
2025	0.03	0.03	0.00	-0.01	0.03	0.03	0.00
2030	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Cumulative CO_2 reduction (Mt): 4 (short tons): 5 000 000

Table EA-8. Reduction of Pollutants for Cooktops, Level Three

SO_2

Year	Abated from Power Plants		Abated from In House		Total Reduction in Emissions		Reduction as a % of Total Residential Emissions
	kt	thousand short tons	kt	thousand short tons	kt	thousand short tons	
2000	0.11	0.13	-0.01	-0.01	0.10	0.11	0.00
2005	0.41	0.46	-0.04	-0.04	0.37	0.41	0.01
2010	0.50	0.56	-0.05	-0.06	0.45	0.50	0.02
2015	0.37	0.41	-0.09	-0.10	0.28	0.31	0.01
2020	0.15	0.16	-0.08	-0.09	0.07	0.07	0.00
2025	-0.04	-0.05	-0.07	-0.07	-0.11	-0.12	-0.01
2030	-0.08	-0.09	-0.08	-0.09	-0.16	-0.18	-0.01

Cumulative SO_2 reduction (kt): 5 (short tons): 6 000

NOx

Year	Abated from Power Plants		Abated from In House		Total Reduction in Emissions		Reduction as a % of Total Residential Emissions
	kt	thousand short tons	kt	thousand short tons	kt	thousand short tons	
2000	0.09	0.09	0.02	0.02	0.10	0.11	0.00
2005	0.33	0.37	0.06	0.07	0.40	0.44	0.01
2010	0.44	0.48	0.13	0.14	0.56	0.62	0.02
2015	0.34	0.38	0.19	0.21	0.53	0.58	0.02
2020	0.15	0.16	0.21	0.24	0.36	0.40	0.02
2025	-0.05	-0.05	0.23	0.26	0.19	0.21	0.01
2030	-0.10	-0.11	0.25	0.27	0.15	0.17	0.01

Cumulative NOx reduction (kt): 11 (short tons): 12 000

CO_2

Year	Abated from Power Plants		Abated from In House		Total Reduction in Emissions		Reduction as a % of Total Residential Emissions
	Mt	million short tons	Mt	million short tons	Mt	million short tons	
2000	0.03	0.04	0.02	0.02	0.05	0.05	0.00
2005	0.14	0.15	0.06	0.07	0.20	0.22	0.02
2010	0.19	0.21	0.13	0.14	0.32	0.35	0.02
2015	0.18	0.19	0.19	0.20	0.36	0.40	0.03
2020	0.09	0.10	0.22	0.24	0.30	0.34	0.02
2025	-0.03	-0.03	0.24	0.26	0.21	0.23	0.01
2030	-0.08	-0.09	0.25	0.28	0.17	0.19	0.01

Cumulative CO_2 reduction (Mt): 8 (short tons): 8 000 000

Table EA-9. Reduction of Pollutants for Cooktops, Level Four

SO_2

Year	Abated from Power Plants		Abated from In House		Total Reduction in Emissions		Reduction as a % of Total Residential Emissions
	kt	thousand short tons	kt	thousand short tons	kt	thousand short tons	
2000	0.17	0.19	-0.01	-0.01	0.16	0.17	0.00
2005	0.61	0.67	-0.04	-0.04	0.57	0.63	0.02
2010	0.80	0.88	-0.05	-0.06	0.74	0.82	0.03
2015	0.73	0.80	-0.09	-0.10	0.63	0.70	0.03
2020	0.45	0.49	-0.08	-0.09	0.37	0.40	0.02
2025	0.20	0.22	-0.09	-0.10	0.10	0.11	0.01
2030	0.12	0.13	-0.08	-0.09	0.04	0.04	0.00

Cumulative SO_2 reduction (kt): 13 (short tons): 14 000

NOx

Year	Abated from Power Plants		Abated from In House		Total Reduction in Emissions		Reduction as a % of Total Residential Emissions
	kt	thousand short tons	kt	thousand short tons	kt	thousand short tons	
2000	0.13	0.14	0.01	0.01	0.14	0.15	0.01
2005	0.49	0.54	0.06	0.07	0.55	0.61	0.02
2010	0.69	0.76	0.11	0.12	0.80	0.88	0.03
2015	0.67	0.74	0.16	0.18	0.84	0.92	0.03
2020	0.45	0.49	0.19	0.21	0.64	0.70	0.03
2025	0.22	0.24	0.20	0.22	0.42	0.46	0.02
2030	0.14	0.16	0.22	0.24	0.36	0.40	0.02

Cumulative NOx reduction (kt): 18 (short tons): 20

CO_2

Year	Abated from Power Plants		Abated from In House		Total Reduction in Emissions		Reduction as a % of Total Residential Emissions
	Mt	million short tons	Mt	million short tons	Mt	million short tons	
2000	0.05	0.05	0.01	0.01	0.06	0.07	0.00
2005	0.20	0.22	0.06	0.06	0.26	0.29	0.02
2010	0.31	0.34	0.11	0.12	0.41	0.46	0.03
2015	0.34	0.38	0.16	0.18	0.51	0.56	0.04
2020	0.26	0.29	0.19	0.21	0.46	0.50	0.03
2025	0.15	0.17	0.20	0.22	0.35	0.39	0.02
2030	0.12	0.13	0.22	0.24	0.34	0.37	0.02

Cumulative CO_2 reduction (Mt): 11 (short tons): 12 000 000

Table EA-10. Reduction of Pollutants for Cooktops, Level Five

SO_2

Year	Abated from Power Plants		Abated from In House		Total Reduction in Emissions		Reduction as a % of Total Residential Emissions
	kt	thousand short tons	kt	thousand short tons	kt	thousand short tons	
2000	0.57	0.63	-0.01	-0.01	0.56	0.61	0.02
2005	1.92	2.12	-0.04	-0.04	1.88	2.07	0.06
2010	2.86	3.15	-0.05	-0.06	2.80	3.09	0.10
2015	3.10	3.42	-0.11	-0.12	3.00	3.30	0.12
2020	2.57	2.83	-0.09	-0.10	2.47	2.72	0.12
2025	1.89	2.08	-0.09	-0.10	1.79	1.98	0.11
2030	1.46	1.61	-0.08	-0.09	1.38	1.52	0.10

Cumulative SO_2 reduction (kt): 67 (short tons): 73 000

NOx

Year	Abated from Power Plants		Abated from In House		Total Reduction in Emissions		Reduction as a % of Total Residential Emissions
	kt	thousand short tons	kt	thousand short tons	kt	thousand short tons	
2000	0.42	0.47	0.00	0.00	0.42	0.47	0.02
2005	1.55	1.70	-0.01	-0.01	1.54	1.70	0.06
2010	2.48	2.74	0.00	0.00	2.48	2.73	0.09
2015	2.88	3.17	-0.01	-0.01	2.87	3.16	0.12
2020	2.57	2.83	0.00	0.00	2.56	2.83	0.11
2025	2.07	2.28	0.01	0.01	2.07	2.29	0.10
2030	1.79	1.97	0.02	0.02	1.81	1.99	0.10

Cumulative NOx reduction (kt): 65 (short tons): 72 000

CO_2

Year	Abated from Power Plants		Abated from In House		Total Reduction in Emissions		Reduction as a % of Total Residential Emissions
	Mt	million short tons	Mt	million short tons	Mt	million short tons	
2000	0.16	0.18	0.00	0.00	0.16	0.17	0.01
2005	0.63	0.70	-0.01	-0.01	0.62	0.68	0.05
2010	1.10	1.21	-0.01	-0.01	1.09	1.20	0.08
2015	1.48	1.63	-0.02	-0.02	1.46	1.60	0.10
2020	1.52	1.67	-0.01	-0.01	1.51	1.66	0.10
2025	1.44	1.59	0.00	0.00	1.44	1.58	0.09
2030	1.46	1.61	0.01	0.01	1.47	1.62	0.09

Cumulative CO_2 reduction (Mt): 36 (short tons): 39 000 000

Table EA-11. Reduction of Pollutants for Conventional Ovens, Level One

SO_2

Year	Abated from Power Plants		Abated from In House		Total Reduction in Emissions		Reduction as a % of Total Residential Emissions
	kt	thousand short tons	kt	thousand short tons	kt	thousand short tons	
2000	0.09	0.09	0.00	0.00	0.09	0.09	0.00
2005	0.29	0.32	0.00	0.00	0.29	0.32	0.01
2010	0.48	0.53	0.00	0.00	0.48	0.53	0.02
2015	0.56	0.61	-0.01	-0.01	0.54	0.60	0.02
2020	0.49	0.54	-0.01	-0.01	0.47	0.52	0.02
2025	0.39	0.43	0.00	0.00	0.39	0.43	0.02
2030	0.31	0.34	-0.01	-0.01	0.29	0.32	0.02

Cumulative SO_2 reduction (kt): 12 (short tons): 13 000

NOx

Year	Abated from Power Plants		Abated from In House		Total Reduction in Emissions		Reduction as a % of Total Residential Emissions
	kt	thousand short tons	kt	thousand short tons	kt	thousand short tons	
2000	0.06	0.07	0.00	0.00	0.06	0.07	0.00
2005	0.23	0.26	0.00	0.00	0.23	0.25	0.01
2010	0.42	0.46	-0.01	-0.01	0.41	0.45	0.02
2015	0.52	0.57	-0.02	-0.02	0.50	0.55	0.02
2020	0.49	0.54	-0.02	-0.03	0.46	0.51	0.02
2025	0.43	0.48	-0.02	-0.02	0.41	0.46	0.02
2030	0.38	0.41	-0.02	-0.03	0.35	0.39	0.02

Cumulative NOx reduction (kt): 11 (short tons): 13 000

CO2

Year	Abated from Power Plants		Abated from In House		Total Reduction in Emissions		Reduction as a % of Total Residential Emissions
	Mt	million short tons	Mt	million short tons	Mt	million short tons	
2000	0.02	0.03	0.00	0.00	0.02	0.03	0.00
2005	0.10	0.11	0.00	-0.01	0.09	0.10	0.01
2010	0.19	0.20	-0.01	-0.01	0.18	0.19	0.01
2015	0.26	0.29	-0.02	-0.02	0.24	0.27	0.02
2020	0.29	0.32	-0.03	-0.03	0.26	0.29	0.02
2025	0.30	0.33	-0.02	-0.02	0.28	0.31	0.02
2030	0.31	0.34	-0.03	-0.03	0.28	0.31	0.02

Cumulative CO_2 reduction (Mt): 6 (short tons): 7 000 000

Table EA-12. Reduction of Pollutants for Conventional Ovens, Level Two

SO_2

Year	Abated from Power Plants		Abated from In House		Total Reduction in Emissions		Reduction as a % of Total Residential Emissions
	kt	thousand short tons	kt	thousand short tons	kt	thousand short tons	
2000	0.17	0.19	-0.01	-0.01	0.16	0.17	0.00
2005	0.63	0.70	0.00	0.00	0.63	0.70	0.02
2010	0.97	1.07	-0.01	-0.01	0.95	1.05	0.03
2015	1.15	1.26	-0.03	-0.03	1.12	1.23	0.05
2020	1.00	1.10	-0.03	-0.03	0.97	1.07	0.05
2025	0.81	0.89	-0.01	-0.01	0.80	0.88	0.05
2030	0.63	0.69	-0.01	-0.01	0.61	0.68	0.04

Cumulative SO_2 reduction (kt): 25 (short tons): 28 000

NOx

Year	Abated from Power Plants		Abated from In House		Total Reduction in Emissions		Reduction as a % of Total Residential Emissions
	kt	thousand short tons	kt	thousand short tons	kt	thousand short tons	
2000	0.13	0.14	-0.01	-0.01	0.12	0.13	0.00
2005	0.51	0.56	-0.01	-0.01	0.50	0.55	0.02
2010	0.84	0.93	-0.03	-0.04	0.81	0.89	0.03
2015	1.06	1.17	-0.04	-0.05	1.02	1.12	0.04
2020	1.00	1.10	-0.05	-0.06	0.95	1.04	0.04
2025	0.89	0.98	-0.05	-0.06	0.84	0.92	0.04
2030	0.77	0.85	-0.05	-0.06	0.72	0.79	0.04

Cumulative NOx reduction (kt): 23 (short tons): 26 000

CO2

Year	Abated from Power Plants		Abated from In House		Total Reduction in Emissions		Reduction as a % of Total Residential Emissions
	Mt	million short tons	Mt	million short tons	Mt	million short tons	
2000	0.05	0.05	-0.01	-0.01	0.04	0.04	0.00
2005	0.21	0.23	-0.01	-0.02	0.19	0.21	0.01
2010	0.37	0.41	-0.04	-0.04	0.33	0.37	0.02
2015	0.55	0.60	-0.05	-0.05	0.50	0.55	0.03
2020	0.59	0.65	-0.06	-0.06	0.53	0.59	0.04
2025	0.62	0.68	-0.05	-0.06	0.56	0.62	0.04
2030	0.63	0.69	-0.05	-0.06	0.57	0.63	0.04

Cumulative CO_2 reduction (Mt): 13 (short tons): 14 000 000

Table EA-13. Reduction of Pollutants for Conventional Ovens, Level Three

SO_2

Year	Abated from Power Plants		Abated from In House		Total Reduction in Emissions		Reduction as a % of Total Residential Emissions
	kt	thousand short tons	kt	thousand short tons	kt	thousand short tons	
2000	0.09	0.09	-0.03	-0.03	0.06	0.06	0.00
2005	0.27	0.29	-0.07	-0.07	0.20	0.22	0.01
2010	0.46	0.51	-0.09	-0.10	0.37	0.41	0.01
2015	0.56	0.61	-0.15	-0.16	0.41	0.45	0.02
2020	0.50	0.55	-0.16	-0.18	0.34	0.37	0.02
2025	0.40	0.45	-0.16	-0.18	0.24	0.27	0.01
2030	0.31	0.35	-0.15	-0.16	0.17	0.18	0.01

Cumulative SO_2 reduction (kt): 9 (short tons): 10 000

NOx

Year	Abated from Power Plants		Abated from In House		Total Reduction in Emissions		Reduction as a % of Total Residential Emissions
	kt	thousand short tons	kt	thousand short tons	kt	thousand short tons	
2000	0.06	0.07	0.02	0.02	0.08	0.09	0.00
2005	0.22	0.24	0.11	0.12	0.32	0.36	0.01
2010	0.40	0.44	0.20	0.23	0.61	0.67	0.02
2015	0.52	0.57	0.29	0.31	0.80	0.88	0.03
2020	0.50	0.55	0.31	0.34	0.81	0.89	0.04
2025	0.44	0.49	0.33	0.36	0.77	0.85	0.04
2030	0.39	0.42	0.34	0.38	0.73	0.80	0.04

Cumulative NOx reduction (kt): 19 (short tons): 21 000

CO2

Year	Abated from Power Plants		Abated from In House		Total Reduction in Emissions		Reduction as a % of Total Residential Emissions
	Mt	million short tons	Mt	million short tons	Mt	million short tons	
2000	0.02	0.03	0.02	0.02	0.04	0.05	0.00
2005	0.09	0.10	0.11	0.12	0.19	0.21	0.01
2010	0.18	0.20	0.20	0.23	0.38	0.42	0.03
2015	0.26	0.29	0.28	0.31	0.55	0.61	0.04
2020	0.30	0.33	0.31	0.34	0.61	0.67	0.04
2025	0.31	0.34	0.32	0.36	0.63	0.70	0.04
2030	0.31	0.35	0.35	0.38	0.66	0.73	0.04

Cumulative CO_2 reduction (Mt): 14 (short tons): 15 000 000

Table EA-14. Reduction of Pollutants for Conventional Ovens, Level Four

SO_2

Year	Abated from Power Plants		Abated from In House		Total Reduction in Emissions		Reduction as a % of Total Residential Emissions
	kt	thousand short tons	kt	thousand short tons	kt	thousand short tons	
2000	1.94	2.14	-0.04	-0.04	1.90	2.09	0.05
2005	6.25	6.89	-0.11	-0.12	6.15	6.77	0.20
2010	9.63	10.61	-0.19	-0.21	9.44	10.40	0.33
2015	11.26	12.41	-0.27	-0.30	11.00	12.12	0.46
2020	10.04	11.06	-0.30	-0.33	9.74	10.73	0.47
2025	8.03	8.85	-0.30	-0.33	7.74	8.52	0.46
2030	6.31	6.95	-0.30	-0.33	6.01	6.63	0.44

Cumulative SO_2 reduction (kt): 247 (short tons): 273 000

NOx

Year	Abated from Power Plants		Abated from In House		Total Reduction in Emissions		Reduction as a % of Total Residential Emissions
	kt	thousand short tons	kt	thousand short tons	kt	thousand short tons	
2000	1.45	1.59	-0.03	-0.04	1.41	1.55	0.05
2005	5.03	5.55	-0.10	-0.11	4.93	5.43	0.18
2010	8.36	9.22	-0.19	-0.21	8.18	9.01	0.31
2015	10.44	11.51	-0.27	-0.30	10.17	11.21	0.42
2020	10.04	11.06	-0.31	-0.34	9.72	10.72	0.43
2025	8.80	9.69	-0.33	-0.36	8.47	9.34	0.41
2030	7.76	8.55	-0.33	-0.37	7.42	8.18	0.40

Cumulative NOx reduction (kt): 236 (short tons): 260 000

CO2

Year	Abated from Power Plants		Abated from In House		Total Reduction in Emissions		Reduction as a % of Total Residential Emissions
	Mt	million short tons	Mt	million short tons	Mt	million short tons	
2000	0.54	0.60	-0.04	-0.04	0.50	0.55	0.04
2005	2.06	2.27	-0.12	-0.13	1.94	2.14	0.15
2010	3.69	4.07	-0.21	-0.24	3.47	3.83	0.25
2015	5.36	5.90	-0.32	-0.35	5.04	5.56	0.35
2020	5.94	6.54	-0.36	-0.39	5.58	6.15	0.37
2025	6.12	6.75	-0.37	-0.41	5.75	6.34	0.37
2030	6.32	6.96	-0.38	-0.42	5.93	6.54	0.37

Cumulative CO_2 reduction (Mt): 129 (short tons): 142 000 000

Table EA-15. Reduction of Pollutants for Conventional Ovens, Level Five

SO_2

Year	Abatted from Power Plants		Abated from In House		Total Reduction in Emissions		Reduction as a % of Total Residential Emissions
	kt	thousand short tons	kt	thousand short tons	kt	thousand short tons	
2000	1.91	2.11	-0.04	-0.04	1.87	2.06	0.05
2005	6.16	6.79	-0.15	-0.16	6.01	6.62	0.19
2010	9.50	10.47	-0.24	-0.27	9.26	10.20	0.33
2015	11.11	12.25	-0.36	-0.40	10.75	11.85	0.45
2020	9.90	10.91	-0.40	-0.44	9.50	10.47	0.46
2025	7.94	8.75	-0.40	-0.44	7.53	8.30	0.45
2030	6.23	6.87	-0.39	-0.43	5.84	6.44	0.43

Cumulative SO_2 reduction (kt): 241 (short tons): 266 000

NOx

Year	Abated from Power Plants		Abated from In House		Total Reduction in Emissions		Reduction as a % of Total Residential Emissions
	kt	thousand short tons	kt	thousand short tons	kt	thousand short tons	
2000	1.42	1.57	-0.01	-0.01	1.42	1.56	0.05
2005	4.95	5.46	-0.02	-0.02	4.94	5.44	0.18
2010	8.26	9.10	-0.01	-0.02	8.24	9.08	0.31
2015	10.30	11.35	-0.03	-0.04	10.27	11.32	0.42
2020	9.90	10.91	-0.05	-0.06	9.85	10.85	0.44
2025	8.69	9.58	-0.05	-0.06	8.64	9.52	0.42
2030	7.66	8.44	-0.05	-0.05	7.61	8.39	0.41

Cumulative NOx reduction (kt): 239 (short tons): 263 000

CO2

Year	Abated from Power Plants		Abated from In House		Total Reduction in Emissions		Reduction as a % of Total Residential Emissions
	Mt	million short tons	Mt	million short tons	Mt	million short tons	
2000	0.53	0.59	-0.01	-0.01	0.52	0.57	0.04
2005	2.03	2.23	-0.03	-0.04	1.99	2.20	0.15
2010	3.64	4.01	-0.04	-0.04	3.60	3.97	0.26
2015	5.29	5.82	-0.07	-0.08	5.21	5.74	0.36
2020	5.86	6.46	-0.10	-0.11	5.76	6.35	0.38
2025	6.05	6.67	-0.10	-0.11	5.95	6.56	0.38
2030	6.24	6.87	-0.09	-0.10	6.15	6.77	0.38

Cumulative CO_2 reduction (Mt): 133 (short tons): 147 000 000

Table EA-16. Reduction of Pollutants for Microwave Ovens, Level One

SO_2

Year	Abated from Power Plants		Abated from In House		Total Reduction in Emissions		Reduction as a % of Total Residential Emissions
	kt	thousand short tons	kt	thousand short tons	kt	thousand short tons	
2000	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2005	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2010	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2015	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2020	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2025	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2030	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Cumulative SO_2 reduction (kt): 0 (short tons): 0 000

NOx

Year	Abated from Power Plants		Abated from In House		Total Reduction in Emissions		Reduction as a % of Total Residential Emissions
	kt	thousand short tons	kt	thousand short tons	kt	thousand short tons	
2000	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2005	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2010	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2015	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2020	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2025	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2030	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Cumulative NOx reduction (kt): 0 (short tons): 0 000

CO2

Year	Abated from Power Plants		Abated from In House		Total Reduction in Emissions		Reduction as a % of Total Residential Emissions
	Mt	million short tons	Mt	million short tons	Mt	million short tons	
2000	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2005	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2010	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2015	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2020	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2025	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2030	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Cumulative CO_2 reduction (Mt): 0 (short tons): 0 000 000

Table EA-17. Reduction of Pollutants for Microwave Ovens, Level Two

SO_2

Year	Abated from Power Plants		Abated from In House		Total Reduction in Emissions		Reduction as a % of Total Residential Emissions
	kt	thousand short tons	kt	thousand short tons	kt	thousand short tons	
2000	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2005	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2010	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2015	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2020	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2025	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2030	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Cumulative SO_2 reduction (kt): 0 (short tons): 0 000

NOx

Year	Abated from Power Plants		Abated from In House		Total Reduction in Emissions		Reduction as a % of Total Residential Emissions
	kt	thousand short tons	kt	thousand short tons	kt	thousand short tons	
2000	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2005	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2010	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2015	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2020	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2025	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2030	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Cumulative NOx reduction (kt): 0 (short tons): 0 000

CO2

Year	Abated from Power Plants		Abated from In House		Total Reduction in Emissions		Reduction as a % of Total Residential Emissions
	Mt	million short tons	Mt	million short tons	Mt	million short tons	
2000	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2005	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2010	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2015	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2020	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2025	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2030	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Cumulative CO_2 reduction (Mt): 0 (short tons): 0 000 000

Table EA-18. Reduction of Pollutants for Microwave Ovens, Level Three

SO_2

Year	Abated from Power Plants		Abated from In House		Total Reduction in Emissions		Reduction as a % of Total Residential Emissions
	kt	thousand short tons	kt	thousand short tons	kt	thousand short tons	
2000	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2005	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2010	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2015	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2020	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2025	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2030	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Cumulative SO_2 reduction (kt): 0 (short tons): 0 000

NOx

Year	Abated from Power Plants		Abated from In House		Total Reduction in Emissions		Reduction as a % of Total Residential Emissions
	kt	thousand short tons	kt	thousand short tons	kt	thousand short tons	
2000	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2005	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2010	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2015	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2020	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2025	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2030	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Cumulative NOx reduction (kt): 0 (short tons): 0 000

CO2

Year	Abated from Power Plants		Abated from In House		Total Reduction in Emissions		Reduction as a % of Total Residential Emissions
	Mt	million short tons	Mt	million short tons	Mt	million short tons	
2000	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2005	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2010	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2015	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2020	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2025	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2030	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Cumulative CO_2 reduction (Mt): 0 (short tons): 0 000 000

Table EA-19. Reduction of Pollutants for Microwave Ovens, Level Four

SO_2

Year	Abated from Power Plants		Abated from In House		Total Reduction in Emissions		Reduction as a % of Total Residential Emissions
	kt	thousand short tons	kt	thousand short tons	kt	thousand short tons	
2000	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2005	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2010	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2015	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2020	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2025	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2030	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Cumulative SO_2 reduction (kt): 0 (short tons): 0 000

NOx

Year	Abated from Power Plants		Abated from In House		Total Reduction in Emissions		Reduction as a % of Total Residential Emissions
	kt	thousand short tons	kt	thousand short tons	kt	thousand short tons	
2000	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2005	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2010	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2015	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2020	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2025	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2030	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Cumulative NOx reduction (kt): 0 (short tons): 0 000

CO2

Year	Abated from Power Plants		Abated from In House		Total Reduction in Emissions		Reduction as a % of Total Residential Emissions
	Mt	million short tons	Mt	million short tons	Mt	million short tons	
2000	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2005	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2010	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2015	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2020	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2025	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2030	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Cumulative CO_2 reduction (Mt): 0 (short tons): 0 000 000

Table EA-20. Reduction of Pollutants for Microwave Ovens, Level Five

SO_2

Year	Abated from Power Plants		Abated from In House		Total Reduction in Emissions		Reduction as a % of Total Residential Emissions
	kt	thousand short tons	kt	thousand short tons	kt	thousand short tons	
2000	0.63	0.69	-0.01	-0.01	0.61	0.68	0.02
2005	1.92	2.12	-0.03	-0.03	1.90	2.09	0.06
2010	2.42	2.66	-0.03	-0.03	2.39	2.63	0.08
2015	2.06	2.27	-0.04	-0.04	2.02	2.22	0.08
2020	1.74	1.92	-0.04	-0.04	1.70	1.88	0.08
2025	1.41	1.56	-0.03	-0.03	1.38	1.53	0.08
2030	1.11	1.22	-0.04	-0.04	1.06	1.17	0.08

Cumulative SO_2 reduction (kt): 53 (short tons): 58 000

NOx

Year	Abated from Power Plants		Abated from In House		Total Reduction in Emissions		Reduction as a % of Total Residential Emissions
	kt	thousand short tons	kt	thousand short tons	kt	thousand short tons	
2000	0.47	0.52	-0.01	-0.02	0.45	0.50	0.02
2005	1.55	1.70	-0.05	-0.05	1.50	1.65	0.06
2010	2.10	2.31	-0.06	-0.07	2.04	2.25	0.08
2015	1.91	2.10	-0.07	-0.07	1.84	2.03	0.08
2020	1.74	1.92	-0.08	-0.08	1.67	1.84	0.07
2025	1.55	1.70	-0.07	-0.08	1.47	1.62	0.07
2030	1.36	1.50	-0.08	-0.09	1.28	1.41	0.07

Cumulative NOx reduction (kt): 48 (short tons): 53 000

CO2

Year	Abated from Power Plants		Abated from In House		Total Reduction in Emissions		Reduction as a % of Total Residential Emissions
	Mt	million short tons	Mt	million short tons	Mt	million short tons	
2000	0.17	0.19	-0.02	-0.02	0.16	0.17	0.01
2005	0.63	0.70	-0.05	-0.06	0.58	0.64	0.04
2010	0.93	1.02	-0.07	-0.07	0.86	0.95	0.06
2015	0.98	1.08	-0.07	-0.08	0.90	1.00	0.06
2020	1.03	1.14	-0.08	-0.09	0.95	1.04	0.06
2025	1.08	1.19	-0.08	-0.09	1.00	1.10	0.06
2030	1.11	1.22	-0.09	-0.10	1.02	1.12	0.06

Cumulative CO_2 reduction (Mt): 25 (short tons): 28 000 000

REFERENCES

1. National Appliance Energy Conservation Act (NAECA), Public Law 100-12, March 17, 1987.

2. U.S. Department of Commerce, Bureau of the Census. 1994. *Statistical Abstract of the United States: 1994*. (114th Edition). Washington, D.C.

3. U.S. Department of Energy (U.S. DOE), 1994. Energy Information Administration. *Emissions of Greenhouse Gases in the United States 1987-1992*, Washington, D.C. DOE/EIA-0573, November 1994.

4. U.S. DOE, *Improving Technology: Modeling Energy Futures for National Energy Strategy*. 1991 Service Report to the 1991 National Energy Strategy, Washington, D.C. SR/NES/90-01.

5. J. Koomey, 1990. *Comparative Analysis of Monetary Estimates of External Environmental Costs Associated with Combustion of Fossil Fuels*. Lawrence Berkeley National Laboratory, Berkeley, CA. LBL-28313.

6. *Ibid*.

The energy value of load shape modifications is measured by the marginal cost of electricity, which depends on the variable cost of operating the power plants that will change their output in response to a change in load. This variable cost consists primarily of the cost of fuel for these marginal units. U.S. utilities are characterized by a substantial difference among the prices of fuels used to generate electricity on the margin. Marginal resources of a utility can be either more expensive oil and gas or less expensive non-oil-and-gas resources, typically coal or economy purchase of power generated by coal. Very low variable-cost nuclear or run-of-river hydro resources are usually base loaded and thus only rarely contribute to marginal energy costs. Even though the relative cost of natural gas as a generation fuel has decreased in recent years, and seasonal price fluctuations often make it cheaper than coal bought under long-term contract, this oil and gas fraction approach is still valid because gas-fired resources are more likely to be marginal because of their greater operating flexibility.

The relevant marginal cost is the cost of each marginal fuel weighted by the fraction of time each fuel is on the margin plus any variable operation and maintenance (O&M). Formally, this relationship can be simplified as follows:

$$\text{Marginal Cost} = OGF_m \cdot \text{Natural Gas Price} + NOGF_m \cdot \text{Coal Price} + \text{Variable O\&M}$$

To calculate the oil-and-gas fraction on the margin, OGF_m, the total amount of oil- and gas-generated electricity is divided by the total forecasted amount of electricity generation from NERC data (1) to obtain the *total oil and gas fraction*, OGF_t. OGF_t can then be related to OGF_m with a simplified load-duration curve (LDC) for each region. Figure E.1 shows this LDC, where B' is the OGF_m. The non-oil-and-gas fraction ($NOGF_m$) is simply $1 - OGF_m$.

The purpose of the following derivation is to calculate the OGF_m (B'). First, note that

$$\tan\Omega = \frac{A}{B}$$

and $B = 1.0$, which implies that

$$A = B\tan\Omega = \tan\Omega$$

The normalized area of the triangle at the top of the LDC represents the fraction of total generation from oil and gas (OGF_t). Calculating the area of this triangle yields

$$OGF_t = 0.5A'B' = 0.5(B'\tan\Omega)B'$$

B' can thus be expressed as follows:

$$B' = OGF_m = \sqrt{\frac{2OGF_t}{\tan\Omega}}$$

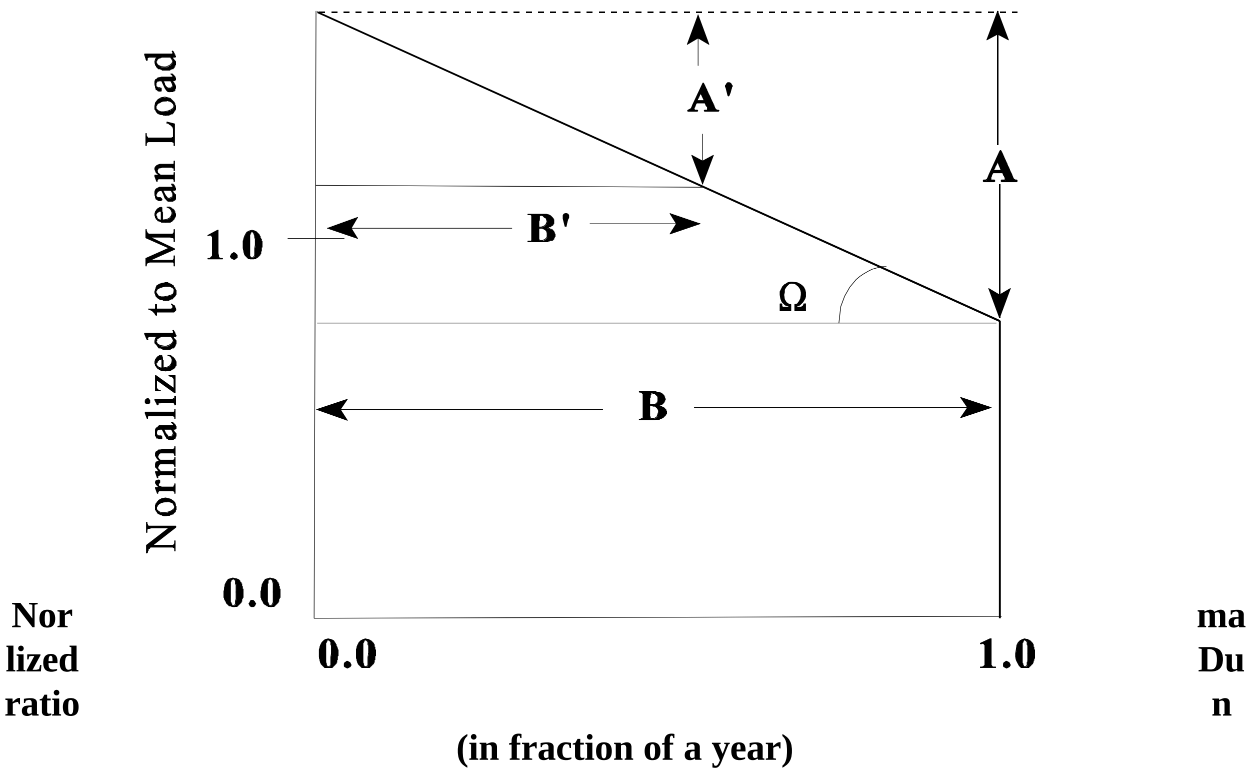


Figure E.1 Simplified Load-Duration Curve

The appropriate value for $A = tan\,\Omega$ is determined empirically: when $OGF_t \geq 0.4$, $OGF_m = 1.0$. The value of A must therefore be greater than or equal to 0.8. Note that when $A = 0.8$,

$$\text{Normalized peak demand} = 1.4 \cdot \text{mean load}$$

and

$$\text{Normalized minimum load} = 0.6 \cdot \text{mean load.}$$

A weighted-average marginal energy cost is determined for each of the NERC regions using the above formulas, and a national weighted-average marginal cost for heating and baseload energy savings is calculated using the regional fuel price multipliers and energy savings fractions described above. This approach assumes that the marginal oil-and-gas fractions remain constant over the analysis period.

For cooling energy savings, the appropriate marginal energy cost (MEC) will exceed the annual average MEC because the OGF_m is typically higher in summer than in winter. The annual average OGF_m is approximately 52% when calculated using the energy savings fractions for heating, cooling, and baseload energy. Cooling MECs are calculated using a national OGF_m of 60% to account for the seasonal differences in marginal fuel usage. Table E.1 shows the annual average OGF_m for each NERC region.

Table E.1 Utility Marginal OGFs and Year of Capacity Need by NERC Region

NERC Region	Marginal OGF	Year Capacity is Needed
NPCC	0.88	now
MAAC	0.61	now
ECAR	0.16	now
MAIN	0.19	now
SPP	0.77	1999
SERC	0.47	now
ERCOT	0.92	1999
MAPP	0.15	1997
WSCC	0.55	1999
National Avg.	0.52	

The calculation of MECs in year *j* can be summarized as follows:

$$OGF_m = \sum_{i=1}^{N} ESF_i \cdot OGF_{m,i}$$

$$NOGF_m = 1 - OGF_m$$

$$MEC_j = (OGF_m \cdot \text{gas price}_j + NOGF_m \cdot \text{coal price}_j + \text{Variable O\&M}_j) \cdot 1.06$$

where:

i denotes a particular NERC region,
ESF_i represents the energy savings fraction for region *i*, and

1.06 adjusts for transmission and distribution losses.

The *ESF* for region *i* is the sum of products of the heating, cooling, and baseload energy savings fractions with the heating, cooling, and baseload factors. Variable O&M is calculated using references (2) and (3). Average O&M (fixed and variable) for all fossil-fuel fired steam-electric power plants for investor-owned utilities in 1990 is reported in (4) as 0.5¢/kWh (in 1990 dollars). This can be split into fixed and variable components using (5). The analysis uses the fraction of O&M that is variable for a supercritical coal steam unit (50%) and for a natural gas combustion turbine (20%), weights these by the appropriate marginal oil and gas fractions, and applies the resulting percentage (variable O&M as a percent of total O&M) to the total O&M (0.5¢/kWh). This calculation results in a variable O&M cost of 0.33¢/kWh (in 1990 dollars).

In keeping with industry practice, labor and other variable cost savings are ignored in this analysis. This practice has arisen first, because labor costs are very low relative to fuel and capital, and, second, because the regulatory treatment of labor cost recovery in the general rate case cycle makes savings difficult to estimate.

E.4 CAPACITY COST SAVINGS

E.4.1 Value of Capacity Savings

The value of capacity is the value associated with having additional generating capacity available to meet load increases. For utility systems with excess capacity, this value may be equal to or close to zero. When capacity does have value, this value is commonly measured by the cost of the marginal investment a utility would make to expand system capacity, such as the purchase of a combustion turbine (6). This investment adds reliability to the system *even if it never operates*, since it is ready to prevent outages if another generating unit fails. If the utility chooses to build another type of plant with higher capital costs, such as a baseload coal unit, it must be basing this choice on considerations other than meeting peak demand alone. Baseload coal plants, for example, can have lower operating costs than gas-fired generation and can be used to displace generators with higher variable cost per kWh. The additional capital cost of a coal plant is thus not related to capacity alone but to energy benefits as well (7). The use of capacity valuation based on the gas turbine proxy, therefore, has a rationale behind it and is widespread in the industry.

The additional coal plant capital cost, sometimes called energy-related capital, is contained implicitly in the marginal energy cost described above. Consider a utility with a large number of expensive oil and gas units on the margin and dwindling adjusted reserves. Such a utility would need capacity to preserve the system's reliability at an acceptable level. It would also benefit from installing a baseload unit that would reduce oil and gas consumption at the margin. This reduction in fuel costs compensates for expending capital in addition to the cost of a combustion turbine. A utility with coal on the margin a large fraction of the time would not have the same incentive and would probably install a combustion turbine to preserve reliability.

The utility will choose to have a baseload plant come on line when the present value of the energy-related capital cost of the plant is just equal to the present value of the reduction in fuel costs from the operation of the plant. The reduction in fuel costs and hence the incentive to build a baseload plant depend on the marginal oil and gas fraction. Thus, the marginal energy cost contains an avoided capital component in addition to an avoided fuel component.

The following two rules are applied to determine the value of capacity for the year 1998 based on DOE's interpretation of NERC data (8):

1. If the NERC region is forecast to have an adjusted reserve margin larger than 5% of forecasted peak demand, there is no reliability value for capacity.[1]

2. If the NERC region is forecast to have a capacity deficiency (operating adjusted reserves of less than 5%), the capacity value for the combustion turbine is applied.

After 1998, DOE has not calculated adjusted reserve margins and it is assumed that every region will need capacity. Table E.1 shows the year that each region will need capacity based on these rules.

The calculations in this analysis follow standard industry practice developed for determining the value of reductions in peak load caused by cogenerators and other small power producers (9). First, the present value of revenue requirements is calculated for a combustion turbine based on its capital cost ($400 per kW in 1990 dollars), a discount rate equal to the utility rate of disadvantage or ROD (10.0%), a fixed charge rate (13.0%),[2] a turbine lifetime of 25 years, and the assumption of straight-line depreciation. The calculation is repeated for each year of the analysis assuming no real capital cost escalation for the combustion turbine. Next, the present values are spread over time using an economic carrying charge (ECC). The ECC technique yields a current dollar stream of costs, escalating at an inflation rate of 5% that has the same present value, when discounted at the ROD, as the original stream. A stream of costs that escalates at the inflation rate is also constant in real terms, so this technique *levelizes* the costs to some constant dollar value ($47.07 per kW/yr a in 1990 dollars). This cost is then converted to dollars per kWh of electricity savings by the method detailed in the next section.

E.4.2 Amount of Capacity Savings

---

[1] An equivalent rule of thumb for adequate reliability is that the overall reserve margin should equal about 20% of forecasted peak demand. *Adjusted reserves* are defined by DOE as [Planned Capacity + Net Power Transfers(in) - (Forced Outages + Scheduled Maintenance + Other Outages) - Forecasted Peak Demand]. *Overall reserves* are defined as [Planned Capacity + Net Power Transfers(in) - Forecasted Peak Demand. This analysis does not account for the possibility that new efficiency levels could cause a significant change in a region's adjusted reserves, and hence change the date when capacity is needed.

[2] The estimates of ROD and fixed charge rate have been calculated based on current interest rates and the corporate tax rate (34%) adopted in the 1986 tax revisions. The standard utility capital structure from EPRI is used (45% debt, 10% preferred stock, and 10% common stock). Nominal costs of capital are 10% for debt and preferred stock and 13.4% for common stock.

An analysis of the load shape impacts of improved efficiencies for residential appliances must consider both the magnitude and timing of the impacts relative to periods of high system loads because residential class load shape changes only have reliability value for the system when they coincide with times of high system loads. This relationship is approximated from modeling runs of the LBNL Hourly and Peak Demand Model (10) and from two LBNL utility case studies (11), (12).

There are large but varying degrees of coincidence between residential peak loads and system peak loads. The case studies show that the average change in the 250 highest residential hourly loads is a reasonable measure of the system-level capacity value of appliance efficiency levels.

The results of these studies also indicated that load shape impacts, measured as a conservation load factor (CLF), vary in a predictable fashion across utility service territories. A conservation load factor is the annual average load savings divided by the peak savings of the conservation measure (13). Peak savings are defined as the forecasted differences between the average of the highest 250 hourly loads before and after the appliance efficiency levels are implemented. The peak savings for residential appliances are calculated using the LBNL Residential Hourly and Peak Demand Model. For the purposes of this analysis, the U.S. is assumed to be a summer peaking system. While there are individual utilities in the U.S. which are not summer peaking, these are unusual and, by and large, small.

Conservation load factors can be used to characterize the peak load impacts of heating, cooling, and baseload energy savings. More formally, a conservation load factor can be expressed as:

$$\text{CLF} = \frac{\text{Annual Load Savings}}{\text{Peak Load Savings}}$$

Multiplying both numerator and denominator by 8760 hours gives:

$$\text{Peak Load Savings} = \frac{\text{Annual Energy Savings}}{\text{CLF} \cdot 8760}$$

$$\text{CLF} \cdot 8760 = \frac{\text{Annual Energy Savings}}{\text{Peak Load Savings}}$$

The peak load savings can be expressed as a function of the annual energy savings and the CLF. Another useful form of this equation is as follows:

$$\text{CLF} = \frac{\text{Annual Energy Savings}}{\text{Peak Load Savings} \cdot 8760}$$

CLF · 8760 = kWh of energy savings needed to yield 1 kW of peak load savings.

The conservation load factors used for all products with alternative efficiency levels are listed in Table E.2. Conservation load factors for mobile home furnaces, pool heaters, and direct heating equipment are undefined as they do not contribute to savings in peak load.

Table E.2 Conservation Load Factors All Products Analyzed

Appliance	Conservation Load Factor
Cooktop/Oven/Microwave	0.46
Room Air Conditioner	0.14
Pool Heater	--
Direct Heating Equipment	--
Mobile Home Furnaces	--
Oil & Gas Water Heaters	0.89
Central Air Conditioner	0.15
Lamp Ballast	0.57
Clotheswasher	0.63
Clothesdryer	0.63
Dishwasher	0.76
Electric Water Heater	0.89
Refrigerator	0.89
Television	0.95

Therefore, the calculation of avoided capacity costs can be summarized in the following equation:

$$ARC_{Baseload,j} = \frac{Capacity\ Value}{CLF_{Baseload} \cdot 8760} \cdot 0.3 \cdot 1.2 \cdot \Sigma\ ESF_{Baseload,j}$$

where:

$ARC_{Baseload,j}$ = Avoided reliability costs in 1990 \$/MMBtu in year j, *Capacity Value* = value of 1 kW of peak load savings in 1990 \$/kW/yr,

0.3 = energy conversion efficiency including T&D losses,

$CLF_{Baseload}$ = conservation load factor for baseload appliances,

1.2 = reserve margin adjustment needed for adequate reliability,

$\Sigma ESF_{Baseload,j}$ = sum of baseload Energy Saving Factors for regions that need capacity in year j.

Capacity savings are peak load savings for only those regions that need capacity in a given year. Load savings in regions that do not need capacity contribute to deferring capacity additions in future years, but this analysis does not account for the value of such deferrals.

Table E.3 Sums of Baseload Energy Savings Fractions for NERC Regions That Need Capacity

Year	Baseload ESF	Regions Needing Capacity
1998	0.596	6
1999	1.000	9
2000	1.000	9

E.4.3 Avoided Transmission and Distribution Capital Costs

Recently, utility planners have begun to account for capital costs of the T&D system that can be avoided by reductions in electricity use. There are a wide range of estimates of such costs, depending on the particular characteristics of the utility system and of the conservation programs and policies that lead to such reductions in electricity use. Krause *et al.* (14) review studies on this topic and settle on a range for T&D savings of from \$10 to \$40/kW/yr. Krause *et al.* also cite reasons why this range is probably too low and suggest that further work will probably raise these values. For example, they cite marginal T&D cost estimates of nine different utilities that (on average) totaled more than \$100/kW/yr.

We adopt the lower end of Krause *et al*.'s range ($10/kW/yr) as our estimate for avoided T&D capital costs. We choose this lower bound estimate because of the substantial uncertainties in applying such estimates (which are derived at the level of individual utilities) in national analyses.

REFERENCES

1. North American Electric Reliability Council (NERC). 1990. *Electricity Supply and Demand for 1990-99*. Princeton, NJ.

2. Electric Power Research Institute (EPRI). 1989. *TAG-Technical Assessment Guide: Vol. I: Electricity Supply-1989*. Palo Alto, CA. EPRI P-6587-L. September 1989.

3. U.S. Department of Energy. 1992. *Electric Plant Cost and Power Production Expenses 1990*. Energy Information Administration. Washington, D.C. DOE/EIA-0455(90). June.

4. U.S. Department of Energy. 1990. *Staff Report: Electric Power Supply and Demand for the Contiguous United States, 1989-98*. Washington, D.C. DOE/IE-0008.

5. EPRI, 1989. *Op. cit*.

6. National Economic Research Associates. 1977. *How to Quantify Marginal Costs: Topic 4*. Palo Alto, CA. EPRI Report No. EURDS-23.

7. *Ibid*.

8. U.S. Department of Energy, 1990. *Op. cit*.

9. *Ibid*.

10. Verzhbinsky, G., H. Ruderman, and M. D. Levine. 1986. *The Residential Hourly and Peak Demand Model: Description and Validation*, Lawrence Berkeley Laboratory Report LBL-18698. Berkeley, CA.

11. Eto, J., J. Koomey, J. McMahon, P. Chan. 1986. *Financial Impacts on Utilities of Load Shape Changes: The Nevada Power Company*, Lawrence Berkeley Laboratory Report LBL-21597. Berkeley, CA.

12. Eto, J., J. Koomey, J. McMahon, P. Chan. 1986. *Financial Impacts on Utilities of Load Shape Changes: The Texas Utilities Electric Company*, Lawrence Berkeley Laboratory Report LBL-21598. Berkeley, CA.

13. Koomey, J., A. H. Rosenfeld and A. K. Gadgil. 1990. Conservation Screening Curves to Compare Efficiency Investments to Power Plants. *Energy Policy*. vol. 18, no.8. p. 774.

14. Krause, F., J. F. Busch and J. G. Koomey. 1992. *Incorporating Global Warming Risks in Power Sector Planning: A Case Study of the New England Region*. Lawrence Berkeley Laboratory LBL-30797 (vols. I and II). November, 1992. Berkeley, CA.

by the time the subject alternative efficiency levels take effect (1).

Regardless of the system type, IID systems were considered for this analysis to consist of three main subcomponents: ignitor device, control module, and ignition sensor. After discussions with equipment maintenance companies, it was decided to assign negligible maintenance costs to the ignitor components. This was based on the assumption that past problems with hot surface ignitors will disappear by the time that the new efficiency levels take effect for cooktops and ovens. Sensors and control modules were considered separately in terms of maintenance costs.

D.3 MAINTENANCE COSTS FOR IID COMPONENTS

The maintenance costs for sensors and control modules were obtained directly from a survey of equipment maintenance organizations in the San Francisco area:

Sensor replacement service call:	$ 79
Control module replacement service call:	$170
Total Cost:	$249

These values represent the total amounts, in the year of the maintenance occurrence and in 1990 dollars, that an appliance owner in the San Francisco area would have to pay for replacement of a defective part. The sensor and control module costs have been added above due to the unavailability of separate lifetime information for sensors. Both sensor and control module were assigned the same lifetime as the control module.

After obtaining the regional (San Francisco area) cost of $249, a location multiplier of (1/1.367 =) .732 was used to adjust the costs to a national average value, $182. The 1.367 factor was obtained from a listing of location multipliers for mechanical construction work cost estimation data by the R.S. Means Company (2).

D.4 MAINTENANCE LIFETIME DISTRIBUTION AND PRESENT VALUE OF MAINTENAN

Maintenance lifetime was estimated from information obtained from IID manufacturers and not from the survey results. This approach was taken because it appeared that IID systems in particular were still evolving rapidly, and that the estimates for lifetimes obtained from services organizations would be faulty if based on experience from the past.

The present value of maintenance cost for IIDs was characterized in this analysis as the average present value for all possible failure times. In order to achieve such an average, a probability density function (PDF) of failures over time was generated based on information obtained from telephone interviews with manufacturers of IID control modules. A separate lifetime was not available for sensors, so the lifetime for control modules was chosen for sensors as well. Conversations with service organizations indicated that sensor lifetimes are probably shorter than control module lifetimes.

The following information was obtained from conversations with IID control module manufacturers:

- Control module average lifetime was estimated to be on the order of 14 years.
- The average control module failure rate during the first year of operation was found to be below 2.5%. The value 2.5 was used for this analysis. Failures in the first year are covered under warranty and do not represent a cost to the consumer.
- After 10 years of production, yearly IID sales for the aftermarket (repairs) were determined to be on the order of 5% of total yearly sales.

Table D.1 presents a tabular summary of the probability density function (Columns A and B) developed using the above information. The values are calculated on the basis of unitary maintenance cost ($1), a discount rate of 6%, appliance installation in year 0, and maintenance cost for an individual year equal to $1 times the probability of failure for the year. The summation (in Column E) is calculated based on an assumed lifetime of 18 years for gas cooktops and ovens. It does not include the cost of failures occurring in the first year. Using the total cost of $182 (given above), the present value for IID maintenance is calculated as follows:

$$MC_{pv} = \$182 \cdot (\$.44/\$1.0) = \$81$$

The annualized maintenance cost (6% discount rate) derived from this value is

$$MC_a = MC_{pv} \cdot CRF = \$81 \cdot .092 = \$7.45 \text{ / year}$$

Table D.1 Calculations for Mean Lifetime of IID Units

Year After Purchase	Yearly Fraction of Units Failing (F)	Present Value Discount Factor (f)	Average Present Value of Maintenance ($1·F·f)	Summation of Present Value of Maintenance
Column A	Column B	Column C	Column D	Column E
1	0.025	na	na	
2	0.01	0.890	$0.009	
3	0.01	0.840	$0.008	
4	0.01	0.792	$0.008	
5	0.01	0.747	$0.007	
6	0.01	0.705	$0.007	
7	0.01	0.665	$0.007	
8	0.0175	0.627	$0.011	
9	0.0275	0.592	$0.016	
10	0.045	0.558	$0.025	
11	0.0575	0.527	$0.030	
12	0.075	0.497	$0.037	
13	0.0875	0.469	$0.041	
14	0.105	0.442	$0.046	
15	0.115	0.417	$0.048	
16	0.1225	0.394	$0.048	
17	0.1275	0.371	$0.047	
18	0.135	0.350	$0.047	$0.44

REFERENCES

1. Dzierwa, R. 1990. "Kindling Appliance Fires." *Appliance*, December, 1990, pp. 20-26.

2. R. S. Means Company, Inc. 1990. *Means Mechanical Cost Data.* Kingston, MA.

Although individual firms must calculate according to their own elasticities of demand, it is ultimately the industry elasticities that determine the level of demand experienced by each firm. This apparent paradox arises because the model assumes that all firms are profit maximizers and thus respond in essentially the same way to the imposition of new efficiency levels. Because of this assumption, all firms change the prices and operating costs of their appliances by the same amount (i.e., the industry acts in unison). When this happens, sales for each firm are determined by the industry elasticities.

C.1.3 Measures of Impact

The LBNL-MAM computes three primary and several secondary measures of impact. The three primary measures, ROE, industry net present value, and net income are presented because they can each move in opposite directions. For instance, if net income increases, but assets and thus equity increase by a greater percentage, ROE will decline. If the decline is large, the net effect will be viewed as negative, but if a small decrease in a healthy ROE is accompanied by a large increase in net income, the net effect might be viewed as positive. Other outputs of the model are total shipments, price, revenues, and average wholesale price. These variables help explain the origins of changes in the primary inputs.

C.1.4 Methodology

How Alternative Efficiency Levels Are Implemented in the Model

Generally, a change in efficiency levels affects the model in three distinct ways. Implementation of new efficiency levels require additional investment, raise production costs, and affect revenue.

The most obvious investment induced by new efficiency levels is the purchase of new plants and equipment. This cost is first evaluated from engineering data and then amortized by taking into account the life of the investment, the timing of the expenditures, tax laws, and the cost of funds. An additional (and sometimes larger) investment is made as old inventory is replaced with more expensive new units. The model assumes that previous inventory ratios are maintained. A third form of investment tracked by LBNL-MAM is the change in the transactions demand for cash that accompanies a change in revenues.

Increased costs of production are modeled by coupling changes in unit costs with changes in product shipments. Changes in unit costs come from engineering data and shipments data come from LBNL-Residential Energy Model (LBNL-REM).

Revenue is affected both by price and shipments. Price is determined by computing the markup over long-run marginal costs, and then using the markup to determine an optimal price. Shipments (demand) is determined by price elasticities and consumer market discount rates, coupled with the changes induced by imposed efficiency levels in price and operating costs.

Typical-year Approach

The LBNL-MAM uses a "typical-year" approach rather than a dynamic approach. This approach models a "typical year" for the industry both in the base case and in the alternative efficiency level case. The year chosen for the model is typically the fourth year after the imposition of new efficiency levels, and is selected because it is believed to be long enough to capture any major impacts from the imposed efficiency level, such as profitability changes or firm entry into or exit from the industry.

Use of Prototypical Firms

Because the engineering and financial data for most firms are proprietary, LBNL-MAM models a prototypical firm. A prototypical firm is a hypothetical firm that is representative of the industry. In many cases, this firm must be thought of as representing an autonomous division of a larger firm. Prototypical firms are defined by parameters that are important for determining the impacts of alternative efficiency levels and are consistent with data for the portion of the industry they represent. Important parameters used in the model include the cost structure of the firms, profitability ratios, relative costs of complying with new efficiency levels, and marketing strategies.

Product Segmentation

The LBNL-MAM assumes that the product market is segmented. Thus, different products have different markups. In general, it is found that appliance manufacturers are able to charge different markups for products that have different characteristics. They can charge higher markups on products that have desirable characteristics. Products without such desirable features are generally bought in larger quantities at lower prices by consumers who are more price-conscious, and thus the markups for these products are lower. The per-unit profits made by manufacturers for these different products may differ significantly.

C.2 STRUCTURE OF THE LBNL-MAM

C.2.1 Economic Theory and Assumptions

The basic question that LBNL-MAM must answer is: how much of the cost increases caused by new efficiency levels can be passed through to consumers? If less than the normal pass-through occurs, profits will suffer, while an above normal pass-through will increase profits. To answer this question precisely, it is necessary to compute a markup; but, before that, a more intuitive understanding of the relevant economics will be useful.

In economics, costs are often divided into fixed and marginal components where fixed costs are just what their name suggests and marginal costs are the costs of producing an additional unit of output. Three points are true in general of these cost distinctions:

1. Under perfect competition, price equals marginal cost.

2. Under imperfect competition (i.e., where the market is characterized by a downward-sloping demand curve) price equals marginal cost times a markup.

3. In neither case do fixed costs affect the calculation of price.[1]

The first point may be understood by assuming for a moment that it is false and that price is higher than marginal cost. In this case, each firm concludes that it is profitable to increase production (since under perfect competition each firm knows that as an individual firm its own output has no effect on price). As a result, prices would certainly fall. If price is below marginal cost, the reverse argument holds, so, in either case, price will inevitably change until it equals marginal cost. The second point is derived in the next section. The third point is most easily understood by examining Figure C.1, which shows a revenue curve and two total-cost curves that differ only in their fixed components.

How will a firm respond to an increase in fixed cost (represented by the upward shift displayed in the cost curve)? Since the firm wishes to maximize the difference between cost and revenue, it chooses the optimal output Q*. This choice is clearly independent of the shift in fixed cost, but once output is determined, the demand curve will dictate the price at which that output can be sold. A change in fixed cost has no effect on the demand curve and thus no effect on price.

The separation of costs into fixed and variable must be done with an eye to the time horizon under consideration, because most (if not all) costs that are fixed in the short run become variable in the long run. Three distinct time horizons are useful: the short run, the long run, and the very long run. In the short run, the productive capacity of the firms in the industry remains fixed. In the long run, capacity may be adjusted, but the number of firms remains constant. In the very long run, firms may enter or leave the industry, with the result that an individual firm's market power, as measured by its price elasticity of demand, may change. Thus, in the very long run, markup may change.

In the long run, price is a markup over long-run marginal cost, while in the short run, price is a markup over short-run marginal cost. Since in the long run, capital is considered a marginal cost, how can the two pricing rules be reconciled? If a firm finds that its long-run plans have been realized (in other words, if the market conditions are those that it foresaw at the time it planned its

---

[1] Two legitimate interpretations may be given to this mathematical result. The first is that given the demand function, marginal cost determines price and fixed costs are not passed on. The second is that one may argue that fixed costs indirectly determine the elasticity of demand, and thereby the markup over marginal cost. Thus fixed costs are indirectly passed on through the markup of marginal cost. The mechanism providing this indirect link is the following: if fixed costs are not covered, then economic profits will be negative and some firms will leave the industry; this will reduce competition and thus reduce each firm's elasticity of demand. Conversely, if fixed costs are more than covered, positive economic profits will induce entry and elasticity and markup over marginal cost will be reduced.

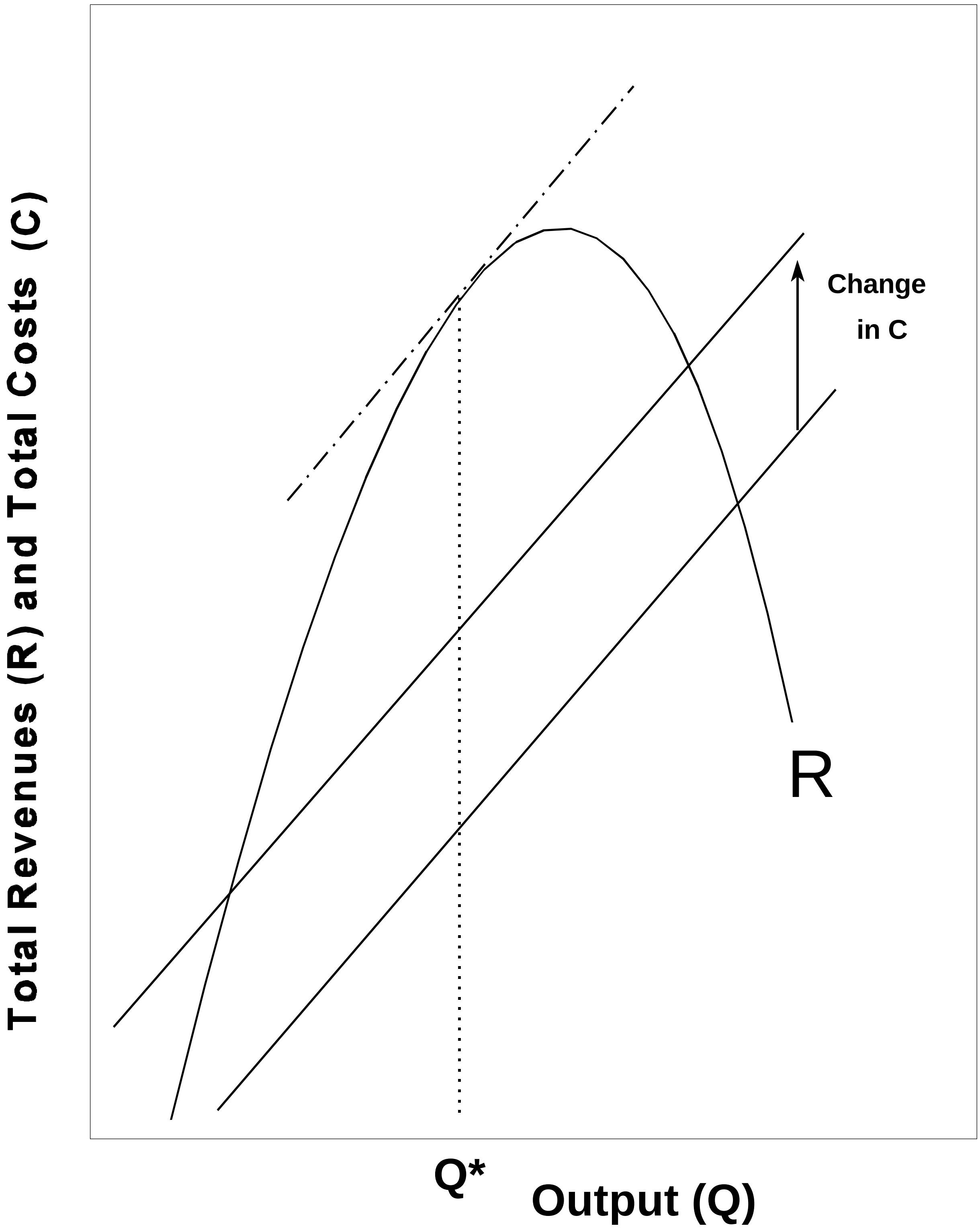


Figure C.1 Profit Maximization and Fixed Costs present capacity), then long- and short-run marginal costs will be equal. This is possible because although capital is not included as a short-run cost, there are other costs that are short-run cost but not long-run costs. These are the costs associated with an increase in output beyond the planned long-run capacity level. If a plant is running optimally, output has been pushed to the point that short-run marginal costs equal long-run marginal costs; otherwise a different size plant would have been more profitable.

The next section gives a theoretical overview of the LBNL-MAM, followed by a derivation of some important results and a review of their application to the long-run model. Finally, we discuss the short-run part of the model.

Theory and the LBNL-MAM

From our discussions with representatives of the appliance manufacturing industries and industry consultants, we know that in appliance manufacturing, unit cost decreases as quantity increases. Therefore, we know that there are fixed costs in the production of appliances. Consequently, each producing firm does not face an infinite elasticity of demand because a small increase in price charged will not result in a 100% loss of sales (because the increase in price would induce entry of new competitors). As a result, we know that the appliance-manufacturing industry is not perfectly competitive. Hence, the LBNL-MAM models typical firms as having a combination of fixed and variable costs, and as facing a demand curve with finite elasticity.

The next section derives the equations relating markup, fixed costs, variable cost, and economic profit. These relationships are part of standard economic theory, hence these derivations are included for the convenience of the reader and not as an explanation of any theoretical results new to this study. One exception to this disclaimer is the discussion on oligopsony power and the "effective" number of firms. There is no generally accepted theory on how to model a market characterized by significant market concentration on both the seller's and the buyer's side. As a result, we developed an approach that is discussed in greater detail below.

Derivation of Markup

To begin the derivation of the markup equation, assume that firms maximize economic profit, where economic profit is revenue minus economic cost, and economic cost includes the cost of equity and all taxes. Economic costs *(C)* are assumed to be linear functions of output (*Q*) and revenues (*R*):

$$C = \beta_0 + \beta_1 Q \qquad \textbf{(C.1)}$$

Although cost is written as a linear function of output, this is not essential; a non-linear cost function would give a mathematically equivalent, but more difficult to express, result.[2]

Next, make the standard economics assumption that firms maximize economic profit *(R-C)*. Since the cost of capital is included in economic cost, a firm with an ROE equal to the cost of capital will find its economic profit to be zero. If, however, a firm can earn a higher ROE, it is assumed that it will do so, in which case *R-C* will be positive. The firm can maximize profit by picking either a quantity to produce *(Q)* or, equivalently, a price to sell it at, but it cannot choose both. The following computations assume that profit is maximized with respect to *Q*. This gives the following first-order condition:

$$\frac{d}{dQ}(R-C)=0 \qquad \textbf{(C.2)}$$

This equation completes the description of the supply-side assumptions. The demand side is described by an elasticity of demand which may vary, but which at the market equilibrium takes the value *e*. Elasticity of demand is the percentage change in demand caused by a 1% change in price *P*, and consequently is negative. Mathematically, this is expressed as follows:

$$\frac{dQ}{dP} \cdot \frac{P}{Q} = e \qquad \textbf{(C.3)}$$

All necessary assumptions have now been made, so all that remains are some mathematical manipulations. From the two supply assumptions, and denoting dR / dQ by R' and dP / dQ by P', we have:

$$\frac{d}{dQ}\left[R - \beta_0 - \beta_1 Q \right] = 0 \qquad \textbf{(C.4)}$$

or equivalently:

$$R' = \beta_1 \qquad \textbf{(C.5)}$$

By definition:

$$R = P \cdot Q \qquad \textbf{(C.6)}$$

---

[2] If we assume that cost is an arbitrary function of Q, $C(Q, R)$, our final result, will differ only in that the two types of cost (β_0 and β_1) will be replaced by $C - Q\,(dC / dQ)$ and dC / dR, respectively.

$$R' = P' \cdot Q + P \qquad \textbf{(C.7)}$$

$$R' = \frac{P}{\frac{dQ}{dP}\,\frac{P}{Q}} + P \qquad \textbf{(C.8)}$$

$$R' = \frac{P}{e} + P \qquad \textbf{(C.9)}$$

Substituting for R' in the first order condition yields:

$$P = \frac{e}{1+e}\beta_1 \qquad \textbf{(C.10)}$$

In this last equation, price is a simple markup over marginal cost. This result may be found in any standard text on industrial organization. Now we define the markup:

$$\mu = \frac{e}{1+e} \qquad \textbf{(C.11)}$$

Note that because the own-price elasticity *(e)* is negative, μ is greater than 1. Of course if $e \leq = -1$, then μ is undefined, since the firm makes more profit the less it sells.

We can now rewrite Eq. C.10 to provide a simpler look at the markup equation:

$$P = \mu\beta_1 \qquad \textbf{(C.12)}$$

Price formation can be explained as follows: marginal costs are marked up by μ and fixed costs are not passed on at all.

It is now easy to derive another representation of μ which is used in the calibration stage of the LBNL-MAM to estimate μ from Eq. C.1:

$$(R-C) = R - \beta_0 - \beta_1 \cdot Q \quad \textbf{(C.13)}$$

Using Eq. C.6 with Eq. C.12:

$$R = P \cdot Q = \mu \beta_1 Q \quad \textbf{(C.14)}$$

so

$$(R-C) = \mu \beta_1 Q - \beta_0 - \beta_1 Q \quad \textbf{(C.15)}$$

and

$$(R-C) = (\mu - 1)\beta_1 Q - \beta_0 \quad \textbf{(C.16)}$$

Finally,

$$\mu = 1 + \frac{(R-C) + \beta_0}{\beta_1 Q} \quad \textbf{(C.17)}$$

This equation shows that markup is economic income *(R-C)* plus fixed costs, all over total variable cost. The calibration calculations of the long-run module uses a simple variation of this equation in which $\beta_1 Q$ is replaced by C-β_0, and the relation, *R-C = EP*, where *EP* is economic profit, is used twice. The new form of the equation is:

$$\mu = 1 + \frac{EP + \beta_0}{R - EP - \beta_0} \quad \textbf{(C.18)}$$

Markup is determined by revenue, economic profit, and fixed costs. Generally, it has been found that fixed costs are large relative to economic profit, so the numerator is controlled largely by the fixed cost. Thus, markup is primarily determined by the size of fixed cost relative to revenue.

Oligopsony Power and the "Effective Number of Firms"

From an evaluation of the analyzed industries (for instance, see Chapter 4, Industry Profile, of the General Methodology section), we see that the market structures of the industries are oligopolies and model them accordingly. However, the situation is further complicated by the fact that the demand side of the market is also heavily concentrated due to the presence of large retailers who have a great deal of market power.[3] In other words, we have an oligopoly facing an oligopsony. Consequently, the standard oligopoly model needs to be modified. Unfortunately, there is no standard theory on how to model an industry with such a market structure. After examining the evidence of oligopsony, we go on to show how we incorporate this into the model.

The rise of large retailers in the home appliance industry is a relatively recent phenomenon. They are generally defined as multi-market large-volume retailers, which includes firms such as Sears, Montgomery Ward, Circuit City, and Highland. For example, the home appliance retail share of Sears and Montgomery Ward alone has been estimated to be about 30% for various products. One indication of this oligopsony power is that if theoretical markups based on the actual number of firms in the industry are estimated, we find that the markups are much too large relative to what we observe in the market.

We address both the problems of oligopsony and of "over-estimated" markups by assuming that the low observed markup is the result of oligopsony power and is an indication of the strength of that power. Since a firm's markup is directly related to the elasticity of the demand it faces, we can find the single-firm demand elasticity that corresponds to the observed markup. This same elasticity is also implied by the industry elasticity and a Cournot oligopoly with some hypothetical number of firms. This allows us to compute the hypothetical or what we refer to as the "effective" number of firms from the observed markup. We then model the industry as if it were a Cournot oligopoly facing a competitive, not oligopolistic, demand for its product, but we use the "effective" number of firms rather than the actual number of firms to reflect the impact of the oligopsony. The effect of this is to reduce the market power of the individual firm to agree with our observation of markup. Although the reduced market power is a consequence of specifying too many firms, and not of modeling oligopsony, we believe that it provides a good first-order approximation to the actual market structure and provides a way around the intractable problem of modeling a market with imperfectly competitive demand and supply sides.

We now show how markup is computed from economic profit and fixed costs, and how the "effective" number of firms is computed from markup and industry demand elasticity. A well-known result for a Cournot oligopoly is:

$$e = NF \cdot e_i \qquad \textbf{(C.19)}$$

where:

e	=	the firm elasticity of demand,
e_i	=	the industry elasticity of demand, and
NF	=	number of firms.

[3] The increasing concentration on the demand side of the market also agrees with comments by the home appliance industry during the comment for these and other appliances. For instance, see AHAM, "State of the AHAM to the Department of Energy on Notice of Proposed Rulemaking on Energy Efficiency Standards for Clothes Dishwashers, Clothes Washers and Clothes Dryers," CE-RM-88-101, October 10, 1989.

We can solve for *NF* if the two elasticities are known. We have an estimate of e_i and can estimate e as follows. From Eq. C.11, we know that:

$$e = \frac{\mu}{1-\mu} \qquad \textbf{(C.20)}$$

We can find the markup, μ, from Eq. C.12 if we know marginal cost β_1. Marginal cost can be found from the firm's return on equity, its fixed costs, and the following price identity: $\pi/Q = P - \beta_1 + \beta_0/Q$, where β_0 is fixed cost and π denotes economic profit, which is equal to revenue minus cost. (This is just a restatement of Eq. C.13.) Noting that revenue, R, equals $P \cdot Q$, we have:

$$\mu = \frac{P}{\beta_1} = \frac{P}{P - \frac{\beta_0}{Q} - \frac{\pi}{Q}} = \frac{R}{R - \beta_0 - \pi} \qquad \textbf{(C.21)}$$

This gives a formula for markup μ based on our most easily observed variables. Solving Eqs. C.19 and C.20 for e, we can now find the number of firms, *NF*:

$$NF = \frac{\mu}{e_i \cdot (1-\mu)} \qquad \textbf{(C.22)}$$

We find that given two elasticities estimated from actual data, *NF* is higher than the actual number of firms observed.

To summarize, we first look at a typical firm's profit and fixed costs. In order to recover fixed costs, a firm must mark up over variable costs, and if it can mark up enough, it will make above "normal" ROE. From these considerations, we find its markup. The markup indicates a firm's industry demand elasticity and the effective number of firms in the industry. We use it in subsequent calculations.

The Base Case

In the *long-run model module*, the calibration case is immediately followed by long-run calculations for the state of the industry in 1996 provided that the 1990 NAECA standards are unmodified. These calculations use the markup that is based on the one just calculated and modified in keeping with the assumption that demand elasticity with respect to life-cycle cost is constant. The modified markup is calculated as in Eq. C.5 but from a modified price elasticity. The new price elasticity is obtained as follows. First, the original price and operating cost elasticities are used to determine a life-cycle cost and an elasticity with respect to that cost. A demand curve with constant life-cycle cost elasticity is then computed. It takes this form:

$$Q = a \cdot (P + ff \cdot F)^{B} \qquad \textbf{(C.23)}$$

where *P* is price, *F* is operating (fuel) cost, *ff* is the fuel-cost factor, and *B* is the elasticity with respect to life-cycle cost. Then price and fuel cost are changed from the calibration case to either the base case or a long-run case. These changes shift the division of demand elasticity between the price and operating cost. In particular, the price elasticity is given by:

$$e = \frac{B \cdot P}{P + ff \cdot F} \qquad \textbf{(C.24)}$$

As price increases as a fraction of life-cycle cost, the price elasticity increases.

The added costs to meet new efficiency levels are divided into two categories: capital, and parts and labor. Capital costs come in two varieties, tooling and equipment. These are not currently separated by the model because we do not have separate data from the manufacturers. Since the chief economic difference between these two is their expected life, the LBNL-MAM, in its amortization procedure, uses an intermediate value for the lifetime of new capital. This procedure takes a one-time capital expense and converts it to an annual expense, taking into account the cost of debt and equity, the tax laws, the lifetime of the capital, and the age of any capital being replaced.

Once the cost of capital has been annualized, it must be divided into fixed and variable parts. The fixed part is then added to β_0, while the remainder is divided by *Q* and added to β_1.

Since there are undoubtedly some economies of scale when parts are purchased, the LBNL-MAM provides for a division of the cost of parts and labor between the fixed and variable categories. However, the savings generated by buying an additional 100,000 units above an initial million, for example, will generally be so small that the cost of parts and labor will be referred to as a variable cost and thus can be thought of as being added directly to $\beta_{1.}$

Once base case costs have been assigned, price is easily computed from Eq. C.13, by using the price elasticity calculated as described above. With the new price in hand, sales *(Q)* can be computed from price and operating-cost elasticities. Revenue is now just $R = P{\cdot}Q$, and economic income is just R-C. Assets are those of the calibration case plus the new capital resulting from 1990 NAECA standards, and equity is computed from the debt-to-equity ratio. This calculation of equity is the last essential calculation for the base case.

The Long-run Analysis: Changed Alternative Efficiency Levels

The analysis of the long-run effect of a change in efficiency levels from their 1990 NAECA level is essentially the same as the analysis of the base case. New costs are divided between fixed and variable categories in the same way and added to the base case costs. From there, the calculation proceeds in exactly the same way as above.

C.2.2 Structural Assumptions

The cost structure. Costs are assumed to have two components: fixed and proportional to quantity.

$$EC = FC + MC_q \cdot Q$$

The asset structure. Assets are assumed to have the same two components.

$$A = A_0 + A_q \cdot Q$$

Demand elasticity. The demand elasticity with respect to life-cycle cost experienced by a single firm is assumed to be independent of price and operating cost over the relevant region. This means that if the industry raises price, the percentage change in demand caused by a 1% change in price remains the same as before the price increase.

Optimizing behavior. A firm is assumed to maximize revenue minus economic cost *(R-EC)*.

Debt-to-equity ratio. The debt-to-equity ratio is assumed to remain constant while the firm finances any investment necessary to meet new efficiency levels. It is generally assumed that firms have some *D/E* ratio that they consider optimal, and there is no reason for new efficiency levels to change this figure.

Amortization of capital costs. It is assumed that the one-time capital cost is to be amortized over its life (typically seven years), that its cost is the weighted average after-tax cost of capital, and that depreciation is straight-line over the tax life.

Structure of cost resulting from changes in alternative efficiency levels. The cost of capital is assumed to be partly fixed and partly variable (i.e., proportional to shipments). For instance, parts and labor are assumed to be variable costs.

C.2.3 Description of Modules

The LBNL-MAM is a Lotus 1-2-3 spreadsheet that is organized into 9 sheets, each of which is subdivided into a number of modules or "pages." A flowchart depicting the main linkages between the most important modules appears in Figure C.2, and a brief description of each is given below. Starting with subsection C.2.3.1, each panel is given a full description.

A. *Primary Page.*

1. *Control panel.* This module displays nine key variables and their control factors, plus a summary of crucial results. The control factors are normally set to one, but can be changed to test the model's reaction to any of the control variables. The change in results is immediately displayed in the lower part of the control panel.
2. *Cost, sales, and revenues.* This module uses prices, markups, market shares, and industry shipment levels to compute variable cost of goods sold and revenues for a single prototypical firm. Changes in operating cost, capital cost, and engineering expense are also computed here.
3. *Costs and assets of one-time investment.* The one-time cost module derives amortized costs from the one-time capital cost and one-time engineering expense associated with the imposition of new efficiency levels.
4. *Model and demand (long-run).* This module does most of the economic calculations. Its calibration phase estimates the markup over variable cost which is used to estimate new prices once new efficiency levels have been imposed. These prices are then used to compute sales, and, from sales, all other descriptive variables.
5. *Short-run model.* This module modifies the price computed by the long-run model in order to take into account the possible short-run effects of excess capacity. An estimate of the responsiveness of price to changes in demand during the business cycle is combined with the change in demand predicted by the long-run model.
6. *Monte Carlo.* The nine control variables can be selected randomly from probability distributions determined by the variables' standard errors and median (estimated) values. The Monte Carlo module is designed to record many such runs and display the mean value and standard deviation of six outputs: percentage change in price, sales, revenue, and net income, plus the change in ROE in the long and short runs.
7. *Variation in Inputs.* This module is similar to the upper portion of the control panel (A1). It displays 20 inputs for the long-run model and their control factors. The control factors are normally set to one, but can be changed to test the model's reaction to any of the variables.

B. *Industry Net Present Value.* This module estimates the impacts of imposing new efficiency levels using an industry net present value approach. This module's functionality is exactly that of the externally developed Government Regulatory Impact Model (GRIM). See C.2.6 for more details.

C. *Linking Page*. The integration of MAM and GRIM required some modification of input variables due to the different ways the two models treat costs. This module aligns inputs for the two models using cost comparison factors. See C.2.6 for more details.

D. *Program*. LBNL-MAM Primary Programming. The program flow is controlled through a series of menus. The program performs the calculations for the various outputs of the model, including efficiency level cost calculations, sensitivity analyses, and a Monte Carlo analysis.

E. *Outputs*.
   1. *Accounting Summary*. The accounting module gives a summary, in the form of a simplified income statement, of the financial impact of alternative efficienc levels on the firm. In addition, a summary of the financial impacts due to new efficiency levels from an economic point of view is shown at the bottom of the page.
   2. *Output Table*. The output page tabulates long-run variables, percent changes, and standard errors from the Control Panel (A1) and Monte Carlo module (A6), and short-run variables and percent changes from the Short-Run Model (A5).
   3. *Charts of Sensitivity to Control Panel Variables.* This module produces two charts. The first shows how profit is affected by a one-standard-deviation change in each of the control variables. The second chart shows how profits change as the alternative efficiency level or engineering design level is changed, but all control variables are kept at their base value.
   4. *Charts of Sensitivity to Model Variables*. This table shows how profit is affected by a one-standard-deviation change in a number of secondary variables.
   5. *Retail Price Output Table*. These retail prices are produced as inputs for the LBNL-REM.

F. *GRIM Outputs*. This module displays the results from the industry net present value module/GRIM (B).

G. *Other Inputs*
   1. *Cost page source inputs*. This module contains primary inputs and simple calculations used as inputs for cost page (A2) calculations.
   2. *Finance source inputs*. The financial module computes the weighted average cost of capital and a factor *describing* how costs depend on revenues.
   3. *One-time cost source inputs*. This module contains primary inputs and simple calculations used as inputs for one-time cost page (A3) calculations.

H. *Cost Inputs*
   1. *Engineering cost input matrices*. The engineering inputs module accepts as input raw engineering data that are used elsewhere in the model for the impacts analysis. These data include incremental variable costs, capital costs, maintenance costs, installation costs, and unit energy consumption for the products being analyzed.
   2. *Alternative Efficiency level distribution matrices*. This module weights the costs given by the engineering inputs module in proportion to the number of products of a particular

design that will be produced at any given efficiency level and thereby generates the costs for that level. These costs appear in the standards level module (H3).

3. *Cost inputs by alternative efficiency levels.* The standards level module provides the same data as the engineering inputs module, except that the data have been processed by the LBNL-REM and/or the "Cost Conversion" module (H2) and are presented for the efficiency levels being analyzed.
4. *Retail price calculation module.* This module provides estimates of retail prices of appliances at different efficiency levels. The primary input for the retail price calculation is the estimate of manufacturer prices.

I. *Engineering Data.* Raw engineering inputs are included on a separate sheet. These values are processed by the Cost Inputs (G1) sheet before being passed to the rest of the model.

J. *General Notes*.

C.2.3.1 Control Panel

The control panel displays the ten most important input variables of the model and allows the user to easily adjust them. These variables are described below. The *input values* are the best available estimates of the relevant variables.

The control panel has one control for each input variable. The controls, found in the column labeled *cntrl*, allow the *input values* to be modified to become the *model values* before they are used by the model. The controls work as follows: when a control is set to zero, its *input value* becomes a *model value* without any adjustment. When a control is set to 1, its *input value* is increased (in absolute value) by approximately one standard deviation to become a *model value*. Because the error distributions associated with the *input values* are not normal, they are not changed by exactly one standard deviation when the control is set to plus or minus 1. A control value of ± 1 actually changes an *input value* by an amount sufficient to make it just as unlikely as a point that is one standard deviation from the mean using a normal distribution. Consider an *input value* that is known to be strictly positive and have a mean of 5 and a standard deviation of 3. Setting its control to -2, which would otherwise change its value to -1 (an impossibility) actually only changes it to some small but positive value. This value would be just as unlikely as a point -2 in a normal distribution.

The *Variation* column shows either the standard deviation of an input variable if the variable is normally distributed, or the coefficient of variation *(S.D./mean)* if the input variable is non-normal.

MAM Modules and Primary Routes of Data Flow

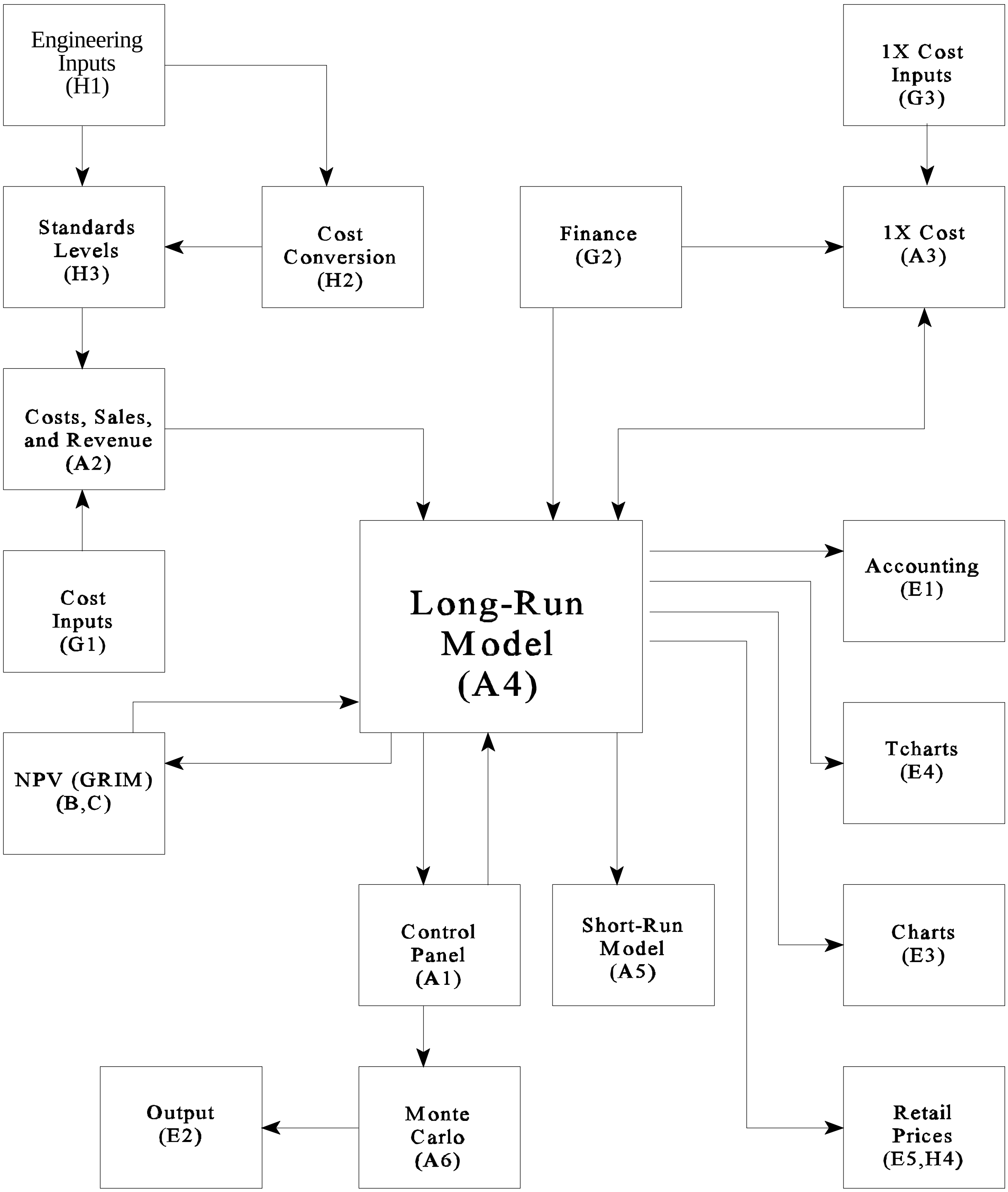


Figure C.2 MAM Modules and Primary Routes of Data Flow

At the bottom of the control panel is a short output summary, which shows the five key output variables: *shipments, price, revenue, net income*, and *ROE*. The first column gives the output values in the base case. The second column assumes some particular change in efficiency levels and gives long-run values—that is, values that would hold after capacity adjustments (by about 2003). The third column gives the percentage change from the base case to the alternative efficiency level case for each of the five key output variables. The fourth column, labeled *Previous Change*, simply lists the results of the previous run to use as a comparison with the results of the current run. The fifth column lists the results from the short-run part of the model (i.e., the estimated output values for the period immediately after the imposition of the new efficiency levels).

The following is a list of the ten key input variables that appear as control factors in the Control Panel module:

1. The industry's price elasticity of demand (IPE),
2. The consumer discount rate (RD),
3. The market cost of capital financed through equity (ECC),
4. Economic profit: the industry's ROE minus normal ROE (EP),
5. The long-run fixed part of costs and assets (FCA),
6. The long-run fixed part of one-time costs and assets (F1X),
7. One-time capital costs resulting from the change in efficiency levels (CC.N),
8. Variable cost of goods sold after the change in efficiency levels (dVC.N)
9. The elasticity curve parameter of the demand function (ro.N), and
10. The short-run price response to demand (SRPR).

C.2.3.2 The Monte Carlo Module

This module estimates the standard errors of the six most important output variables by randomly choosing the ten control variables in accordance with estimates of their standard errors, running the model, and recording the six output variables. This procedure is repeated up to 400 times. Afterwards, the mean and standard deviations of the 400 computed values of each output variable are computed and displayed near the top of the Monte Carlo module. The top row, labeled *Value*, is the most recently computed random set of outputs.

The first four output variables are the percent change resulting from new efficiency levels, in output *(Q)*, price *(P)* and revenue *(R)*. The last three variables are changes in net income *(NI)* and long- and short-run return on equity (ROE).

C.2.3.3 The Accounting Module

The Accounting Summary consists of a simplified income statement that is presented in standard form, along with several key financial ratios and figures that highlight the firm's financial position. The income statement and financial ratios are presented for the calibration case and base cases that include the impact of the 1990 NAECA standards, and an alternative efficiency level case that lists the firm's financial results under the alternative efficiency level being analyzed. Thus, the financial impacts of the alternative efficiency levels are easily seen by comparing the two energy efficiency scenarios. To highlight the results, a final column in the Accounting Summary indicates the percentage change from the base case to the alternative efficiency level case.

A second table at the bottom of the Accounting Summary page lists financial data for the firm using figures that are necessary for an economic analysis. Note that the assets and expenses are broken down into two categories: fixed and proportional to quantity produced. These proportionalities have economic significance when the price markup is computed, and for that reason they are reported separately in the economic analysis.

Table C.1 Accounting Module

Item	Formula
Earnings Before Interest and Taxes	EBIT = Revenue – Total Expenses
Total Expenses	Does not include interest or taxes
Interest	(Interest rate · Debt ratio · Assets) – Interest earned on "Cash" assets
Taxes	(EBIT – Interest) · Tax rate
Net Income	EBIT – Interest – Taxes
Gross Margin	1 – (Variable Cost of Goods Sold/Revenue)
Return on Sales	Net Income/Revenue
Return on Assets (ROA)	(EBIT – Taxes – (Tax rate · Interest))/Assets This calculation eliminates interest tax shield
Return on Equity (ROE)	Net Income/Equity

Note that "one-time" *(1-X)* in the Accounting module refers to expenses incurred because of the change in alternative efficiency levels.

C.2.3.4 The Engineering Inputs Module

The Engineering Inputs module receives all the engineering cost data and energy consumption data for the product classes being analyzed. The data include the incremental variable cost, change in unit energy consumption, maintenance cost, and installation cost for each design option. They also include the one-time capital costs incurred in meeting the imposed efficiency levels; the module assigns these costs to design options and product classes where appropriate or necessary. The various components of the module are described below:

1. *Increment in Additional UVC (Unit Variable Cost)*: Engineering input data. Each "increment" is measured relative to the previous engineering design. The figures are in 1990 dollars.

2. *Additional UVC above Level 0 cost (VCS.E):* "Additional" UVC is measured relative to the 1989 calibration case, which is shown as level 0. In other words, this table is a cumulative version of the above "incremental" table.

3. *Cumulative Maintenance Cost:* These engineering input data are the maintenance costs, per year for each product class and engineering design option.

4. *Annual Unit Energy Costs per Year:* These engineering input data are the energy use per year measured in 1990 dollars.

5. *Total Annual Operating Costs (KWS.E):* These costs are the sum of cumulative maintenance costs and annual unit energy costs.

6. *Installation Costs (INCOST.E):* These are engineering input data used for the calculation of life-cycle cost.

7. *Capital Costs (CC.E):* These engineering input data are given on a per-unit basis amortized (with zero interest) over seven years.

8. *Additional Capital Cost (above Level 0 Cost)(ADD.E):* This matrix translates the amortized capital costs into total one-time per firm capital costs.

9. *Total Capital and Engineering Costs (CCEE.E):* This row is the sum of the columns in the "additional capital cost" matrix. Thus the *CCEE.E* matrix gives the combined added capital cost for all classes of an appliance. The *CCEE.E* matrix contains the capital costs that are used as inputs to the rest of the model. The Long-Run module calculates the average prices for all classes and for each level.

10. *Research and Development Costs (RD.E):* These engineering input data, when available, are treated separately from other capital conversion costs.

11. *Total Capital Conversion Cost, Excluding R&d (TCC.E):* This matrix translates amortized capital costs into total undepreciated one-time per industry capital costs. This is used for the industry net present value calculations.

C.2.3.5 The Standards Levels ("REM") Module

The Standards Levels module provides the same information as the Engineering Inputs module except that instead of listing the cost and energy data for various engineering design options, it lists the data for the various alternative efficiency levels being analyzed.

The data that appear in the seven REM panel tables for each product—VCS.R, KWS.R, INCOST.R, CC.R, ADD.R, RD.R and TCC.R—may correspond exactly to some specific engineering levels or, if it has been determined that the manufacturer, when faced with certain efficiency levels, would use a mixture of engineering designs, then the "Standards Level Distribution Module" appropriately averages the engineering data and places the results in the seven REM tables. The exact mixtures of engineering options are determined by the LBNL-REM.

The top section of this module allows the user to determine what alternative efficiency levels will be analyzed in a particular run. The module is used interactively by the user, who can choose "levels" LEV.B and LEV.N, which correspond to the Base case and Long-Run case, respectively. The bottom numbers in the "LevIn" matrix determine whether these levels will refer to "alternative efficiency levels" or "engineering designs." The top numbers specify the exact level or design.

The values in the "LevIn" matrix determine what values are placed in the bottom two matrices when the model is run. For example if in "LevIn," LEV.B = 4 and S|E.B = 0, then the columns of VCB, KWB, CCB, and INCSTB will contain data for the fourth engineering design option. Changing S|E.B from 0 to 1 would cause all of these data to be replaced with data for the fourth efficiency level.

C.2.3.6 The Costs, Sales, and Revenue Module

This module has two functions. First, it provides the Long-Run Model module with several inputs; these are averages. Second, it uses many of the data from the input pages and processes these data into prices, quantities sold, and revenue. These intermediate output data are then used in the financial and economic summaries to give output results, which are used for the analysis of the impact of implementing new efficiency levels. Table C.2 lists the equations that are used in the Costs, Sales, and Revenue module.

In the alternative efficiency level case, the variables are named with a ".N" suffix instead of a ".B" suffix. The "Totals" row gives the weighted average change in UVC *(dVC.B)*, the weighted average change in price, the new weighted average price *(P.B)*, the firm's total revenues (∑*(Ri), R.B*), the weighted average change in operating costs (*OC%.B*), and the total firm shipments (*Q.B*). *P.B, Q.B* and *R.B* are actually computed in the Long-Run module.

The first stage in this module is setting up the calibration case, which uses known information about industry shipments, product class market shares, prototypical firm market shares,

Table C.2 Equations Used in the Costs, Sales, and Revenue Module

Item	Calibration Case Formula or Definition
Size	Prototypical firm market share
Industry Shipments	Annual industry shipments for a product class
Relative Shipments (Q%)	Product class market share (product class units sold/total units sold)
Shipments (Q.1)	Product class shipments for a prototypical firm
Price (P.1)	Unit Variable Cost (UVC) · input markup (MU.0)
Revenue (R.1)	Price · Shipments
Markup (M.1)	1 + (*P*.1 - *BB*)/*AA*
Unit Variable Cost (UVC.1)	*P*.1/*M*.1
Weighted UVC	UVC Relative Shipments (Q%)
New Shipments (Qi.B)	Q% · Q.B
Rule-of-Thumb Change in Price	M.1 · (change in UVC + change in variable part of per unit investment costs)
Rule-of-Thumb Revenue	(P.1 + Rule-of-Thumb dP) · Qi.B
Alpha.B	Scaling factor to insure $\sum$Ri.B = R.B
New Price (Pi.B)	P.1 + (1 - Alpha.B · Rule-of-Thumb dP) · Rule-of-Thumb dP
New Revenue (Ri.B)	Pi.B · Qi.B
Operating Cost Ratio	1996 UEC/1990 UEC
Weighted Operating Cost Ratio	Operating Cost Ratio · Relative Shipments
Percent Change in Operating Cost (OC%.B0)	$\sum_{Class}$Wtd Operating Cost Ratio · KWHR - 1

markups for each of the product classes, and baseline unit variable costs to calculate the prototypical firm's shipments for each product class, its cost of goods sold, and its revenue. Also calculated are a weighted-average unit variable cost, selling price, and markup. Markup is calculated from data on the ratio between the highest and lowest markups (*ratio*) and the typical markup (*mid*).

The next stage in the Costs, Sales, and Revenue Module calculates the changes necessary to produce the base case and the alternative efficiency level case.[4] The calibration case is used as a base, and the changes in unit variable cost and unit energy consumption are received from the Standards Level cost inputs module. From these inputs, new unit variable costs and prices are calculated for each of the product classes. The model then uses known price elasticities and discount rates to calculate changes in shipments for each of the alternative efficiency level cases. For each of the efficiency level cases, the model calculates the firm's new shipments, revenue, and the weighted-average change in unit variable cost and price.

The manufacturer markup listed in the panel is used to calculate the baseline model prices, but it is *not* used in calculating the manufacturer prices for the alternative efficiency levels. In these cases, LBNL-MAM uses an economic markup to determine prices.[5] This markup is on *economic* variable costs, which are a broader category than the typical business definition of variable costs. The markup varies depending on price elasticities, discount rates, and changes in prices and operating costs at different efficiency levels. Thus, prices at different efficiency levels do not exactly reflect the manufacturer cost times the manufacturer markup.

C.2.3.7 The Financial Module

The Financial module lists the financial characteristics of the prototypical firm being analyzed. Some of the inputs are used to calculate intermediate outputs of financial characteristics of the firm. The financial inputs and intermediate outputs are then used elsewhere in the model when the impacts of new efficiency levels are calculated. Table C.3 gives the formulas used in the module.

Several variables in the Financial module are not related to alternative efficiency levels and thus require explanation. First, in order to make the model adjustable to a particular point in time when the size of the firm may be different from what it was in the year in which the data were collected, some of the inputs are listed as ratios proportional to revenue. For instance, the historical ratio between depreciable assets and revenues for the cooktop manufacturing industry (called *DA:R*) is 0.37. This is used by the model to compute a value for depreciable assets at some typical year in the future after efficiency levels have changed by multiplying *DA:R* by revenue in that year.

---

[4] The base case allows the analysis of intermediate efficiency levels or other alternate efficiency level analysis scenarios in addition to the new efficiency level case scenarios. For the purposes of this analysis, the base case is identical to the calibration case.

[5] For a thorough description of how markups are derived and used in LBNL-MAM, see C.2.1.

Table C.3 Financial Module

Item	Definition	Formula
DR [ER]		Debt [Equity] /(Debt+Equity)
DRR	Depreciation	Average depreciation rate · depreciable assets (expressed as a percent of revenue)
ECC	Equity cost of capital	
PECC	Pre-tax ECC	*ECC*/(1 - Tax Rate)
WACC	Weighted average CC	*DR* · *I*nterest rate + ER · *PECC*
ATWACC	After-tax WACC	*WACC* · (1 - *T*ax Rate)
ROE	Return on Equity (expected ROE for a prototypical firm)	ATWACC + Economic Profit

A complication may occur if a value changes in proportion to revenue between now and the typical year, but under efficiency levels which have been implemented it is expected that a portion of the value will remain proportional to revenue while another portion of the value will not change with revenues because of the change in efficiency levels (i.e., it is "fixed"). In this case, that value is analyzed as having a "variable" and a "fixed" component, where "variable" and "fixed" are used with respect to a change in efficiency levels.

C.2.3.8 The One-Time Cost Amortization Module

Crucial to the manufacturer impact analysis are the capital costs that the industry will incur because of the change in imposed efficiency levels. This module takes as input from the Engineering Analysis the estimate of the total value of the one-time capital costs and reduces them to annual expenses. To annualize (or "amortize") these costs, the module takes into account: the expected life of the new capital, the tax life of the investment, the weighted average cost of capital, and the timing of the investment relative to any capital that is being replaced.

The amortized capital costs are calculated for the change from the calibration case to whatever efficiency level case is under consideration. Also, the average value (over the amortization period) of the new capital is computed. Two important factors are derived here, the gross tax effects and the levelized capital cost factors.

Both calculations are based on a model of investment where new capital will be paid for according to the *CC SCHEDULE*. This schedule gives expenditures for the four years previous to 1993; these expenditures are assumed to occur at the middle of each year. They are assumed to be financed by debt and equity in the firm's normal debt-to-equity ratio.

Tax benefits will accrue over the tax life of the capital. Some part of the capital expenditure (commonly 50%) is assumed to be for new plant and equipment that do not take the place of existing capital; the remainder is assumed to replace inadequate existing equipment. The replaced equipment is assumed to have had the same potential lifetime (*L*) as the replacing equipment and is assigned a certain age. If the new equipment replaces old equipment that would soon have needed replacing anyway, savings are included at the time the natural replacement would have occurred. Because these savings are not tax-related, they reduce initial capital cost but are not calculated under tax effects.

The computed annualized cost tells what constant real dollar payment would need to be made each year in order that at the end of the capital's useful life all of the issued debt could have been paid off, and all of the issued equity could have been repurchased.[6] Since imposed efficiency levels are assumed to last indefinitely, new capital will need to be purchased at the end of this cycle; but of course the next cycle starts with a clean slate and repeats the same process we have just described. This process can repeat indefinitely with no change in amortized payments.

This procedure overestimates the burden to the firm because, since industry is constantly improving the efficiency of product lines, those lines would undoubtedly be much nearer to meeting the implemented efficiency levels by the beginning of the second cycle. Thus, much of the capital equipment re-installed at the end of the first capital's lifetime would have been a normal expense by this date (around 2001). For the interested reader, the details of the calculation method are given in Table C.4.

Table C.4 should be read in conjunction with the One-Time Cost Amortization module. Note that the calculations are all done with continuous interest and discount rates, which makes it necessary to convert *ATWACC* to a continuous equivalent cost of capital *(ATR)* by taking the natural log of *(1 + ATWACC).* The continuous rate is equivalent to, and for small rates it is numerically close to, the annual rate. The continuous time formula for the present value of *$Y* received *t* years in the future is $Y \cdot exp(-rt)$, where *r* is the discount rate and *exp* denotes exponentiation. For a constant stream of income at $*Y* per year for *L* years, the present value is $Y \cdot (1 - exp(-rL))/r$.

The most important output of this module are the capital cost amortization factor *CCLF* and the capital cost levelization tax factor *CCLTF*. *CCLF* includes the initial cost (normalized to 1 in order to produce a cost factor instead of an actual cost) and the present value of savings from not replacing old capital at the end of its normal life if it has already been replaced with new capital to meet new efficiency levels. These two present values are converted to an equivalent constant stream of payments that continues for the lifetime of the capital. *CCLF* is calculated to take into account the fact that investment must start before the implementation of new efficiency levels. The capital cost levelization tax factor *CCLTF* similarly levelizes the present value of the tax benefit from straight-line depreciation of the initial cost, the tax benefit from the one-time depreciation of the old capital when it is scrapped, and the loss of tax benefit from the old capital after it has been scrapped. The formula for these equations are shown in Table C.4.

---

[6] Of course tax benefits are counted toward eliminating debt and equity.

Table C.4 One-Time Cost Amortization Module

Item	Definition	Formula
T	Tax rate (36%)	
TL	Tax life of existing capital	
L	Economic life of existing capital	
AGE	Age of existing capital	
%NC	Percent of one time capital that is add-on (not replacement)	
RTL	Remaining tax life	max (TL - AGE, 0)
ATR	Continuous after-tax weighted average cost of capital*	ln(1 + *ATWACC*)
EMRT		$e^{-ATR \cdot TL}$
EMRL		$e^{-ATR \cdot L}$
BN	Tax benefit rate	T/TL
BEN	Tax benefit of existing capital	(1 - %NC) · BN
DIS	PV discount factor	$e^{-ATR \cdot (L - (TL - RTL))}$
*CCi**	Capital cost I years before effcy levels have been implemented	
*CCWi**	Weighted CC lead-time factors	CCi · $e^{(ATR \cdot I)}$
LTC	Cumulative CC lead-time factor	Sum of CCWi over 4 years
*OCS**	Savings from old capital not replaced later	-(1 - %NC) · $e^{-ATR \cdot (L - AGE)}$
*PVCC**	Present value of capital cost (CC)	1 + OCS
CCLF	CC amortization factor	ATR · PVC · LTC /(1 - EMRL)
*PVD**	Tax benefit of straight-line depreciation	- BN · (1 -EMRT)/ATR
LEC1	Loss of tax benefit on existing capital	BEN · (1 - $e^{-ATR \cdot RTL}$)/ATR
LEC2	Loss of tax benefit on discounted existing capital in the future	DIS · BEN · (1 - $e^{-ATR \cdot TL}$)/ATR
*OCTL**	Loss of tax benefit from existing capital	-(LEC1 + LEC2)
*LTB**	1X depreciation of existing capital	(1-%NC) · RTL · BEN · ATR · LTC
CCLTF	CC levelization tax factor	LTB + (ATR · LTC · (PVD+OCTL))/(1 - EMRL)
AFB	Asset Factor for any new capital or asset	$\frac{1 - ATR \cdot L \cdot EMRL /(1 - EMRL)}{1 - EMRL}$
AAF	Average asset factor	%NC · AFB
LCC.B	Gross levelized 1-X CC, base	CCLF · CC.B
LCC.TB	Levelized 1-X CC tax effect, base	CCLTF · CC.B
LA.B	Levelized 1-X assets, base	AAF · CC.B
GLCC.N	Cost comparison factor for net present value calculations	
LCC.N	Gross levelized 1-X CC, new	(CCLF · CC.N) + GLCC.N
LCC.TN	Levelized 1-X CC tax effect, new	CCLTF · (CC.N + (GLCC.N/CCLF))
LA.N	Levelized 1-X assets, new	AAF · (CC.N + (GLCC.N/CCLF))

* Not a variable used in the model. Provided here for ease of exposition.

Because capital depreciates, its average value is lower than its initial value. In order to derive the factor *AAF*, by which the initial value should be multiplied to arrive at the average value, it is necessary to account for the exact path by which the capital depreciates. Since the value of a piece of capital is, at any time, simply the present value of its future income stream, the value of the depreciated capital as a function of time can be found from the stream of income that the capital will generate. If that stream has a constant flow for a period of *L* years, then the depreciated value of a unit of capital is:

$$\mathrm{DF(t)} = \frac{1-e^{-r(L-t)}}{1-e^{-rL}}$$

Now if that capital is held for a period of *L* years, it is logical to ask what the average value of the asset is over the *L* years. Because of discounting, a unit of capital now should weigh more heavily than a unit of capital later. This is properly taken into account by requiring the following equivalence:

$$\mathrm{PV(DF(t))} = \mathrm{PV(AAV)}$$

where *PV()* is the *L*-year present value operator, and *AAV* is the average asset value corresponding to *DF(t)*. This equation can be solved for *AAV*, to find the following:

$$\mathrm{AAV} = \frac{1}{1-e^{-rL}}\left[1-\frac{rL\ e^{-rL}}{1-e^{-rL}}\right]$$

This is the average asset factor for the productive income of any new capital or asset. In order to get the factor we want—the average asset factor for add-on capital—we must multiply *AAV* by the fraction of one-time capital that is add-on rather than replacement capital, *%NC*.

At the bottom of the One-Time Cost Amortization module are found the capital costs for the base and long-run levels, and its coefficient of variation. The three factors just derived, *CCLF*, *CCLTF*, and *AAF*, can be applied to *CC* (for either the base case or long-run case), to derive the amortized outputs *LCC*, *LCC.T* and *LA*, respectively.

C.2.3.9 The Long-Run Model Module

The Long-Run Model module is the heart of the LBNL-MAM. It does all of the computations concerning a typical firm's behavior. It proceeds in three stages. The calibration stage uses data on present costs and profit to estimate the firm's markup. The second stage estimates the industry's current situation. The third estimates a typical firm's situation with more stringent efficiency levels. A detailed discussion of the economic assumptions and results used by this section may be found in C.2.1.

Notation. The following naming conventions have been followed for the variables in the Long-Run Model module and generally throughout the LBNL-MAM. The suffixes .F and .Q, are used with variables that measure an asset or a cost that is fixed or proportional to sales, respectively.

The suffixes .B and .N refer to the base case and the alternative efficiency levels, respectively. A combined suffix such as .BF has the natural interpretation (i.e., a fixed variable in the base case). The most important variable names in the Long-Run Model module are *A* for assets, *TC* for total cost excluding taxes and the cost of equity, *EC* for economic cost (including taxes and equity), *EI* for economic income, and *mu*1 for markup above marginal cost, $\mu - 1$.

Calibration. The calibration stage estimates a typical firm's markup over unit variable costs using the following basic economic equation:

$$\text{Markup} = \frac{(\text{Fixed Cost} + \text{Economic Profit})}{\text{Variable Cost}}$$

(In this equation, fixed and variable cost are components of total cost and are not per-unit costs.) *Economic Profit* is the difference between ROE and the equity cost of capital, both of which are obtained by observation. *Fixed* and *Variable Costs* must be deduced from accounting data and from information on economies of scale in the industry.

Assets and costs in the calibration stage are both represented as proportions of revenue, so firm size is irrelevant. This means, for instance, that fixed and marginal costs are not given as dollars and dollars per unit, but instead, total fixed and total marginal costs are described as a fraction of revenue.

Depreciable assets are divided between fixed and marginal according to the input parameter *FCA*, the "fixed part of costs and assets." Cash and inventory and receivables are classified as proportional to revenue.

Now consider total costs (i.e., those that are tax-deductible). *FCA* is also used to determine the proportion of fixed (total) costs in revenues. All other costs are marginal, and their amount is deduced from the firm's rate of economic profit.

Because the costs so far are tax-deductible, but revenue is taxable, economic fixed costs are given by the following formula:

$$\text{EC.F} = (1 - \text{T}) \cdot \text{TC.F} + \text{A.F} \cdot \text{ER} \cdot \text{ECC}$$

where T is the tax rate, ER is the ratio of equity to assets, and ECC is the cost of assets. In principle, we could now estimate marginal economic cost (*EC.Q*) directly and use this value to finish our analysis. However, because costs cannot be measured accurately enough, there could be considerable error in the implied value of economic profit and thus in markup. (Typically a 5% error in total estimated cost will cause a 10% error in implied economic profit.) It is much better to deduce marginal economic cost from economic profit, because economic profit is relatively well-known. This approach gives us the equation for economic marginal cost:

$$EC.Q = 1 - EC.F - T - EP \cdot ER \cdot A{:}R$$

where *EP* is the rate of economic profit, and *A:R* is the ratio of total assets to revenue.

Now the markup is easily computed using the formula given at the beginning of this section on calibration and the model is ready to analyze the base level of alternative efficiency levels.

The base case. The base case is an analysis of what may happen in the current period. The variables in both the base case and the alternative efficiency level case give fixed costs and assets in dollars and variable costs in dollars per unit. Since most calibration case costs and assets are reported as a percent of revenue, those values are multiplied by revenue to get their base case counterparts.

Most base case variables are the same as the calibration case unless we are analyzing the impact of any possible interim efficiency levels. In that case, new variable costs due to the interim efficiency level are added into *TC.Q*, and levelized one-time assets are added into the total asset calculation. Economic costs are computed from *A* and *TC* as before, except for the addition of amortized capital costs (*LCC*), which are divided between fixed and variable according to the input parameter *F1X*.

In addition, an adjustment is made for the changing level of working capital as revenue changes. The following working capital corrections are calculated:

$$WCA.B = \text{Total working capital correction (assets)} = DVC.B \cdot Q \cdot IR{:}R$$

$$WCCEC.B = \text{Working capital correction (per unit EC)} = (WCA.B \cdot ATR)/Q$$

$$WCCI.B = \text{Total working capital correction (interest)} = WCA.B \cdot I$$

These corrections are added to the calculations for *A.B*, *EC.BQ*, and *TC.B*, respectively.

The alternative efficiency level case. For the case of changes in efficiency levels, new values of *dVC* (the change in variable cost), *LA*, and *LCC* are used. The formulas contain several terms not included in the base case calculations. These terms allow the model to converge when the industry net present value module is run (see Section C.2.6). When the industry net present value model is not being run, these terms are equal to zero.

The remaining descriptive variables. For the calibration case, most of the remaining descriptive variables, *Q, P, R, UVC, TC, A,* and *ROE* are known because they are inputs or have been computed. The others are obtained as follows:

$$\text{Variable Cost of Goods Sold} = VCGS = UVC \cdot Q$$

$$\text{Interest, Not 1X} = IC = I \cdot DR \cdot A - C{:}R \cdot R \cdot (I - ICash)$$

$$\text{Pre-interest Cost} = PIC = TC - IC$$

$$\text{Pre-tax Cost} = PTC = TC$$

$$\text{Taxes} = TAX = (R - TC) \cdot T$$

$$\text{Equity} = EQ = ER \cdot A$$

$$\text{Economic Income} = EI = NI - ER \cdot A \cdot ECC \quad \text{and}$$

$$\text{Net Income} = NI = R - TC - TAX$$

For the base case the above formulas hold with the exception of the one for *NI*, but several other descriptive variables must be computed. Their formulas follow:

$$Q.B = QRO.B^{1/ro} = ae \cdot Xro + be \cdot (\text{life cycle cost})^{ro}$$

$$P.B = \frac{(\mu 1 + 1) \cdot EC.BQ}{(1 - T)}$$

$$R.B = Q.B \cdot P.B$$

$$UVC.B = UVC + DVC.B$$

$$VCGS.B = UVC.B \cdot Q.B$$

$$\text{1X depreciation} = X1D.B = \frac{CC.B}{L}$$

$$\text{1X interest} = X1I.B = LA.B \cdot DR \cdot I \cdot LTC$$

$$\text{1X equity cost} = X1E.B = LA.B \cdot ER \cdot ECC$$

$$\text{1X tax benefit} = X1T.B = LCC.TB$$

$$IC.B = I \cdot DR \cdot (A.B - LA.B) - C{:}R \cdot R.B \cdot (1 - ICASH)$$

$$PIC.B = TC.B + X1D.B - IC.B$$

$$PTC = TC.B + LCC.B$$

$$TAX.B = (R.B - TC.B) \cdot T - X1T.B$$

$$NI.B = R.B - PTC.B - TAX.B$$

$$EI.B = NI.B - ER \cdot (A.B - LA.B) \cdot ECC - X1E.B$$

$$EQ.B = ER \cdot A.B$$

$$ROE.B = ECC + \frac{EI.B}{EQ.B}$$

Q.B is calculated from the life-cycle cost using a constant elasticity of substitution (CES) demand function. *Xro* is a linear term calculated from the calibration case, and *ae* and *be* are parameters. The descriptive variables for the changed efficiency level (long-run) case are computed in exactly the same way as the corresponding variables in the base case, with the exception of TAX.N, which includes a convergence factor for the industry net present value calculations (see Section C.2.6.)

C.2.3.10 The Short-Run Model Module

During a recession an appliance manufacturing industry will typically face a substantial decline in demand for its product, which will usually cause increased price competition within the industry, with a consequent fall in price. By regressing price on quantity sold and on a time trend, we can estimate the industry's "short-run price response to demand" *(SRPR).* The LBNL-MAM uses this variable as an input to the Short-Run Model module. From *SRPR*, the short-run impact calculation proceeds as follows. Assume for explanatory purposes that demand has fallen because of the change in efficiency levels. From *SRPR* compute the implied fall in price resulting from this unexpected drop in demand. At this new price level, compute a new level of demand that will necessarily be a little higher at the new lower price than at the previous higher price. Now take the new estimate of the level of (and change in) demand resulting from new efficiency levels and repeat the calculations. After five or fewer repetitions of these calculations, our estimates will converge to a stable answer. At this point, the price correction exactly agrees with the estimated fall in demand, and the estimated demand agrees with the price. At no other values of price and quantity would this be true.

Once price and quantity are known, all other variables are easily computed using procedures that have already been described.

C.2.3.11 Sensitivity Charts Module

This module produces a chart which shows how profit is affected by a one-standard deviation change in each of the Control Panel variables. These changes are all made with the alterantive efficiency level set to its middle value.

C.2.3.12 Engineering-to-Standards Cost Conversion Module

This module weights the costs given by the engineering analysis for each design option in proportion to the number of appliances of a particular design that will be produced at any given efficiency level and thereby generates the costs for that level. These costs appear in the Standards Level Module.

C.2.3.13 Industry Net Present Value Module

The LBNL-MAM includes the current version of the Government Regulatory Impact Model (GRIM Ver. 1.2) to calculate the impact of alternative efficiency levels on industry net present values. The integration of this externally developed model into the LBNL-MAM required the resolution of a number of issues. These are covered in more detail in Section C.2.6.

C.2.4 Model Inputs

C.2.4.1 Input Generating Assumptions

Many of the necessary input data are not publicly available and so have been estimated from available data or estimated from averages of subjective estimates made by industry representatives. This section describes the various origins of LBNL-MAM's data.

Cost data. All cost data are provided by the Engineering Analysis.

Elasticities and discount rates: Industry price elasticity and consumer discount rates are supplied by the LBNL-REM.

Financial data. Financial data are collected from publicly available sources such as Value Line, Standard and Poor's, Moody's, and company reports. The data are often for firms whose operations in the industry under consideration are only part of the firm's total business operations. It is assumed that the relevant division is similar to the firm as a whole.

Amortization data. New capital has a seven-year amortization lifetime. Values relating to such issues as taxation are displayed in the spreadsheet and are generally derived from historical discussions with industry representatives. The timing of capital costs come from the Engineering Analysis.

Fixed and marginal costs and assets. Some costs increase in proportion to shipments, and some are fixed. Industry representatives indicate that the bulk of costs and assets are proportional to shipments. The specific values are shown in the Control Panel.

The following sections list and describe the inputs used by the model.

C.2.4.2 Control Factors in the Control Panel

Industry price elasticity. Industry price elasticity measures the way a change in the average industry price for a product will affect the industry's shipments. For example, if the price of a product increases 4% and shipments drop 2% as a result, the price elasticity is -0.5. Because imposed efficiency levels will cause the prices of products to increase, this input is obviously crucial in determining the impact of new efficiency levels on manufacturers.

Consumer discount rate. The consumer market discount rate is a measure of how much consumers value future operating cost savings from energy-efficient design options. Because new efficiency levels mandate more efficient products that will have lower operating costs, this input will affect consumer demand and is therefore important in determining the impact of new efficiency levels on manufacturers.

Equity cost of capital. This is the rate of return expected by equity shareholders. This figure is in real terms (i.e., with inflation subtracted). It is an after-tax rate, which means that it is the rate of return the company must earn for its shareholders after its taxes have been accounted for. Data values come from calculations using standard finance equations and public financial data.

Economic profit. Economic profit is the profit earned by a firm above its expected return on equity. In other words, it is the profit earned after all costs are taken into account, including the cost of equity (the market rate of return). A firm makes economic profit only when it has some degree of market power.

Long-run fixed part of costs and assets. This figure is the portion of all costs and assets that is fixed over time, that is, which does not vary with quantity sold or with revenue. It is expressed as a percent of the base case costs and assets. From an economic standpoint, this figure is important for determining the impact of new efficiency levels on manufacturers.

Long-run fixed part of one-time capital cost. This figure is the portion of one-time capital costs that is fixed in the long run. Although all capital costs are normally considered fixed in the short run, this portion of the capital costs is spent regardless of the output capacity of the tooling purchased. The other portion of one-time capital costs varies proportionally with the output capacity of the new equipment.

One-time capital costs. Some of the design options used to meet the increased efficiencies mandated by the alternative efficiency levels require additional capital investment in the form of retooling, new equipment, or other capital expenditures. The "one-time capital costs" figure represents the capital costs expended to meet a specific efficiency level being analyzed; this number covers all products in a product type and is an input from the Engineering Inputs module.

Unit variable cost increase. This number is the shipment-weighted average increase in unit variable costs incurred by the manufacturer in meeting new efficiency levels. The incremental variable cost includes raw materials, direct labor, purchased parts, and increased transportation costs. This number is an input from the Costs, Sales, and Revenues module.

Elasticity Curve Parameter. This parameter of the CES demand function determines the shape of the demand curve. Changing the value of *ro* permits specifications other than constant demand elasticity (*ro* = 0.)

Short-run price response to demand (SRPR). When industry demand falls by *Y%*, price will, in the short run, fall by *SRPR* · *Y%*. This response is expected to die out within a few years, and *Y%* should be less than 20% when *SRPR* is used.

C.2.4.3 Engineering Data

Incremental unit variable cost. The incremental unit variable costs are the variable costs associated with design options that increase a product's energy efficiency. This input differs from the variable cost increase input for the Control Panel (Section C.2.3.1) in that it lists incremental variable costs for each design option for each product class of the product type being analyzed, rather than a single shipments-weighted average number. The increased variable cost includes costs such as raw materials, direct labor, purchased parts, and increased transportation costs. The data also come in the form of a table that lists the incremental variable cost for each product class for each of the efficiency levels being analyzed.

Maintenance Cost. This data comes in the form of a table which lists annual maintenance costs for each product class at each engineering design option. Maintenance costs are measured in dollars per year.

Unit energy consumption (UEC). Unit energy consumption is the annual energy cost (in dollars) of a product. The input data come in the form of a table that lists the UEC for each product class for each design option (and alternative efficiency level) being analyzed.

Installation costs. The cost (in dollars) of installing each product class for each design level is provided in tabular form. Installation costs are incurred by the purchaser at the time of purchase and are part of the life-cycle cost of the product.

Capital costs. Some of the design options used to meet the increased efficiencies mandated by the alternative efficiency levels require additional capital investment in the form of retooling, new equipment, or other capital expenditures. This input is given as a table listing the cost associated with each design option that requires a capital expenditure. The input is also given in a table listing the total capital expenditure for the design options used to reach each of the various efficiency levels being analyzed. The capital cost input covers all product classes within a product type, unless noted otherwise. The one-time capital costs resulting from imposed efficiency levels generally vary with the size of the manufacturer. If more than one size of manufacturer is being analyzed for a product type, then input data for all sizes being analyzed are included.

C.2.4.4 Costs, Sales, and Revenues

Industry shipments. Industry shipments are annual shipments for all classes of the product type being analyzed. These inputs are actual data for a calibration and base case and long-run estimates for each of the alternative efficiency levels being analyzed. The long-run shipments estimates are based on projected product price increases and product price elasticities and market discount rates which are based on forecasts provided by the LBNL-REM.

Product class market shares. Each of the classes within a product type has a "market share" of the shipments for that product type. For example, coil element electric cooktops comprise about half of all cooktop shipments. The product class market share combined with the total industry shipments give a breakdown of annual shipments by product class.

Manufacturer market share. Each of the prototypical firms in the analysis is assigned a market share appropriate to that segment of the industry. For example, five large room air conditioner manufacturers may each be assigned a 20% market share. The manufacturer market share, combined with the total industry shipments, gives a firm's annual shipments. This figure, combined with the product class market shares, gives a typical firm's annual shipments for each product class.

Markups. The markup is the figure used by the manufacturer to determine the firm's selling price for a particular product. It is an increase over the unit variable cost of that product, and it covers overhead, capital costs, and profit. In some industries, manufacturers use different markups on different product classes. The markup input lists the markup used for each class in the product type being analyzed.

Initial prices. This input is the baseline manufacturer's selling price per unit for each product class. Added to the baseline unit price are the incremental costs of reaching the higher efficiency levels required by meeting new implemented efficiency levels.

Energy price. This figure is the price ratio of a 1992 kWh to a 1998 kWh taken from the LBNL-REM; energy price is used to calculate the change in operating cost from the calibration case to the base case (*OC%.B*) and to the alternative efficiency level case (*OC%.N*).

C.2.4.5 Financial Inputs

Rates of financial costs:

After-tax equity cost of capital. This input is explained in Section C.2.3.1, Control Panel.

Interest rate on debt. This is the interest rate paid by a corporation on its debt. This figure is in real terms (i.e., with inflation subtracted), and is the yield of corporate bonds with a Moody's rating comparable to ratings in the industry being analyzed.

Interest lost on cash. Companies hold a portion of their current assets in the form of cash in bank accounts, marketable securities, and other liquid holdings, all lumped under the term "cash." This category of assets has a cost associated with it because of the cost of the debt and equity associated with all assets. However, companies manage their cash accounts very well and are able to earn interest each day on the cash they are not using that day. The interest earned on the cash accounts tends to be low, since the investment is only overnight and varies from day to day. The interest earned is lower than the cost of the capital used to form the asset. Thus, the cash account costs the company money but the cost is lower than for any of the company's other assets.

Rate of depreciation. This figure is the rate of depreciation on fixed assets for a typical firm in the industry. It is obtained by assuming straight-line depreciation and an average tax life of eight years for the firm's fixed assets. It is then revised by analyzing actual depreciation data from the industry under consideration.

Tax rate. This rate is the average tax rate faced by an industry in 1996. It is based on past data and recent revisions to the tax law.

Assets and costs as a percent of revenue:

Cash. Companies hold a portion of their current assets in the form of cash in bank accounts, marketable securities, and other liquid holdings, all lumped under the term "cash." In the model, this input is expressed as a percent of total revenue.

Inventory and receivables. This figure represents the inventory and receivables assets, expressed as a percent of total revenue. Inventory includes raw materials owned by the company, work in process, and finished goods that have not yet been shipped. Receivables refers to goods that have already been sold and shipped by the firm for which the firm has not yet been paid, but is instead owed money.

Depreciable assets. This figure represents the net depreciable, or fixed, assets of the firm, expressed as a percent of revenue. Depreciable assets are tooling, equipment, production facilities, and other goods that have an original lifetime of longer than one year and thus are depreciated over several years rather than expensed in one year.

General and administrative expenses (G&A). This figure represents the general and administrative and selling expenses for the firm, expressed as a percent of revenue. It is the "overhead" of the company.

Fixed and variable costs:

Fixed part of all costs and depreciable assets. This input is explained in the Control Panel section of C.2.3.1.

Fixed part of one-time capital cost. This input is explained in the Control Panel section of C.2.3.1.

Other financial inputs:

Economic profit. This input is explained in the Control Panel section of C.2.3.1.

Debt-to-equity ratio. All of a firm's assets are paid for either by debt or by equity. The debt-to-equity ratio is used in calculating a firm's weighted average cost of capital. It is also associated with the risk factor of the firm and affects how much money a firm is able to borrow and at what interest rate, so it is important in the analysis of the impacts of new efficiency levels.

Markup on a typical model. This figure is the markup used by a firm in determining the manufacturer's selling price. It is the markup used on the unit variable cost of a typical product in the industry being analyzed.

Ratio of highest to lowest markup. In some industries, manufacturers use different markups on different product classes. If such a situation exists in the industry being analyzed, this ratio indicates the range of markups used.

Costs and assets of one-time investment:

One-time capital cost's life. This input is the productive life of the equipment purchased to meet the imposed efficiency levels, expressed in years. The number is also used as the period of time over which the one-time costs induced by imposed efficienc levels are amortized.

One-time capital cost's tax life. This input is the tax life of the equipment purchased to meet the imposed efficiency levels, expressed in years.

Percent additional one-time capital. Meeting new efficiency levels may require both the addition of new capital that replaces nothing, and the replacement of old capital that has become inadequate. This variable tells what percent of new capital is additional rather than for replacement.

Age of old (replaced) capital. This input gives the age, in years, of the old capital that gets replaced because of the new efficiency levels. Under new efficiency levels, some old equipment will get scrapped before the end of its productive life and replaced by new equipment. Depending on the age of the replaced capital, tax and/or economic consequences are factored into the calculations of the cost of the new equipment.

One-time capital cost schedule. The one-time capital cost schedules list the costs incurred over time for preparations to meet the imposed efficiency levels. A percentage of the total cost is attributed to each year before the new efficiency levels go into effect, because that is when these expenses will occur. These cost schedules allow the model to be more accurate in calculating the present value of the amortized costs, rather than assuming that the costs all occur when the new efficiency levels go into effect.

C.2.5 Model Outputs

C.2.5.1 Control Panel Outputs

The Control Panel outputs are the summary outputs of the model. This output section enables the reader or model user to see at a glance the main short-run and long-run impacts of alternative efficiency levels on a few key variables: shipments, price, revenue, net income, and return on equity.

For each of the five variables listed above, the Control Panel output table lists the base case number, the new long-run number, and the percentage change between the two. The table also lists the percentage changes for these variables from the most recent previous run for comparison purposes. The last column in the output table lists the short-run results for each of the variables.

The base case values refer to the current state of the industry. The long-run numbers are the model's estimates for these variables when alterantive efficiency levels are implemented and after manufacturers have had time to adjust to the changes and find new optimal selling prices and production quantities. The short-run numbers are the model's estimates of impacts on manufacturers in the short run, before they have time to find a new optimum.

Shipments. Shipments are the total units sold by a prototypical firm in a given year, expressed in millions of units. The shipments variable is the sum of shipments for all product classes within a product type. Shipments data are calculated on the Costs, Sales, and Revenues page.

Price. Price is the shipments-weighted average of the manufacturer's selling prices for the different classes within the product type being analyzed. Price data are calculated on the Costs, Sales, and Revenues page.

Revenue. Revenue is the amount of money received by the manufacturer for the products it has sold. It is the sum of the revenue for each of the product classes being sold by the manufacturer and it is expressed in millions of dollars. It can also be calculated by multiplying the annual shipments times the shipments-weighted average price. Revenue data are calculated on the Costs, Sales, and Revenues page.

Net income. Net income is the after-tax profit made by the company, expressed in millions of dollars. Net income and the associated return-on-equity are primary measures of a company's financial performance. In LBNL-MAM, net income is calculated in the Accounting Summary.

Return on equity (ROE). Net income is a dollar amount that varies in part simply because of a firm's size, and ROE adjusts for different-sized companies by giving net income as a proportion of stockholders' equity. It is the return an investor makes on his investment in the stock of a particular company. ROE is calculated in the Accounting Summary.

C.2.5.2 Accounting Summary Outputs

Net income. See the Control Panel section above for a description of net income. In the Accounting Summary, net income is expressed in thousands of dollars rather than millions.

Gross margin. Gross margin shows, on a percentage basis, how much revenue remains after the variable cost of goods sold is accounted for: $GM = (R - VCGS)/R$.

Return on sales. Return on sales is net income as a percentage of revenue.

Total assets. Total assets is the sum of all of the prototypical firm's assets. This includes cash, inventory, and receivables; depreciable assets; and in the case of alternative efficiency levels, the one-time assets acquired to meet the new efficiency levels.

Return on assets. Return on assets is the total return on the debt and equity portions of a firm's assets. It is a measure of how productively a firm's assets are being used. The interest paid on debt instruments and the net income that belongs to equity shareholders are the returns on the firm's assets. The returns are divided by the total assets of the firm to calculate return on assets.

Equity. Equity is the portion of a firm's assets owned by the stockholders of the firm. It is the difference between a firm's assets and its liabilities. In this model it is calculated by multiplying the equity percentage obtained from the debt-to-equity ratio times the total assets figure.

Return on equity (ROE). See the Control Panel section above for a description of ROE.

C.2.5.3 Economic Analysis Outputs

The economic analysis outputs give a clear and concise picture of what is going on in the company from an economic standpoint. Most of the outputs show up in the other two outputs sections. Shipments, price, and revenue are discussed in the Control Panel section. The total assets number is calculated in the Accounting Summary section, and the economic analysis output breaks down total assets into three categories: cash, inventories, and depreciable assets. Expenses are looked at from an economic point of view rather than an accounting one. Thus expenses are broken down into fixed expenses and expenses that vary with the quantity produced.

C.2.5.4 Monte Carlo Outputs

The Monte Carlo Outputs section lists the results of six key measures of impact when the Monte Carlo option is used. For key input variables, the Monte Carlo option randomly generates values around the best available estimates of their true values. As a result, the outputs vary from run to run, and the model can calculate means and standard deviations for the key measures of impact. It is then possible to bound the estimates of impacts and attribute a degree of certainty to them.

The Monte Carlo Outputs section is a table that lists for each variable the value of the current iteration, the mean of all the iterations done in the current run, and the standard deviation of the results. It then lists in chronological order the results of all the iterations done in the current run.

The measures of impacts are percentage change in shipments, percentage change in price, percentage change in revenue, change in net income, and percentage point change in ROE for both the long-run analysis and the short-run analysis. See the Control Panel section (Section C.2.3.1) for a more complete description of each of these outputs.

C.2.5.5 Retail Price Calculation

One important role of LBNL-MAM is to provide estimates of retail prices of appliances at different efficiency levels for the LBNL-REM and the Life-Cycle Cost analysis. The primary input for the retail price calculation in LBNL-MAM is MAM's estimates of manufacturer prices. The manufacturer prices are derived from base manufacturer costs, engineering production costs, and appropriate manufacturer markups for each product. The base manufacturer cost is derived from current retail price data for appropriate product classes. These prices are divided by both the retail markup for the product and the wholesale (manufacturer) markup. This calculation is described in more detail in the description of the Costs, Sales, and Revenue module (Section C.2.3.6).

The model generates a matrix of manufacturers' selling prices for each product class at each efficiency level. These manufacturers prices are then multiplied by an estimate of the manufacturer-to-retail markup appropriate for the product class. This gives the estimated retail price.

C.2.6 Development and Integration of the Industry NPV Module

During 1991-1993, three industry trade associations[7] contracted with the Arthur D. Little consulting firm to develop a model that presents industry impacts using industry net present value (NPV) as an impact variable. Their model was named the Government Regulatory Impact Model (GRIM). The latest version of this model is Version 1.2 and was released in April 1993. Since NPV is theoretically identical to ROE as an impact measure, the U.S. Department of Energy decided to include the GRIM as part of the analysis. Hence the entire GRIM Version 1.2 model is integrated into the LBNL-MAM.

As a result, if the reader were to use the cost, price, and shipments inputs that were used in the LBNL-MAM for input to a standalone version of GRIM, they will obtain the same answer. There has been no modification of the GRIM's functionality as part of the integration.

C.2.6.1 The Integration and Cost Iteration Process

The integration of GRIM presented three major issues: They were:

- The GRIM model's programming did calculate the net cash flows well, however there is no price-estimation algorithm (i.e., there is no mechanism to forecast price). The model assumes that price and shipments inputs be supplied from some external forecasting source.

- The GRIM has a cost analysis structure such that it uses annual costs and revenues to compute annual cash flows and then calculates a net present value of the industry based on those cash flows. On the other hand, while the LBNL-MAM recognizes different costs in different years for its demand function and price-formation algorithm, it "levelizes" these costs before it calculates price and quantity. Hence in integrating the two models, the costs in the two approaches need to be converted such that both approaches recognize the same costs.

- There are several categories of costs that GRIM calculates as fixed ratios of revenues. Hence there are several categories of costs that are higher in GRIM than in the LBNL-MAM.

In the absence of an alternate solution, the lack of a price-formation algorithm in GRIM was addressed by using the demand function and price formation algorithm that was developed in the LBNL-MAM. This entailed the following:

---

[7] The Association of Home Appliance Manufacturers, Gas Appliance Manufacturers Association, and Air-conditioning and Refrigeration Institute.

i. Since the cost structure of GRIM is different from that of LBNL-MAM, the costs for both modules need to be translated into the same basis. As a result, a "cost levelization" methodology was developed to translate the format of the GRIM-style costs into MAM-style costs. (There is no change in the amount of costs, just how the costs are represented as necessary for input to the cost analyses of the two modules.)

ii. In the absence of GRIM-style cost inputs from the industry, we take the baseline per-unit cost inputs of materials, labor, and overhead costs, along with baseline per-unit price and shipments (supplied by the Engineering Analysis), and constructed a GRIM cost input table. These same basic cost inputs are also used in the LBNL-MAM.

iii. Using this cost input table, the LBNL-MAM is run to estimate price and shipments for the alternative efficiency level case.

iv. The price and shipments estimated by LBNL-MAM are then input to the GRIM module, and the GRIM module is run to generate its results. Because several of the cost assumptions in the GRIM module are proportional to revenue, the costs for several major cost categories (i.e., variable cost of goods sold, capital costs, working capital, and selling and general administration costs) will change from the original inputs.

v. The LBNL-MAM then compares the costs used in MAM that supplied the inputs to the GRIM module and the resulting costs from the GRIM module. These differences are incorporated back into the LBNL-MAM costs via "cost comparison factors" (defined below). The LBNL-MAM is then run again to generate new price and shipments estimates based on these revised costs.

vi. This iterative process is repeated until the cost differences between the major cost categories used in the GRIM module and that of the LBNL-MAM run that generated the inputs is equal to zero.

vii. After convergence has been obtained, the final industry net present value results from the GRIM module are reported.

The data flows and linkages between the LBNL-MAM, the GRIM module, and the cost comparison factors used to link the modules are illustrated in Figures C.3 and C.4.

Cost Comparison Factors

Since the cost structure in the LBNL-MAM and GRIM modules may differ due to the differing assumptions in the two models, cost comparison factors are used in the integration of the two models to properly align and adjust their costs. For instance, if the GRIM assumptions resulted in a lower capital maintenance expense, the initial GRIM cost assumption would be adjusted by a cost comparison factor.

In this section, we discuss each of the Comparison Factors in the MAM Long-Run page that are used for the adjustment of MAM and GRIM, why they are needed, and how they are implemented in the model.

Levelized Capital Costs (LCC):

GRIM's assumptions of the level of capital maintenance expense is higher than MAM's. Hence an initial adjustment is needed to align the costs between the two approaches. Further, GRIM's level of capital expenditure is a fixed percentage of revenues, hence when quantity changes (e.g., when other cost adjustments are made), *LCC* will change.

MAM already computes per unit levelized capital costs for alternative efficiency levels (*LCC.N*) in the model. Hence we create a new variable, *GLCC.N*, which is the per unit difference between MAM and GRIM, which we add to *LCC.N*. Further, we need to take *GLCC.N* into account for tax effects and new assets. Since *LCC.TN* and *LA.N* (the tax effects of one-time capital cost and assets due to one-time capital costs, respectively) are obtained by applying levelization factors to *CC.N* (unlevelized capital costs), the adjustment to these variables is made by “unlevelizing” the cost comparison factor *GLCC.N* and adding it to *CC.N* before the appropriate levelization factor is applied.

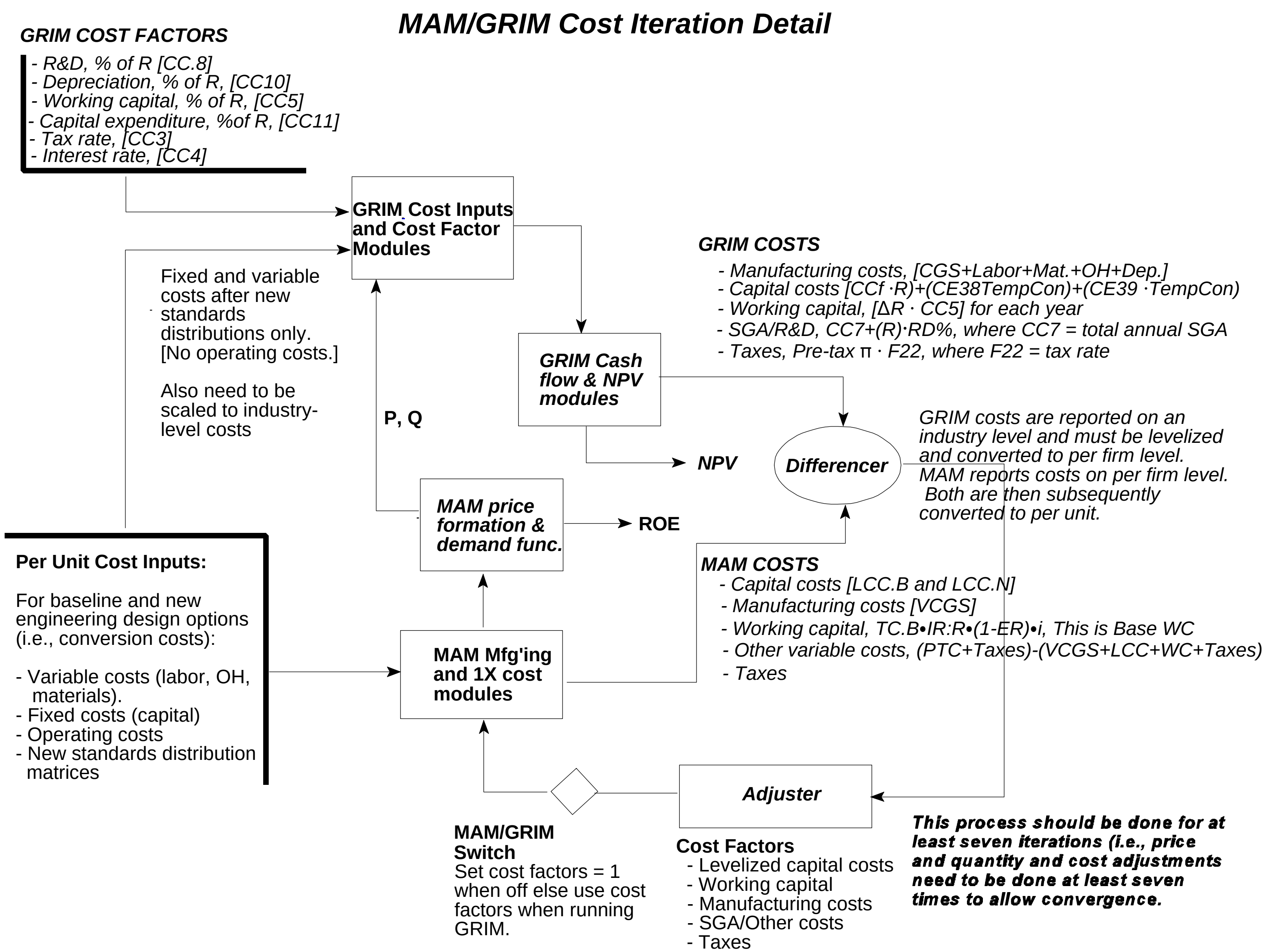


Figure C.3 LBNL-MAM and GRIM Integration Overview

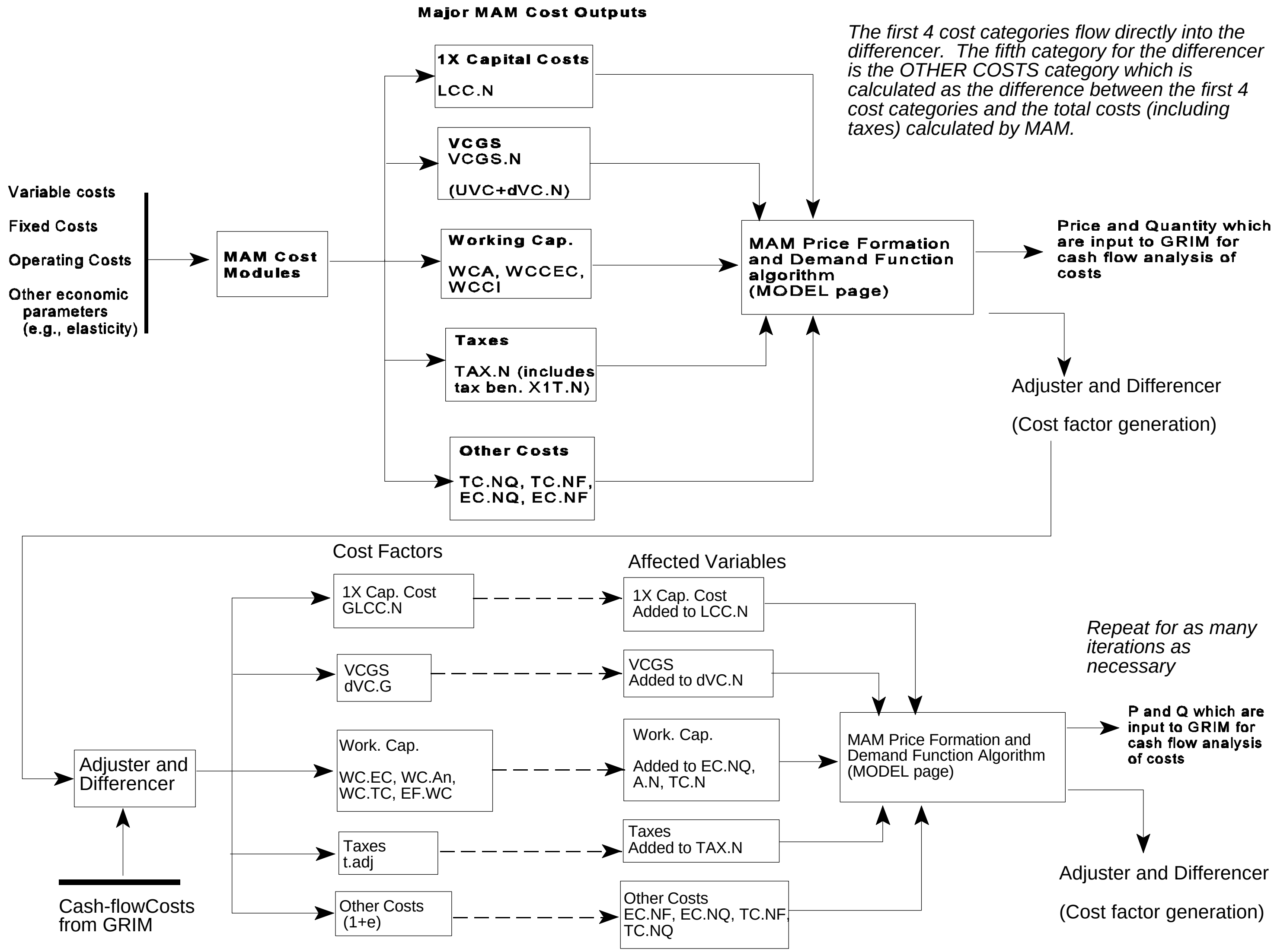


Figure C.4 Cost Comparison Factors and Their Relationships

Manufacturing Costs:

Manufacturing costs are the sum of materials, labor, and overhead costs. In MAM, this is the Variable Cost of Goods Sold (*VCGS.N*) variable. In GRIM, it is the same three cost inputs, but it also includes depreciation. However in GRIM, depreciation is only included for the purpose of tax calculation and it is netted out later in the cash flow calculation. Since it plays no role in the NPV calculation (aside from taxes), we do not include it in the Manufacturing Costs calculation.

The baseline per unit costs of materials, labor, and overhead are inputs into the models. But in the case after new efficiency levels have been implemented, the GRIM Overhead cost component has a portion that varies with shipments.[8] Since shipments will vary when other adjustments are made, overhead costs and consequently manufacturing costs, will change.

In MAM, the per unit cost of alternative efficiency levels is calculated in the change in variable cost variable, *dVC.N0*. Hence we created a new variable, *dVC.G*, where we input the per unit difference in manufacturing costs which is added to *dVC.N0*.

Working Capital:

In GRIM, working capital is a fixed percentage of revenues. Since revenues are likely to change as a result of other cost adjustments, an adjustment for working capital is needed. Hence we define a variable, *WC.EC*, which is the sum of the per unit differences in working capital costs from each iteration. The model adds *WC.EC* to the variable part of economic costs, *EC.NQ*.

Next the total difference in working capital assets is calculated as:

$$WC.AN = \frac{WC.EC_i \cdot Q_{io}}{ATR}$$

[8] The GRIM Overhead formula is $OH = OH_b + (OH_f \cdot Q.N)$, where OH_b is the baseline Overhead cost, OH_f is the per unit difference between Overhead costs in the pre- and post-efficiency level case, and *Q.N* is shipments in the post-efficiency level case.

where $(WC.EC_i \cdot Q_{io})$ is the sum of each per unit difference times the $Q.N$ from that respective iteration. ATR is the after-tax weighted cost of capital. $WC.AN$ is then added to new efficiency level assets, $A.N$.

The total "accounting" cost of working capital is:

$$WC.TC = WC.AN \cdot (1 - ER) \cdot i$$

where ER is the equity ratio and i is the interest rate. However, as we mentioned earlier, to facilitate convergence with GRIM, we assume $(1 - ER) = 1$. $WC.TC$ is added to total costs in the alternative efficiency level case, $TC.N$.

Finally, from an accounting cost standpoint, $WC.TC$ will probably be less than total cost of working capital. Hence to facilitate convergence, we define one more "extra factor" variable:

$$EF.NC = (WC.AN \cdot ATR) - WC.TC$$

where $(WC.AN \cdot ATR)$ is the total costs of working capital and $WC.TC$ is the accounting portion recognized earlier. $EF.NC$ is also added to $TC.N$.

Adjustment for Other Variable Costs (MAM) and SGA/R&D (GRIM):

MAM contains Other Variable Costs which are the variable portion of fixed costs such as capital costs.[9] GRIM also contains explicit variable costs for selling and general administration expense and research and development. These GRIM costs are a fixed percentage of revenue and thus are variable costs also. Since they are both relatively close in size, both are variable costs, and both are cost categories which are not in the other model, we align these two costs.

Some iteration will be necessary because the GRIM costs are a proportion of revenue. And so as other cost adjustments are made, revenue will change and hence these costs will change.

When we align these costs, we want to affect both the accounting and the economic costs. The accounting costs are defined as:

$$TC.N = TC.NF + (TC.NQ) \cdot Q.N$$

[9] This is because in MAM, even fixed costs such as capital costs are considered to have a variable portion in the long run.

where $TC.N$ is total costs in the alternative efficiency level case, $TC.NF$ is the total fixed part of costs, $TC.NQ$ is the per unit variable part of costs, and $Q.N$ is shipments. These accounting costs are important in the determination of financial variables such as Net Income, Taxes, and ROE.

Economic costs are defined as:

$$EC.N = EC.NF + (EC.NQ \cdot Q.N)$$

where $EC.N$ is total economic costs, $EC.NF$ is the total fixed part of economic costs, $EC.NQ$ is the per unit variable part of economic costs, and $Q.N$ is shipments. Economic costs are important for the determination of price.

Since the MAM Long-Run page calculates fixed and variable costs separately and the cost components are used as inputs to other areas of the models, we define a factor, *e*, which will be applied to each of the cost components. Hence we will have:

$TC.NF \cdot (1 + e)$, $TC.NQ \cdot (1 + e)$, $EC.NF \cdot (1 + e)$, $EC.NQ \cdot (1 + e)$

Generally, the MAM Other Variable Costs need to be scaled up to align with the GRIM *SGA/R&D* costs.

We can derive a formula as follows. We want to find a formula for a factor that does the following:

$$OTHER_{mam} + TC.N \cdot (e) = SGA_{grim}$$

where $OTHER_{mam}$ is MAM Other Variable Costs, $TC.N$ is total costs, e is the adjustment factor, and SGA_{grim} is GRIM *SGA/R&D* costs.

Solving for e, we have:

$$e = \frac{SGA_{grim} - OTHER_{mam}}{TC.N}$$

Thus, in the model, we input the per unit values for SGA_{grim}, $OTHER_{mam}$, and $TC.N$. We scale each of the per unit values to firm values by multiplying by $Q.N$ and then calculating e. (For successive iterations, e is the sum of the individual calculations.)

Cost Levelization

Most costs in the GRIM are annualized costs and are thus in the same format as those of the LBNL-MAM. However, there are two types of costs which will differ from year to year. These are:

- *Conversion costs:* In GRIM, conversion costs are broken into two types: design costs and capital costs, which are incurred in the three years leading up to new efficiency levels in the *SGA* and Capital Expenditure categories, respectively.

- *Working capital:* Working capital is incurred as a one-time cost when there is a change in revenue as in the first year of new efficiency levels when price and quantity changes.

To convert these "one-times" costs into continuous, annualized costs, we "levelize" them via the following procedures:

I. If they are alternative efficiency level costs incurred in years prior to new efficiency levels, future value them to the first year that new efficiency levels take affect. This may be accomplished by the following formula where the total future value C_o is:

$$C_o = \sum C_{t-n} \cdot (1+r)^n$$

II. To derive the formula for levelized costs (L) from the future valued costs (C_o), we perform the following:

$$\sum_{n=0}^{\infty} \frac{L}{(1+r)^n} = C_o$$

$$L + \frac{L}{1+r} + \ldots = C_o$$

$$C_o \simeq L + \frac{L}{1+r} + \ldots = (C_o - L) \cdot 1 + r$$

$$\frac{C_o}{1+r} = C_o - L$$

$$L = C_o - \frac{C_o}{1+r} = \frac{C_o(1+r) - C_o}{1+r} = \frac{r}{1+r} C_o$$

choice (market share) elasticity (E_{ms}):

$$E = E_u + E_e + E_{ms} \qquad \textbf{(B.2)}$$

B.1.2 Housing

The model performs calculations for three house types, (i) single-family homes, (ii) multi-family homes, and (iii) mobile homes. Inputs for housing information includes annual projections of occupied households and housing starts.

B.1.2.1 Occupied Households

The number and type of occupied households for the base year (1980) are from the 0.1% Public Use MicroSample (PUMS) of the 1980 Decennial Census. Projection of occupied households by house type from 1992 to 2010 is obtained from DOE/EIA's *Annual Energy Outlook 1995* (1). The stock of households is interpolated in years 1981 to 1991. Household figures after 2010 are obtained by assuming constant annual decay rates of 0.5%, 1%, and 3.9% for single-family, multi-family, and mobile homes, respectively, and adding housing starts (see B.1.2.2) to the surviving housing stock.

B.1.2.2 Housing Starts

Figures for past (1980-1989) housing starts by house type come from the Bureau of Census' *Housing Starts* (2). Projections (1990-2010) come from the *Annual Energy Outlook 1995*. Housing starts in later years (2011-2030) are extrapolated using the projected annual growth rates from 2000 to 2010.

B.1.3 Building Shell Thermal Integrity

The equation used in the LBNL-REM to represent the thermal performance/cost tradeoff for structures is:

$$\frac{TIN}{TIN_O} = \frac{TINF}{TIN_O} + \left[\frac{TBETA}{TBETA+C}\right]^{TALFA} \left[1 - \frac{TINF}{TIN_O}\right] \qquad \textbf{(B.3)}$$

where *TIN* is the thermal performance (relative heating energy normalized to 1980 existing houses); *C* is the change in the initial cost of the structure due to the change in *TIN*; and *TINF*, *TALFA*, and *TBETA* are parameters.

Table B.1 shows values of the parameters $TINF/TIN_0$, *TALFA*, and *TBETA*.

Table B.1 Parameters of Thermal Integrity/Cost Curves by House Type

	$TINF/TIN_0$	TALFA	TBETA
Single-Family	0.25	11.14	26717
Multi-Family	0.24	6.87	6067
Mobile Homes	0.34	7.56	9931

The thermal integrity factor (*TI*) is the relative energy consumption corresponding to a set of building shell characteristics (e.g., ceiling insulation, floor insulation, glazing, floor insulation, infiltration rate), associated with an incremental cost (*C*). For space heating, it is calculated from the relationship each year to minimize the life-cycle cost, given current energy prices, using a discount rate consistent with historical market tradeoffs. The thermal integrity factor for air conditioning depends on, and differs from, the thermal integrity factor for heating.

Thermal integrity is largely irrelevant in the analysis of ranges and ovens. The only interaction between energy consumption of these products and the building shell characteristics is through internal loads generated by these products. Those internal loads interact with space-conditioning requirements.

B.1.4 Equipment Efficiency

The LBNL-REM projects the average efficiency or unit energy consumption for a new unit purchased in each future year. The method involves characterization of historical market behavior, in the form of market discount rate. The observed average efficiency of the unit purchased is characterized as a function of the range of designs available from manufacturers, equipment prices (set by manufacturers and distributors), current residential fuel prices, and trade-off decisions made by purchasers (including homebuilders, contractors, landlords, and homeowners). The range of available designs and their prices are from the Engineering Analysis. Historical average efficiencies are reported by industry trade associations. Taking the average efficiency of units purchased as the minimum life-cycle cost defines the market discount rate. The average efficiency in future years is projected based on the range of engineering designs available (characterized by unit price and efficiency) and projected residential energy prices, given the market discount rate.

B.1.5 Market Shares

The number of potential purchasers is calculated for two markets: housing starts and potential replacement/retrofit in existing housing. Total product sales for each year are determined by applying market share elasticities to projected equipment price, operating expense, and income to determine the fraction of potential purchasers who will actually purchase the product. The market share elasticities include cross-price variables, where appropriate, to capture inter-fuel competition, e.g., the choice between electric or gas cooktop.

The market share elasticities are constant over the projection period. The market shares for ranges and ovens in future years are given in Chapter 2, Table 2.5 of the product-specific discussion of ranges and ovens (Volume 2) of this Technical Support Document. The percent share for each class in future years is assumed to be the same as that in 1992 and is shown in Table B.2 a-B.2b.

Table B.2a Percent Share of Each Class of Electric Cooktops

coil element	85%
smooth element	15%

Table B.2b Percent Share of Each Class of Electric and Gas Ovens

Electric Ovens	
self-cleaning	56%
non self-cleaning	44%
Gas Ovens	
self-cleaning	24%
non self-cleaning	76%

B.1.6 Usage Behavior

The usage elasticities for ranges and ovens are given in Appendix B of the product-specific discussion of ranges and ovens (Volume 2).

B.1.7 Equipment Turnover

Chapter 2 in the product-specific discussion of ranges and ovens (Volume 2) shows average equipment lifetimes. These lifetimes are assumed to be constant over the projection period. The retirement functions (the percent of products which survives, as a function of years after purchase) are shown in Table B.3.

Table B.3 Survival Function of Cooktops and Ovens

Age (year)	Cooktop	Oven	MicrowaveOven
1 to 6	100%	100%	100%
7	100%	100%	97%
8	100%	100%	83%
9	100%	100%	62%
10	100%	100%	38%
11	100%	100%	17%
12	100%	100%	3%
13	100%	100%	0%
14	100%	100%	0%
15	100%	100%	0%
16	87%	87%	0%
17	65%	65%	0%
18	41%	41%	0%
19	20%	20%	0%
20	6%	6%	0%
21 to 30	0%	0%	0%

B.1.8 Outputs

The LBNL-REM produces annual projections of:

- number of houses in stock by house type;
- housing starts by house type;
- thermal integrity factors for stock and new houses by house type;
- average unit energy consumption of new units sold (by class and by end use/fuel);
- average unit equipment price of new units sold (by class and by end use/fuel);
- fraction of existing houses having each end use;
- fraction of new houses having each end use;
- usage behavior factor, by end use/fuel;
- fuel consumption by housing type, by fuel, and by end use;
- total equipment expenditures by end use; and
- total fuel expenditures.

The LBNL-REM produces cumulative values for a period (1998-2030):

- fuel use by end use and fuel type;
- discounted fuel expenditures by end use and fuel type;
- discounted equipment expenditures; and
- discounted total (fuel and equipment) expenditures.

The LBNL-REM produces cumulative values for new units purchased in a period (1998-2030):

- discounted fuel expenditures by end use and fuel type;
- discounted equipment expenditures by end use and fuel type;
- discounted total (fuel and equipment) expenditures by end use and fuel type;
- units installed by end use and fuel type; and
- total discounted life-cycle expenditures per unit by end use and fuel type.

Product types usually correspond to end uses.

B.1.9 Changes Since Previous Technical Support Document

The principal changes since the previous Technical Support Document in 1993 are:

(1) The set of clases being analyzed has changed for room air conditioners: certain non-louvers classes have been removed.
(2) The set of design options, efficiencies, and cost data have changed (see Chapter 1 of the product-specific discussion of ranges and ovens (Volume 2)).
(3) Occupied household and housing start projections have been revised to agree with *Annual Energy Outlook 1995* (see Chapter 5 herein).
(4) Energy price projections have been updated to *Annual Energy Outlook 1995* (see Chapter 5 herein).
(5) Historial shipments of room air conditioners have been updated.
(6) The average equipment lifetime of room air conditioners has been re-estimated.
(7) A consistent set of market discount rates is used in calculating market shares and in forecasting equipment efficiencies.

B.1.10 Input Data

The complete input listing is available on electronic medium in ASCII format. The input database includes demographic, economic, and engineering data. The input listing for products in the current proposed rule is reproduced in Appendix B of the product-specific discussion of ranges and ovens (Volume 2).

REFERENCES

1. U.S. Department of Energy, Energy Information Administration. 1995. *Annual Energy Outlook 1995 with Projections to 2010*. Washington, D.C. DOE/EIA-0383(95). January.

2. U.S. Department of Commerce, Bureau of the Census. 1990. *Housing Starts*. Washington, D.C. July.

distributions were typically truncated at two standard deviations from the mean. This truncation excludes the smallest 2.28% and the largest 2.28% of the possible values in a normal distribution. This was done to eliminate potential outliers that could unnaturally skew the results.

Graphic Contains Data for
Postscript Printers Only.

Figure A.1 Schematic of @RISK Uncertainty Analysis for Spreadsheet Calculations

REFERENCES

1. @RISK, Palisade Corporation, Newfield, NY, 1992.

Table 5.1 Occupied Households Projections (millions)

	Occupied Households	Single-family	Multi-family	Mobile Homes
1980	80.4	53.8	22.7	3.9
1985	86.5	58.3	23.6	4.6
1990	93.4	63.8	24.5	5.1
1995	97.5	68.0	24.2	5.3
2000	101.9	71.8	24.7	5.4
2005	106.2	75.2	25.6	5.5
2010	110.7	78.6	26.6	5.5
2030	130.8	91.6	33.4	5.8

Sources: DOE/EIA *Annual Energy Outlook 1995.*
U.S. Department of Commerce, Bureau of Census (2).

5.1.2 Housing Starts

Figures for past (1980-1989) housing starts by state come from the Bureau of Census' *Housing Starts*. Projections (1990-2010) come from DOE/EIA's *Annual Energy Outlook 1995*. Housing starts in later years (2011-2030) are extrapolated using the projected annual growth rates from 2000 to 2010.

Table 5.2 Housing Starts Projections (thousands)

	Total	Single-family	Multi-family	Mobile Homes
Past				
1980	1514	852	440	222
1985	2025	1072	670	284
Projected				
1990	1392	901	303	188
1995	1605	1142	230	233
2000	1645	1041	388	216
2005	1721	1063	435	223
2010	1780	1059	496	225
2030	2110	1093	775	242

Sources: Bureau of Census, Housing Starts (3).
DOE/EIA *Annual Energy Outlook 1995.*
LBNL extrapolation.

5.1.3 Disposable Personal Income

Disposable personal income (1980-1986) is from the *Survey of Current Business* (4), converted to 1990 dollars using the Consumer Price Index-Urban. For 2011-2030, the projection is extended, assuming a linear increase in disposable personal income, with the annual increase being the average of the increases from 1993 to 2010. *Annual Energy Outlook 1994* (5) provides the figure for 1990 and *Annual Energy Outlook 1995* provides the most recent projections for 1992 to 2010. The figures for 1987-1989 and 1991 are obtained by interpolation.

Table 5.3 Disposable Personal Income (1990$)

	Total (Billions)	Per Occupied Household (Thousands)
Past		
1980	2890	35.9
1985	3435	39.4
Projected		
1990	4046	43.1
1995	4478	45.9
2000	5029	49.4
2005	5481	51.6
2010	5914	53.4
2030	8787	66.4

Sources: (1980-1986) *Survey of Current Business*.
(1990) DOE/EIA *Annual Energy Outlook 1994*.
(1992-2010) DOE/EIA *Annual Energy Outlook 1995*.
(2011-2030) LBNL extrapolation.

5.1.4 Residential Energy Prices

Past energy prices (1980-1988) are from the DOE/EIA's *Monthly Energy Review* (6). Energy prices for 1989 and 1990 are from DOE/EIA's *Annual Energy Outlook 1994*. Energy prices for 1992 to 2010 are obtained from DOE/EIA's *Annual Energy Outlook 1995*. Extrapolation of energy prices (2011-2030) assumes average annual increases of 0.3% per year for electricity, 0.8% per year for natural gas, 1.7% per year for distillate, and 1.6% per year for LPG.

Electricity prices are further adjusted to reflect differences in effective price by specific end uses. Table 5.5 shows multipliers for obtaining effective prices for space heating, water heating, air conditioning, and other end uses from the average sector prices in Table 5.4.

These multipliers capture regional differences in residential rates and appliance holdings, as well as effects of rate structure. (For example, if electric heat is common in areas with lower residential rates, then the effective rate for electric space heating is lower than the average residential rate. Also, if the block structure offers declining rates for increased consumption, then end uses associated with higher consumption, including space heating, will have lower effective rates.) The multipliers are derived from the 1990 *Residential Energy Consumption Survey (RECS)* (7).

Table 5.4 Average Residential Energy Prices (1990 Dollars per Million Btu)

	Electricity*	Natural Gas	Distillate Oil	LPG
Past				
1980	22.44	5.71	11.16	12.37
1985	27.75	7.21	9.41	9.25
1990	23.74	5.69	7.64	8.31
Projected				
1991	23.87	5.76	7.57	8.41
1992	24.62	5.87	6.86	8.52
1993	24.30	6.00	6.55	8.63
2000	23.93	5.88	7.70	9.55
2005	24.66	6.71	8.24	11.65
2010	25.67	6.92	8.71	12.99
2030	28.44	13.77	12.03	20.10

*3412 Btu/kWh.
Source: (1980-1988) DOE *Monthly Energy Review*.
(1989-1990) DOE/EIA *Annual Energy Outlook 1994*.
(1991) interpolated by LBNL.
(1992-2010) DOE/EIA *Annual Energy Outlook 1995*.
(2011-2030) extrapolated by LBNL.

Table 5.5 Relative Electricity Price by End Use (Average Residential Electricity Price = 1.00)

	Electricity	Natural Gas
Space Heating	0.87	0.98
Water Heating	0.90	1.01
Air Conditioning	0.99	NA
Other End Uses	1.04	1.11

Source: LBNL derived from 1990 *RECS*.

5.2 SENSITIVITY ANALYSIS OF THE BASE CASE

5.2.1 Residential Sector Sensitivity Cases

The sensitivity cases for the residential sector are defined as follows:

- *Lower Equipment Price*. For each class, the price of the baseline unit and the incremental prices associated with each other design option are reduced by the uncertainty estimated for that cost.

- *Higher Equipment Price*. For each class, the price of the baseline unit and the incremental prices associated with each other design option are increased by the uncertainty estimated for that cost.

- *Lower Energy Price*. Assume lower energy prices. Starting from 1996 to 2030, electricity prices are 3% lower, while gas and distillate prices are 5% lower than those in the *Annual Energy Outlook 1995* forecast.

- *Higher Energy Price*. Assume higher energy prices. Starting from 1996 to 2030, electricity prices are 3% higher, while gas and distillate prices are 5% higher than those in the *Annual Energy Outlook 1995* forecast.

- *High Equipment Efficiency*. Assume continuing future improvement in appliance efficiencies at a rate of 2% per year.

- *Market Discount Rates Decline*. Assume that market discount rates used to determine future efficiency choices are declining over time by 2% per year, i.e., efficiency improvements appear in the marketplace sooner.

The results of these sensitivity cases are presented in Sections 2.3 (base case sensitivity) and 3.6 (alternative efficiency level impacts) of the product-specific discussion of ranges and ovens (Volume 2) of this Technical Support Document.

REFERENCES

1. U.S. Department of Energy (U.S. DOE), Energy Information Administration. 1995. *Annual Energy Outlook 1995 with Projections to 2010*. Washington, D.C. DOE/EIA-0383(95), January.

2. U.S. Department of Commerce, Bureau of the Census. 1983. *1980 Census of Population and Housing*. Washington, D.C. PC80-1-A.

3. U.S. Department of Commerce, Bureau of the Census. 1994. *Housing Starts*. Washington, D.C. CB-95-151, July.

4. U.S. Department of Commerce, Bureau of Economic Analysis. 1981-1987. *Survey of Current Business*. Washington, D.C.

5. U.S. DOE, Energy Information Administration. 1994. *Annual Energy Outlook 1994 with Projections to 2010*. Washington, D.C. DOE/EIA-0383(94), January.

6. U.S. DOE, Energy Information Administration. 1994. *Monthly Energy Review*. Washington, D.C. DOE/EIA-0035(94/06), June.

7. U.S. DOE, Energy Information Administration, Office of Energy Markets and End Use. 1990. *Residential Energy Consumption Survey: Household Energy Consumption and Expenditures 1990*. Washington, D.C. DOE/EIA-0321(90), February.

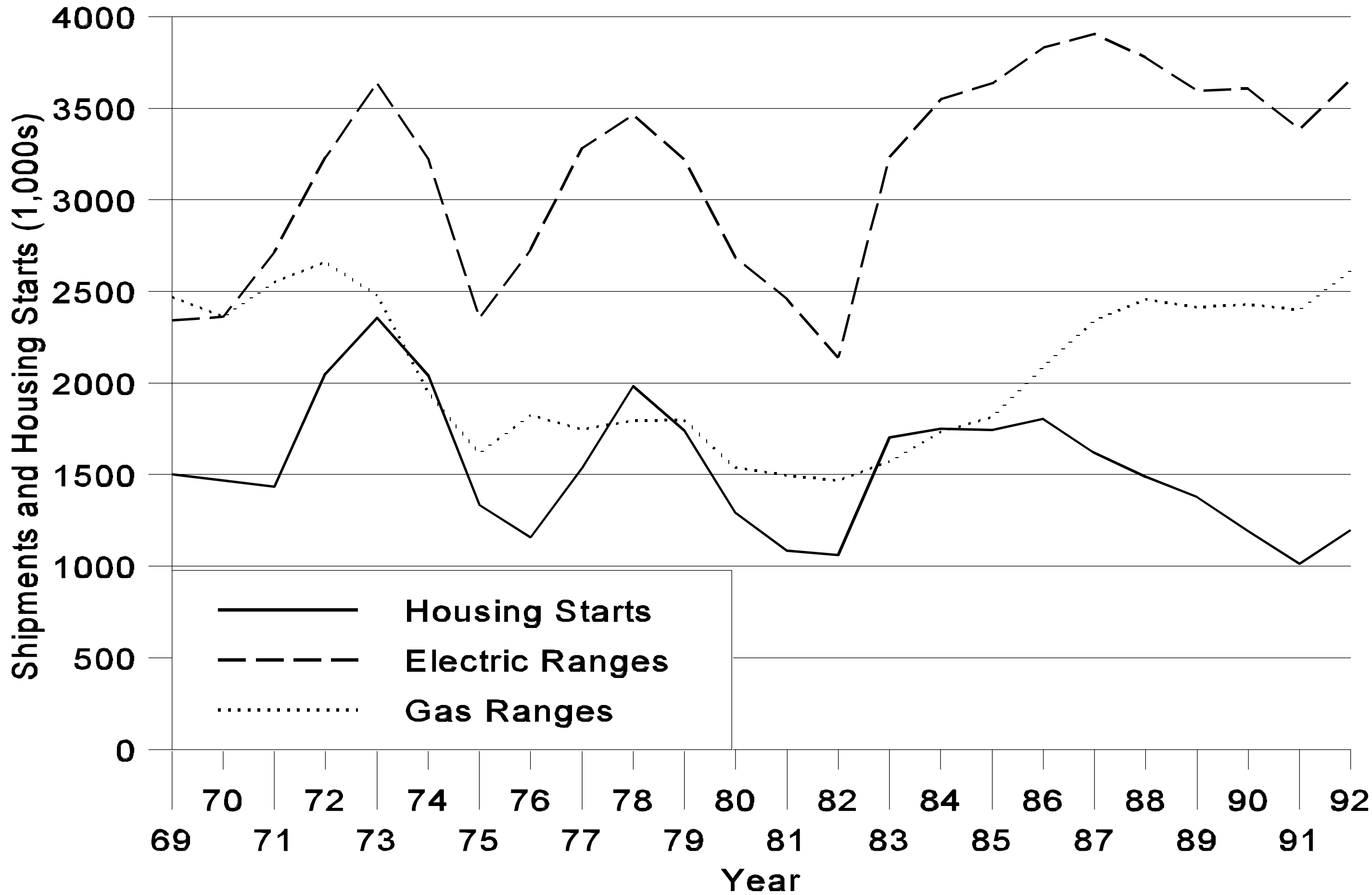
Appliance Saturation Rates

The saturation rate is the percentage of homes that own a particular appliance. Tables 4.1 and 4.2 list the saturation rates for ranges and ovens in selected years during the past 20 years. Note that the data do not reflect the fact that some homes have more than one appliance of a particular type. In general, if most homes own an appliance but few homes have more than one unit, we expect that the appliance will have a relatively low elasticity of demand because the appliance is usually considered a necessity. This observation corresponds with the relatively low price elasticity of ranges and ovens and the higher price elasticity of products such as microwave ovens.

Table 4.1. Market Saturations

Product	**1973 (%)**	**1978 (%)**	**1983 (%)**	**1987 (%)**	**1993 (%)**
Ranges (Electric)	47	51	58	59	58
Ranges (Gas)	52	48	43	42	45
Microwave Ovens	1	7	33	66	86

Source: *Appliance,* September, 1994.



Sources: ***Statistical Abstract of the United States 1994***, ***Appliance*** "Statistical Review", (Var. Years)

Figure 4.1 Kitchen Range Shipments and Housing Starts

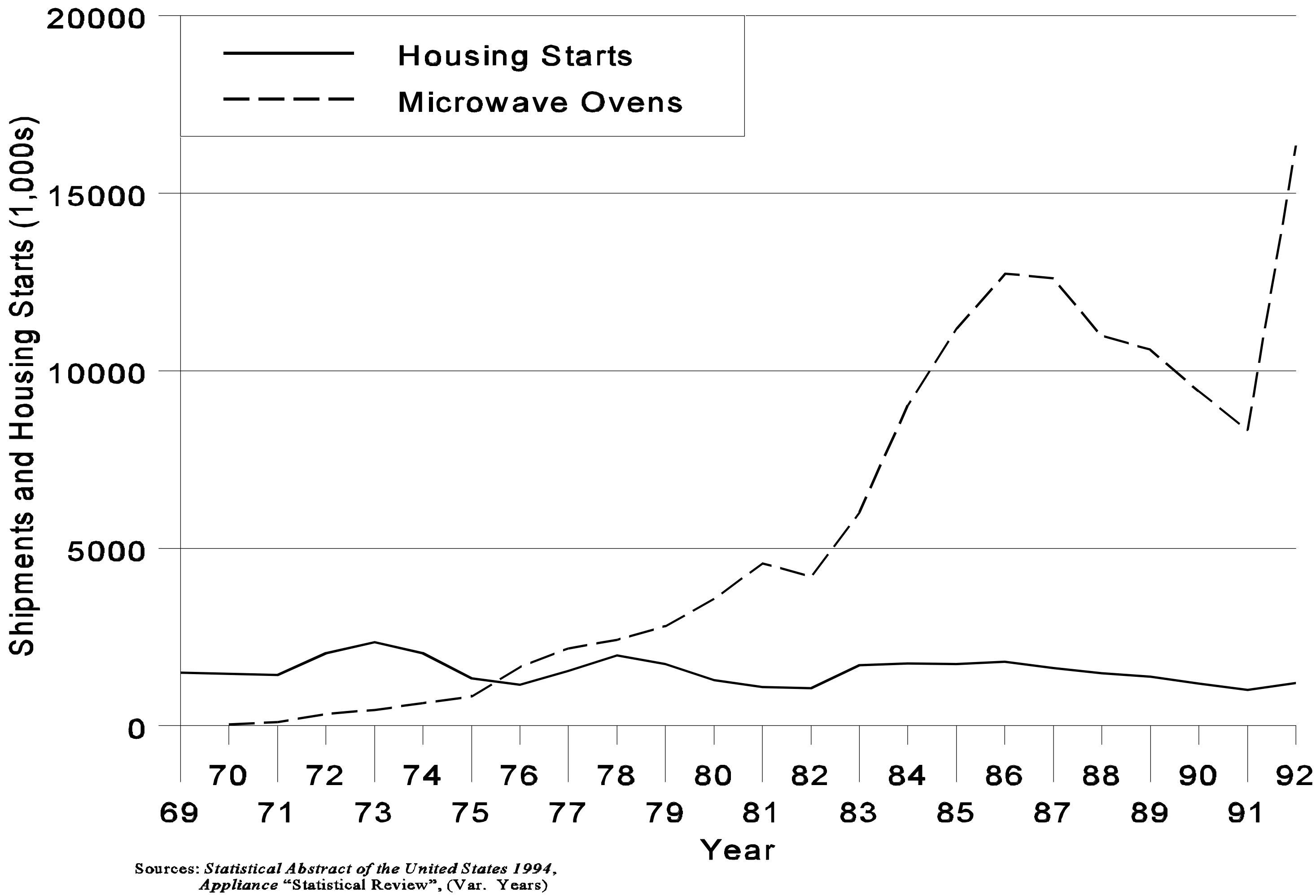


Figure 4.2 Microwave Oven Shipments and Housing Starts

Table 4.2. Market Saturations*

Product	1981 (%)	1984 (%)	1987 (%)
Electric Stove	54/29	54/79.5	57/77
Electric Oven	52/74	49/73	57/75
Gas Stove	46/21	45/20	2.7/21
Gas Oven	40/17	42/18	41/21
Microwave	17/23	34/51	61/76

Source: RECS, 1981, 1984, 1987.[2]

*Initial figure is for the stock of dwellings, the second is for new construction. RECS figures include mobile homes, and single- and multi-family dwellings.

4.2 SUPPLY

Market Concentration

Market concentration is the extent to which market share is controlled by the largest firms in an industry. Table 4.3 shows the market concentration for the products according to the degree of the market controlled by the two, four, and five largest manufacturers in each industry.

All of the products show a high level of market concentration. The market concentrations of the top five producers are at least 80%. The largest producer controls from 40% to more than 50% of the market for each of these products. Market concentration plays a part in the analysis because it may indicate the existence of market power[3] in a particular industry. Firms with the largest market shares may have some market power, a factor that affects the markups used by these firms both in the base case and the alternative efficiency level case.

---

[2] The relevant RECS reports are the data from the public use tapes for the various surveys discussed in *Residential Energy Consumption Survey: Housing Characteristics, 1981*, August 1983, DOE/EIA-0314(81), U.S. Department of Energy; *Residential Energy Consumption Survey: Consumption and Expenditures, 1984*, October 1986, DOE/EIA-0314(84), U.S. Department of Energy; and *Household Consumption and Expenditures, 1987*, October 1989, DOE/EIA-0321/1/(87). U.S. Department of Energy.

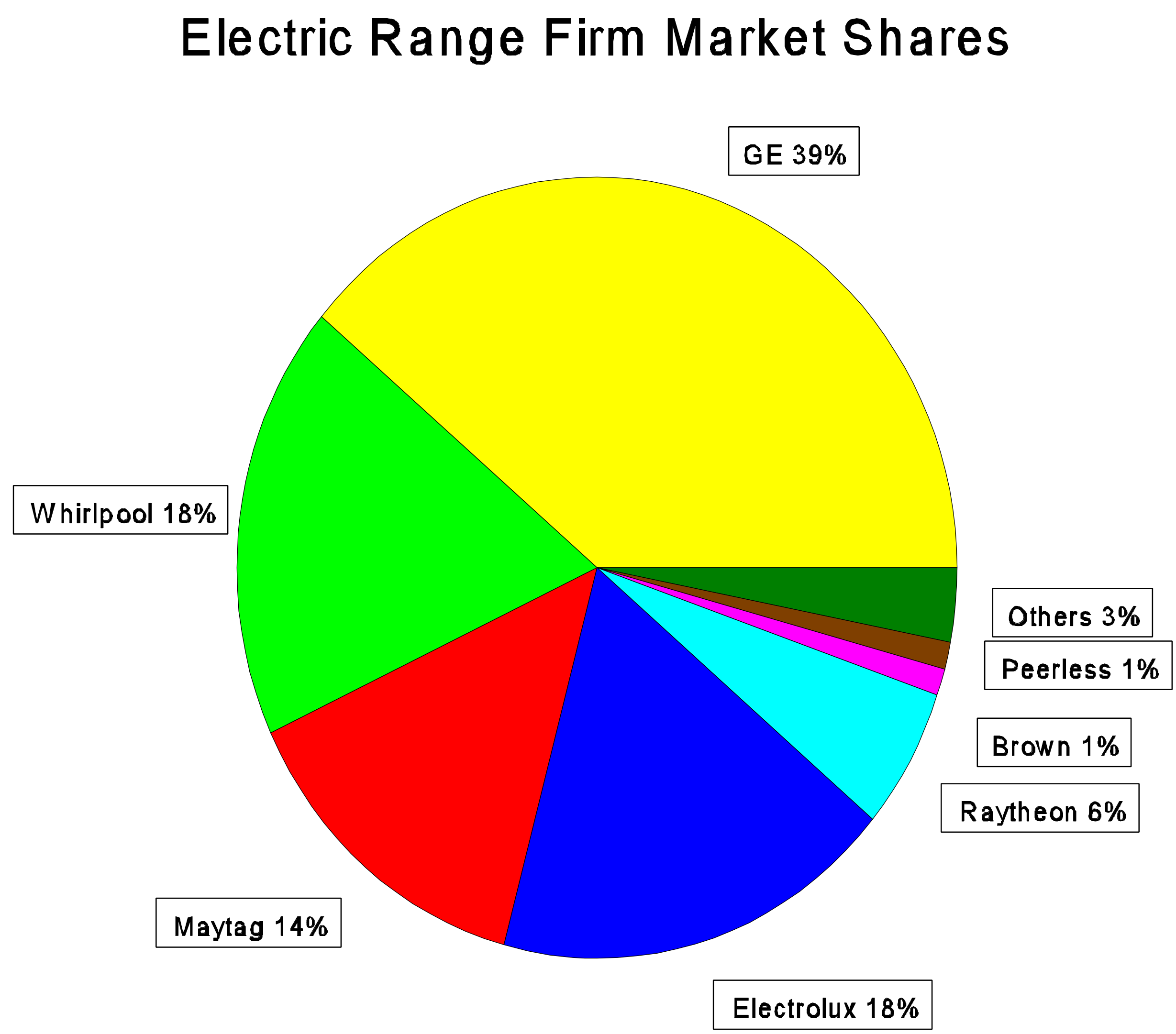
[3] Market power is the ability to set price within a limited range. More technically, it is the freedom that results from facing a demand curve that is not infinitely elastic. This means that if price is raised by some small amount, sales will not fall to zero, and if price is lowered by some small amount, sales will not become essentially infinite.

Table 4.3 Percent of Market Controlled by the Largest Producers of Each Product

Product	Number of Firms Top Two (%)	Top Four (%)	Top Five (%)
Ranges (Electric)	57	89	95
Ranges (Gas)	49	93	96
Microwave Ovens	46	74	82

Source: *Appliance*, September 1994.

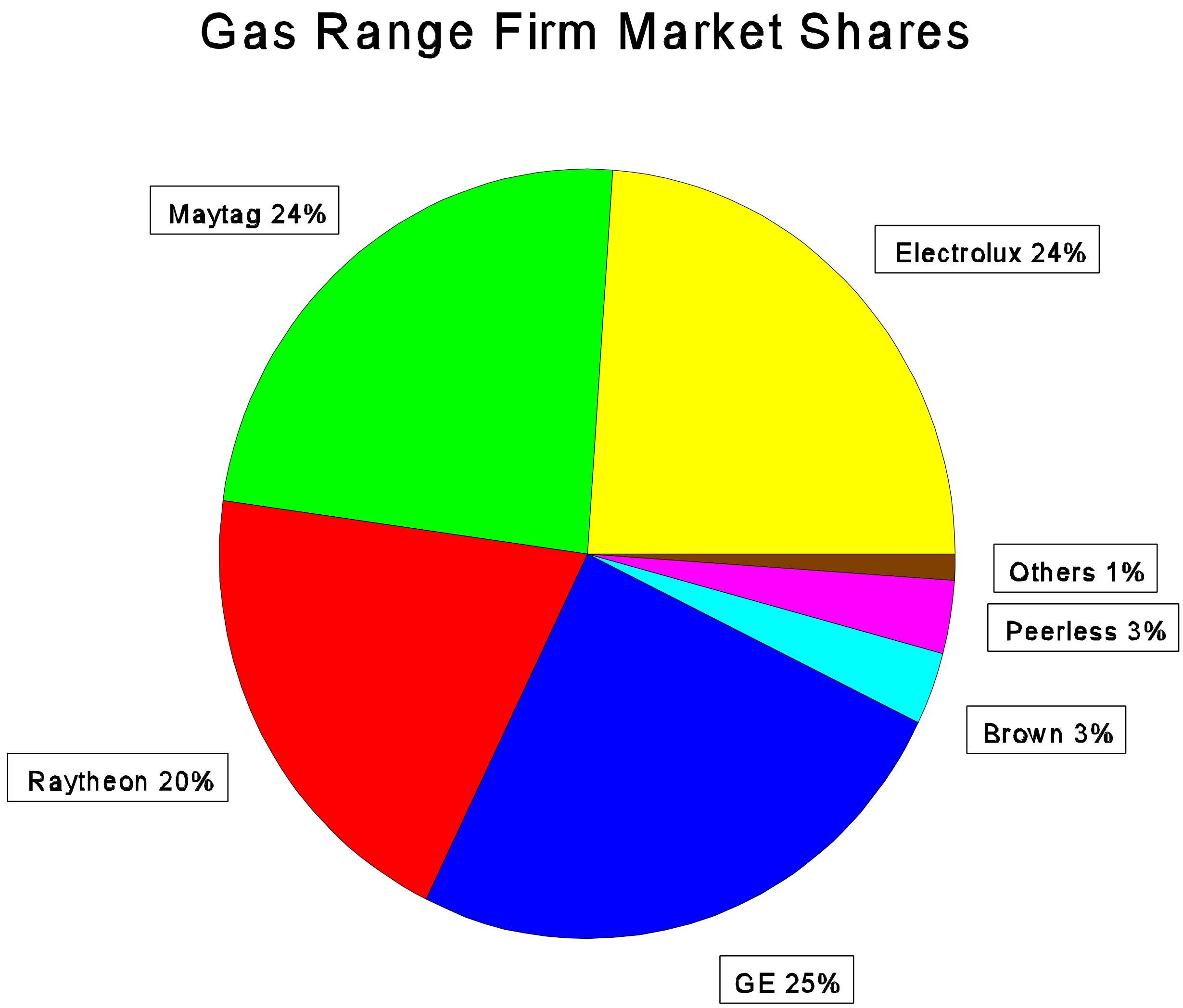
Figures 4.3 to 4.5 give a picture of the manufacturer market shares for each of the analyzed products. Most products are produced by a few manufacturers, each of which have large market shares.



Maytag owns Jenn-Air, Hardwick and Magic Chef brand names.
Electrolux owns the Frigidaire and Tappan brand names.
Raytheon owns the Caloric brand name.
GE includes what was Roper.

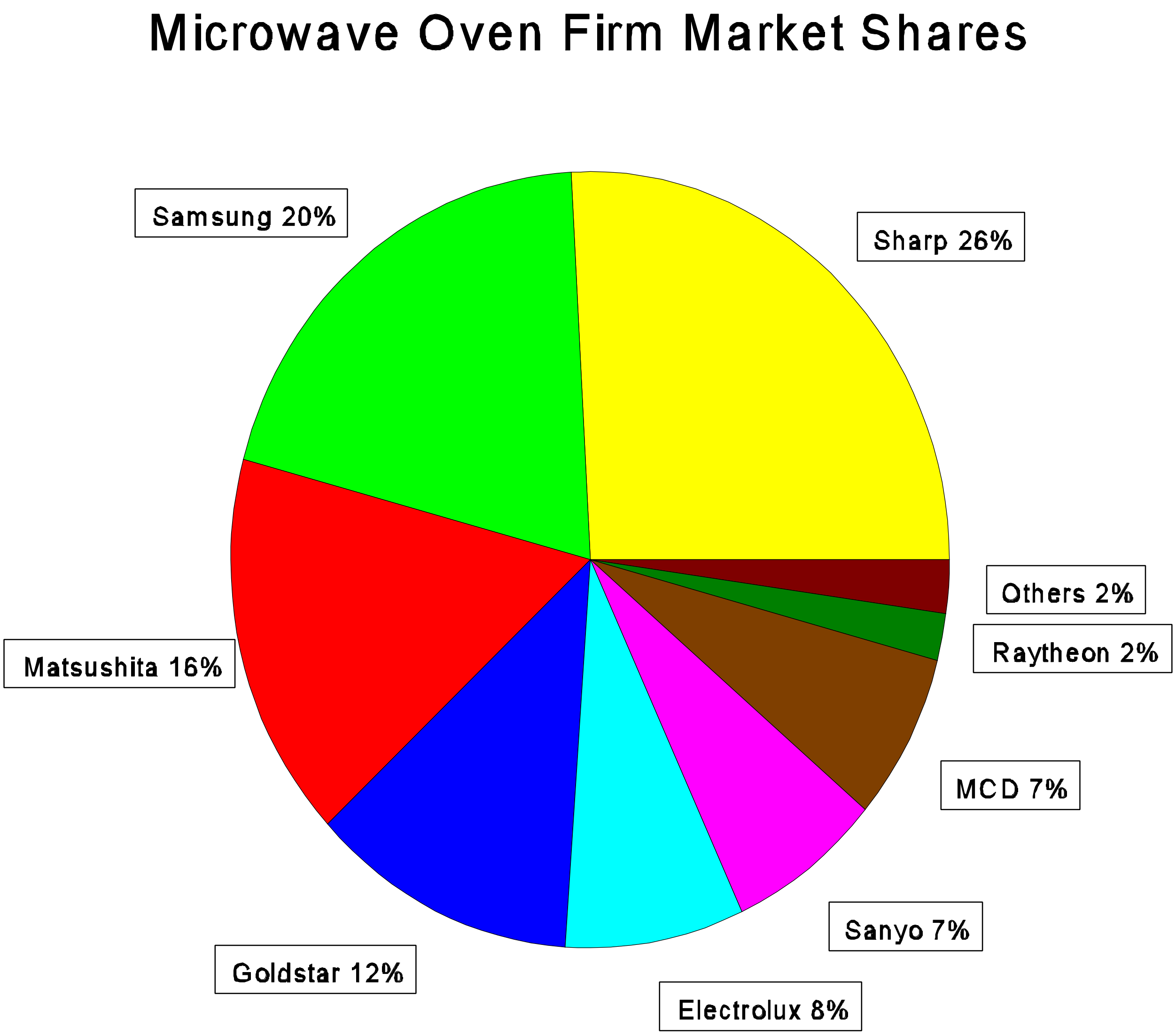
Source: *Appliance*, September 1994

Figure 4.3 Electric Range Firm Market Shares: 1993.



Source: *Appliance*, September 1994.

Figure 4.4 Gas Range Firm Market Shares: 1993.



Source: *Appliance*, September 1994.

Figure 4.5 Microwave Oven Firm Market Shares: 1993.

Mergers and Acquisitions

The appliance-manufacturing industry has had a continuing history of consolidation. Mergers and acquisitions have two purposes: First, they produce large corporations with the financial resources and stability to be successful in an increasingly competitive market. Second, mergers and acquisitions mean manufacturers can have a complete line of home appliances for product diversification and can therefore offer a complete set of appliances to consumers, an important feature in the builder market. There is increasing worldwide competition in the major appliance market, so mergers or acquisitions are likely to continue. Table 4.4 is a partial list of major acquisitions of appliance manufacturers.

Table 4.4 Acquisitions of Appliance Manufacturers

Buyer	Purchase	Year
Whirlpool	Heil-Quaker	1964
Raytheon Co.	Amana Refrigeration, Inc.	1965
White Consolidated Inc.	Franklin Appliance Div. (Studebaker Corp.)	1967
White Consolidated Inc.	Kelvinator Appliance Div. (American Motor Corp.)	1968
Emerson Electric Co.	In-Sink-Erator	1968
Magic Chef, Inc.	Gaffers & Sattler	1968
Magic Chef, Inc.	Dixie-Narco, Inc.	1968
Magic Chef, Inc.	Johnson Corp.	1971
AB Electrolux (Sweden)	Eureka	1974
Rockwell International	Admiral Co.	1974
White Consolidated Inc.	Westinghouse Electric Corp.'s, Major Appliance Operations	1975
Caloric Corp. (Raytheon)	Glenwood Range Co.	1978
White Consolidated Inc.	Philco Appliance Business (Ford Motor Co.)	1979
White Consolidated Inc.	Frigidaire Appliance Business (General Motors Corp.)	1979
Magic Chef, Inc.	Admiral Div. (Rockwell)	1979
Carrier	Jenn-Air	1979
Raytheon Co.	Modern Maid Co.	1979
Raytheon Co.	Speed Queen (McGraw Edison)	1979
United Technologies Corp.	Carrier	1979
AB Electrolux (Sweden)	Tappan	1981

Table 4.4 Acquisitions of Appliance Manufacturers - Con't.

Buyer	Purchase	Year
Dart & Kraft	Hobart Corp.	1981
Magic Chef, Inc.	Revco	1981
Maytag Co.	Hardwick Stove	1981
Maytag Co.	Jenn-Air (Carrier/United Techn)	1982
Hobart (Dart & Kraft)	Chambers Corp. (Rangaire Corp.)	1983
Magic Chef, Inc.	Toastmaster	1983
Admiral (Magic Chef)	Warwick Manufacturing Co.	1985
Chicago Pacific Corp.	The Hoover Co.	1985
Masco Corp.	Thermador-WasteKing (NI Ind.)	1985
AB Electrolux (Sweden)	White Consolidated Industries	1986
Maytag Co.	Magic Chef, Inc.	1986
Chicago Pacific Corp.	Rowenta Group (West Germany) (Allegheny Int'l and Rothmans Deutschland GmbH)	1986
Whirlpool Corp.	Kitchen-Aid Division (Dart & Kraft, Inc.)	1986
General Electric Co.	RCA	1986
Inter-City Gas Corp. (Canada)	Heil-Quaker Home Systems, Inc. (Whirlpool)	1986
Emerson Electric Co.	Kitchen-Aid dishwashing manufacturing facility (Whirlpool)	1986
White Consolidated Ind. (Electrolux)	Design & Manufacturing Corp.	1987
Thomson S.A. (France)	GE/RCA consumer electronics	1988
Toastmaster Div.	Mgt. team buys division from Maytag Co.	1988
Speed Queen	Holiday-Hammond	1988
Whirlpool Corp.	Roper Corp.'s brand name	1988
General Electric Co.	Roper Corp.'s physical assets (inc. manufacturing facilities)	1988
Maytag Co.	Merger with Chicago Pacific Corp.	1988
Fedders	Emerson Quiet Kool	1990
Hayward Pools	ComfortZone	1991
MCD	Maytag microwave oven business	1992

4.3 PRICES

Appliance prices have, on average, risen more slowly than aggregate indexes measuring consumer and producer prices. The appliance industry has a long history of price stability even through fluctuations in the business cycle. Despite increased energy and component prices during the 1970s and 1980s, the industry has, through increased productivity, kept price increases lower than increases in the Consumer Price Index (CPI).[4] In recent years, the industry has made a strong push toward automation to keep costs down, spending hundreds of millions of dollars to automate production facilities.

Figures 4.6 to 4.7 show the real Producer Price Index (PPI) for various product groupings compared to the CPI. Figure 4.7 shows the PPI for all commodities and for household appliances for the years 1985 to 1993. The PPI for household appliances increased about half as much as the PPI for all commodities. The real PPI for each product grouping is defined as the PPI for that product grouping, holding the overall PPI constant at 1982 = 100. In other words, this figure indicates the relative increase or decrease in the price index of a product grouping, using the PPI for all commodities as the yardstick. The subsequent figures and their products are

- Figure 4.6: Household Cooking Equipment (kitchen ranges and ovens and microwave ovens),
- Figure 4.7: Household Appliances.

[4]The consumer and producer price indices are from a personal communication with the San Francisco, CA office of the U.S. Bureau of Labor Statistics, May 1995.

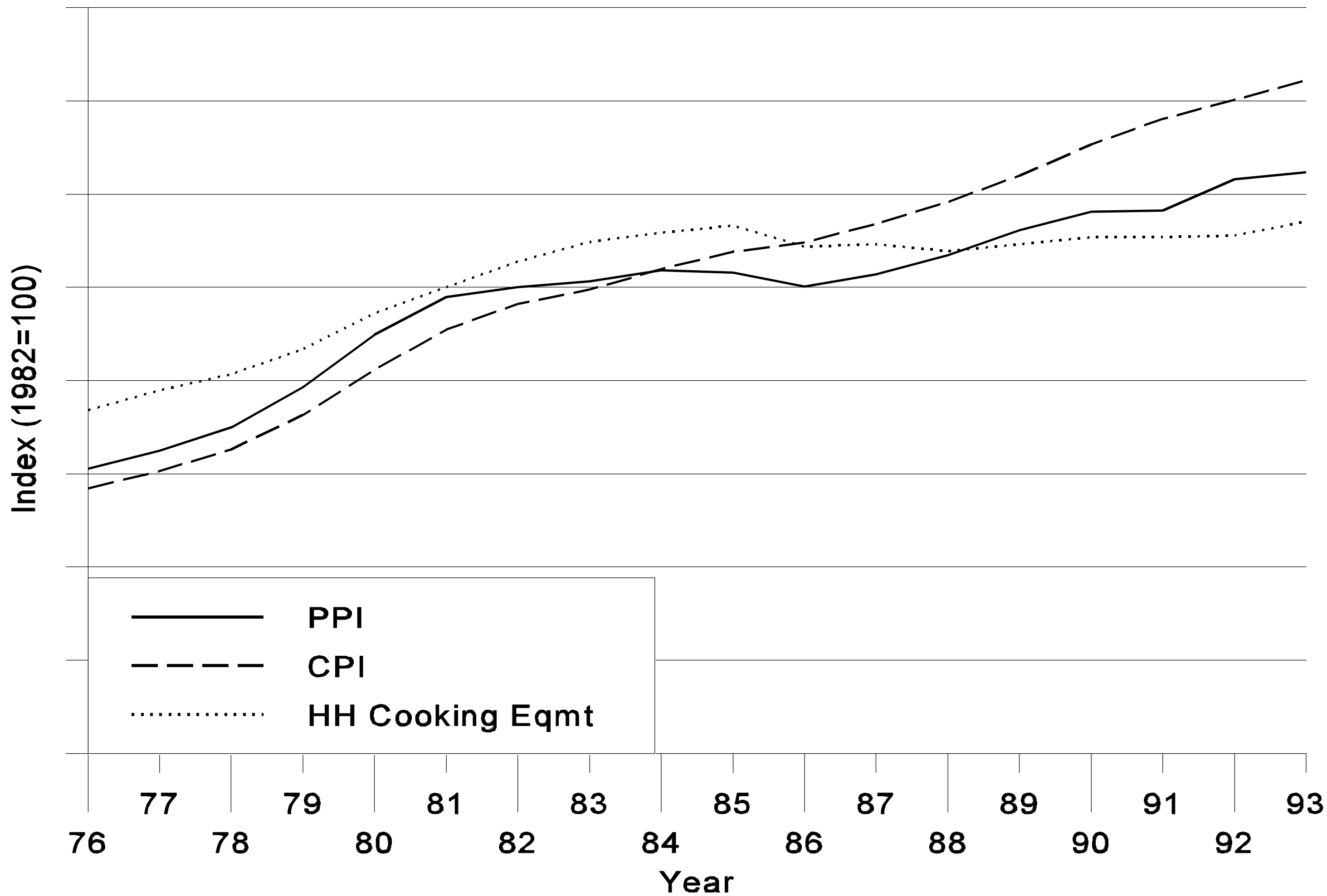


Figure 4.6 National PPI and CPI Compared to Household Cooking Equipment Product Group PPI

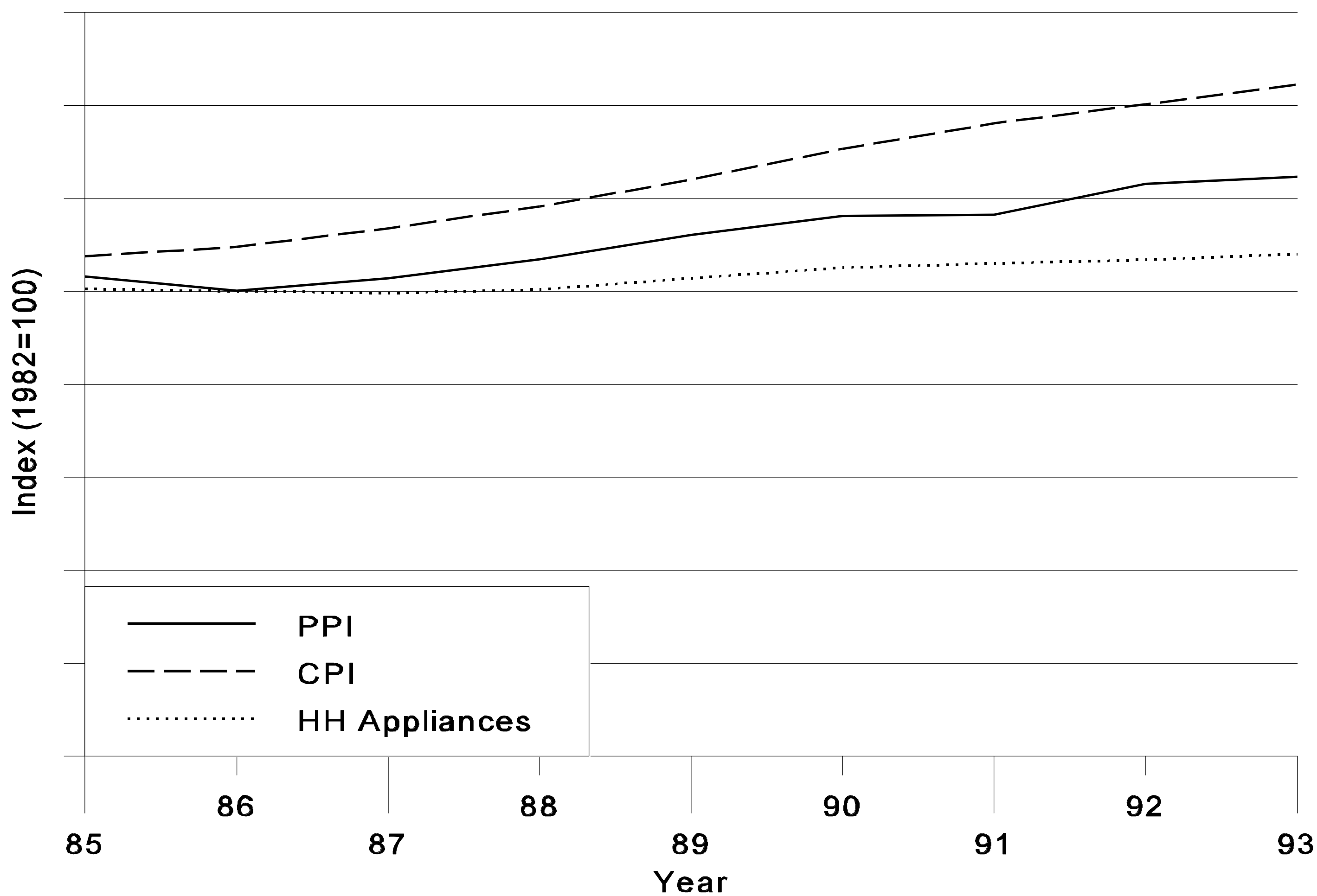


Figure 4.7 National CPI and PPI Compared to All Household Appliances

REFERENCE

1. "A Portrait of the U.S. Appliance Industry 1994," *Appliance*, September, 1994, p. 70.

This chapter briefly describes how the economic analysis of alternative efficiency levels was performed. Section 3.2 presents an overview of the analytic methodology and discusses the major components of the analysis: the Engineering Analysis, the Consumer Analysis (national and individual), the Manufacturer and Industrial Analyses, and the Utility Analysis. The emphasis is on how these components fulfill the seven legislative requirements listed in the Introduction. This section discusses the interrelationships among the components that ensure consistency throughout the analysis.

Section 3.3 describes the computerized models used in the analysis. The models predict consumer, manufacturer, and utility responses to future changes in the economy, including the imposition of efficiency levels. Quantitative estimates of the impacts of implementing new efficiency levels are calculated from the outputs of the models. The models utilized in the analysis are:

- Engineering Cost and Performance Models;
- Consumer Impact Models;
- Manufacturer Impact Models;
- Utility Impact Model.

The function, data sources, assumptions, and validity of the results for each model are in the product-specific discussion of ranges and ovens (Volume 2).

Section 3.4 below discusses the sensitivity analysis performed on the economic impacts and focuses on the methods used to determine the parameters that have the largest effects and to determine their range of variation.

3.2 OVERVIEW OF ANALYTIC FRAMEWORK

The impact of implementing new efficiency levels is determined by comparing projections of a wide range of economic variables under the existing legislation with the projections under the imposed efficiency levels. For each product analyzed, these projections are first made for a base case (existing legislation) using the analytic models described below. In the Volume specific to ranges and ovens, Chapter 2 describes the data and assumptions used to calculate the baseline forecasts. The calculations are then repeated imposing the alternative efficiency levels as discussed in Chapter 3 of that Volume. The differences between the projections of the energy consumption and economic variables in the base and efficiency level cases provide quantitative estimates of the impacts of the imposed efficiency levels. To evaluate the significance of the differences, a sensitivity analysis is performed on the key parameters and assumptions.

The economic impact analysis is performed in seven major areas:

- An *Engineering Analysis*, which establishes technical feasibility and product attributes including costs of design options to improve appliance efficiency;

- A *Consumer Analysis* at two levels: national aggregate impacts, and impacts on individuals. The *national aggregate impacts* include LBNL Residential Energy Model (LBNL-REM) forecasts of appliance sales, efficiencies, energy use, and consumer expenditures. The *individual impacts* are analyzed by Life-Cycle Cost (LCC), Payback Periods (PBP), and Cost of Conserved Energy (CCE), which evaluate the savings in operating expenses relative to increases in purchase price;

- A *Manufacturer Analysis*, which provides an estimate of manufacturers' response to the alternative efficiency levels. Their response is quantified by changes in several measures of financial performance for a firm;

- An *Industry Impact Analysis*, which shows financial and competitive impacts on the appliance industry;

- A *Utility Analysis* that measures the impacts of the altered energy-consumption patterns on electric utilities;

- An *Environmental Effects Analysis*, which estimates changes in emissions of carbon dioxide, sulfur oxides, and nitrogen oxides, because of reduced energy consumption in the home and at the power plant; and

- A *Regulatory Impact Analysis*, which collects the results of all the analyses into the net benefits and costs from a national perspective.

A simplified diagram of the analysis is shown in Figure 3.1. Each type of analysis is performed for the two products. If appliances having the maximum efficiency improvement that is technologically feasible show no significant energy savings in the Engineering Analysis, then the legislation requires that no modified standard be prescribed for that product type. If the appliance efficiency can be increased to produce significant energy savings, then a detailed energy savings, economic, and impact analysis is done. For each of the products, the analysis is performed for a base case plus several alternative efficiency levels. The selection of efficiency levels by class is described in Chapter 3 of the product-specific discussion of ranges and ovens (Volume 2).

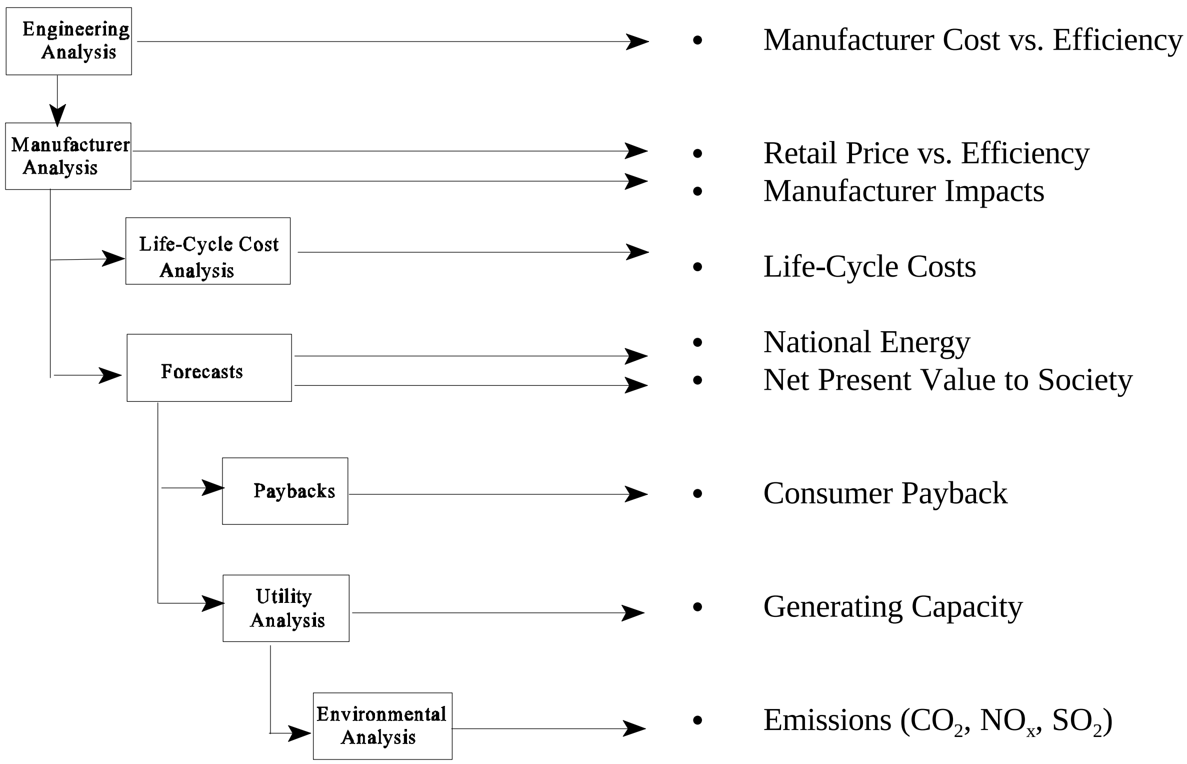


Figure 3.1 Analytic Framework for the Analysis of Appliance Alternative Efficiency Levels

Figure 3.1 illustrates the relationships among the Engineering, Manufacturer, and Consumer Analyses. The Engineering Analysis establishes appliance designs and related attributes such as efficiency and costs. Based on these costs, the Manufacturer Analysis predicts retail prices for use in the consumer analysis (the Life-Cycle Cost Analysis and Forecasts). Based on the relationship between the prices and efficiencies of design options, the consumer analysis forecasts sales and efficiencies of new and replacement appliances. These data are used as inputs to the Manufacturer Analysis to determine financial impacts on typical firms within the industry. The consumer analysis also forecasts energy savings and consumer expenditures for the purchase and operation of the appliances. Consumer expenditures are used in the Life-Cycle Cost Analysis to determine consumer impacts. Changes in sales, revenues, investments, and marginal costs of utilities are calculated from the energy savings in the Utility Analysis.

Three time frames are considered by the analysis. First, the analysis of consumer and utility impacts extends over a time frame consistent with the life of the products and includes the time required to approach market saturation. This time frame extends to 2030 and the new efficiency levels come into effect in 1999. Second, the Manufacturer Analysis is performed for a typical year after the implementation of new efficiency levels. Third, the Engineering Analysis examines the technical feasibility of improving the efficiency of appliances before the efficiency levels come into effect—within the next three years.

3.3 MODELS, DATA, AND ASSUMPTIONS

3.3.1 Engineering Cost and Performance Models

The Engineering Analysis provides information on efficiencies, manufacturing costs, and other appliance characteristics for use in other components of the analysis. Appliance features that provide utility to the consumer are incorporated into the analysis through the creation of appliance classes. Classes are a subset of appliance types. For example, a water heater is an appliance type, but a gas-fired storage water heater is an appliance class. The Engineering Analysis develops cost and efficiency data for a set of design options within each appliance class. These data are the output of the engineering performance and cost models discussed later in this section. The Engineering Analysis is performed in seven steps: 1) select appliance classes; 2) select baseline units; 3) select design options within each class; 4) determine maximum technically feasible designs; 5) calculate the efficiency improvement provided by each design option; 6) develop cost estimates; and 7) generate cost-efficiency relationships.

Appliance Classes

The first step in the Engineering Analysis is the segregation of product types into separate classes to which different alternative energy efficiency levels apply. DOE differentiates classes by the type of energy used (oil, natural gas, or electricity), and capacity or performance-related features that provide utility to the consumer and affect efficiency. For specific appliances, classes are defined using data collected in discussions with appliance manufacturers, trade associations, other interested parties, and from comments received on the ANOPR and NOPR. Those classes for which no DOE test procedure has been specified are omitted. The appliance classes covered by the analysis are listed in Chapter 1 of the product-specific discussion of ranges and ovens (Volume 2).

Baseline Units

A baseline unit is the starting point for analyzing design options for improving energy efficiency. To select a baseline unit, the Engineering Analysis uses information gathered from trade organizations, manufacturers, consultants with expertise in specific product types, and from public comments on the ANOPR and NOPR. For each product class, the baseline unit generally represents a model with the maximum allowable energy use specified by the National Appliance Energy Conservation Act (NAECA). Other than efficiency, features are representative of the class as a whole.

Design Options

The Engineering Analysis identifies individual or combinations of design options with a potential for improving energy efficiency. Design options that are commercially available at the present time or that are present in prototypes are considered. They are selected after discussions with experts and an extensive literature review. The efficiency improvement and manufacturer cost of design options added to the baseline unit are calculated.

Maximum Technologically Feasible Designs

For each product class, a maximum technologically feasible design option or combination of design options is identified. This option, or combination of options, results in the highest energy efficiency for each product class. The maximum technologically feasible efficiency level is one that can be reached by the addition of design options, both commercially feasible and in prototypes, to the baseline units. This design must be possible to assemble, but not necessarily to manufacture in large numbers. Economic criteria are applied to all design options in other parts of the analysis.

Efficiency Calculation

For each of the product classes, the efficiency levels corresponding to various design options are determined from manufacturer data and from engineering calculations.

Cost Estimates

The manufacturer cost data are obtained through a lengthy process that included meetings and tours at manufacturing facilities, submission of formal requests to manufacturers for costing data, and review of the data received. Estimates of manufacturer cost are also received in response to the ANOPR and NOPR. In the product-specific discussion of ranges and ovens (Volume 2), Appendix A contains detailed incremental cost data disaggregated into labor, purchased parts, materials, shipping/packaging and tooling.

Cost-Efficiency Relationships

The results of the Engineering Analysis are summarized in the cost-efficiency relationships showing the efficiency and manufacturer cost of the design options for each appliance class. Manufacturer and dealer markups derived in the Manufacturing Analysis are applied to the factory costs to arrive at the purchase price of the appliance. Additional installation costs required for some designs are included in the purchase price. Additional maintenance costs associated with specific design options are also estimated. The price-efficiency relationships are a fundamental input to the Consumer Analysis.

Assumptions in the Analysis

Justifications for the most important assumptions of the Engineering Analysis are listed below.

Assumption	*Justification*
Industry production processes can be characterized in terms of medium and large manufactur-ing facilities.	Manufacturing costs for small manufacturers are highly varied because of dependence on purchased parts and sensitivity to labor and distribution costs. An effort was made to obtain these data, but they were not made available by small firms. Because of this difficulty and the fact that they represent a small fraction of total shipments for most of the product classes, analysis concentrated on the medium and large manufacturers.
Unit energy consumption is based on DOE usage estimates, unless otherwise noted.	The baseline unit is the starting point to which design options are added to create higher efficiency units. The selection of baseline units is based on studies of products on the market in 1990 and consultations with manufacturers.
Unit energy consumption is based on DOE usage estimates, unless otherwise noted.	As part of the Consumer Product Efficiency Standards program, DOE was required to establish test procedures to determine average consumer utilization and energy usage for the covered products. Test procedures for each product type have been promulgated and were employed to determine unit energy consumption throughout the Engineering Analysis. If field data indicate that appliance energy use is different than that determined by the test procedure, alternative energy use estimates based on the field data are provided.

Data Sources

Shipment data are based on information from industry sources and published data from industry trade associations. Costs of purchased materials and parts are based on quotations from product manufacturers and suppliers of these items. Data on engineering and labor costs are taken from on-site visits to manufacturing plants and from manufacturer information. Data characterizing baseline units for each class are based on information from industry sources and published data.

Outputs from the Engineering Analysis

For each combination of design options considered in the analysis, the models and data provide:

- energy efficiency (expressed as the DOE energy factor[1] and/or unit energy consumption);
- increased material, labor, and investment costs by product class for medium and large manufacturers;
- annual energy consumption per unit (based on DOE test procedures or field-based estimators);
- the relationship between cost and energy use by product class; and
- other information on product characteristics such as appliance lifetimes, installation costs, and maintenance costs.

Validation of the Results

Experimental data on efficiencies are available for some of the design options studied. For the others, engineering calculations based on physical principles are performed.

3.3.2 LBNL Residential Energy Model (LBNL-REM)

Purpose

The LBNL-REM models the appliance purchase choices made in households, as well as these households' subsequent usage behavior and energy consumption. See Appendix B (herein) for details about the model.

Engineering, economic, and demographic data are used in LBNL-REM. The engineering data for appliances are described in Section 3.3.1. Additional data include age distribution of existing appliance stock and retirement functions. Economic data include projected energy prices and household income and models of energy investment, appliance purchase, and usage behavior (including fuel and technology choice for each end use). Demographic data include number of households by type, projected housing starts and demolitions, and appliance holdings.

Historical Development

Early energy-demand modeling focused on engineering estimates or on the relationship between energy

[1] The energy factor is a measurement of energy efficiency derived from the DOE test procedure for each product.

consumption and economic growth. In the 1970s, Oak Ridge National Laboratory (ORNL) developed the first model to integrate these two important aspects of energy demand, the Engineering-Economic Model of Residential Energy Use (1).

The ORNL Model was brought to LBNL in 1979 and adapted to the analysis of federal appliance alternative efficiency levels. Further extensive changes were made at LBNL from 1979 to the present, resulting in the LBNL-REM (2). Many of these changes have already been documented (3). More recent changes for this rulemaking are described in Appendix B.

Structure of the Model

The LBNL-REM segments annual energy consumption into house types, end uses, and fuel types. The house types include single-family, multifamily, and mobile homes. Calculations are performed separately for existing and new housing construction each year during the forecast period, 1980-2030.[2] The end uses are space-heating (including room and central), air-conditioning, water heating, refrigeration, freezing, cooking, dish-washing, clothes-washing, clothes-drying, televisions, lighting, and miscellaneous. Up to four fuels are considered, as appropriate to each end use: electricity, natural gas (utility gas), heating oil, and liquid petroleum gas (LPG). The national version of the model, which treats the country as a single region, is used in the analysis.

The model projects five types of activities: technology/fuel choice, building shell thermal integrity choice, appliance efficiency choice, usage behavior, and turnover of buildings and appliances. The interrelationship of the five types of activities is shown in Figure 3.2.

The initial number of occupied households, by type, is taken from the *1980 Census of Population and Housing* (4). Historical housing starts (1981-1991) are from Census data; housing starts and stocks (1992-2010) are from *Annual Energy Outlook 1995* (5). The historical housing stocks (1981-1991) are obtained by interpolating between the 1980 census figures and the 1992 figures from *Annual Energy Outlook 1995*. Housing stocks and starts after 2010 are projected extrapolations. The method is fully described in Appendix B.

[2] The model forecasts beginning in 1981. Historical data from 1981-1992 are used to check the validity of the forecast.

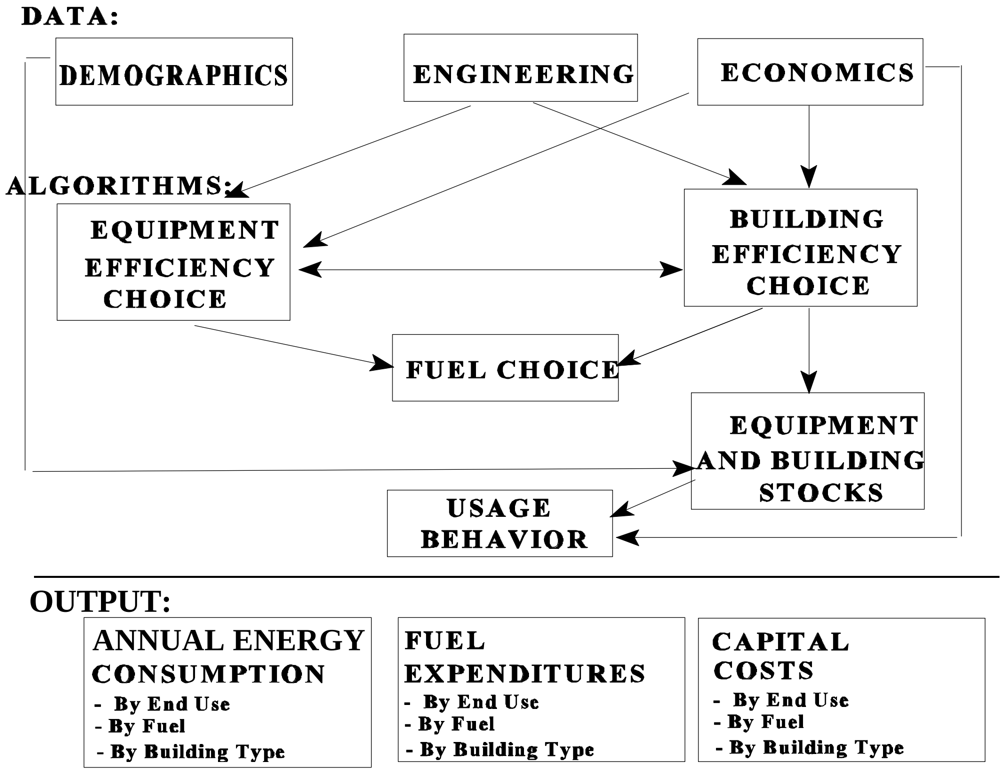


Figure 3.2 Activities in the LBNL-REM

Efficiency Choice Algorithm

Historical efficiency data are available for selected years through 1992 for kitchen ranges and ovens (depending on availability of data). After 1992, efficiency improvements are projected as a function of designs available (technological change) and of electricity, oil, or gas prices. If energy prices increase, the life-cycle cost of more efficient designs will increase more slowly than that of less efficient designs, making the more efficient designs more attractive. When the life-cycle cost of a more efficient design falls below the life-cycle cost of the current average design, then the more efficient design is projected to be purchased. However, if energy prices decline, the model projects no further efficiency change.

Thermal Integrity

The projection of investment in thermal integrity measures in new houses is based on a life-cycle cost calculation analogous to that done for equipment efficiencies.[3] Engineering estimates of the incremental costs of thermal integrity measures are used together with current fuel prices and a market discount rate for each house type and heating fuel type. Secondary impacts of appliance efficiency changes on energy consumed to heat or cool houses are not estimated in the current analysis.

Modeling Alternative Efficiency Levels

The LBNL-REM projects the average efficiency of new products, purchased each year, taking account of existing federal regulations. A distribution of unit energy consumptions (UEC) is constructed around the projected average unit energy consumption for each class, based on relative efficiency distributions previously observed in the marketplace. Federal energy efficiency levels would eliminate at least part of the distribution. A new distribution is constructed in which all units below the alternative efficiency levels are increased in efficiency to meet the new efficiency levels. The new shipment-weighted average efficiency then characterizes the efficiency of new units in that year. The same process is applied to all years after implementation of the efficiency levels. The model is then run again for the efficiency level case, with the adjusted average efficiencies, to calculate any changes in market shares, usage behavior, or investment in building shell thermal improvements that may occur as a result of implementing new efficiency levels, and to calculate the net energy savings.

Turnover of Appliance Stocks

The initial age distribution of appliances in stock is characterized from industry data about historical annual shipments and national surveys of appliance holdings. The fraction of each product that retires each year is based on the number of years since purchase for each age cohort.[4] Each age cohort is associated with an average efficiency; when older appliances retire, they are identified as less efficient.

The number of potential purchasers of an appliance in new homes is equal to the number of new homes constructed each year. The number of potential purchasers in existing houses is equal to the number of retiring appliances, plus a small fraction of those households that did not previously own the product.

Calculation of Market Shares

---

[3] The equipment efficiency and thermal integrity decisions are not solved simultaneously, but recursively. The previous year's thermal integrity is assumed in projecting this year's equipment efficiency; then this year's equipment efficiency is used to calculate this year's thermal integrity.

[4] For example, a cohort consists of all 8-year-old gas-fired water heaters. Up to 30 cohorts, one for each year of purchase, are tracked.

Potential buyers may make no purchase or may buy any competing technology within an end use. For each product, the decision to purchase or not is modeled, and the fraction of the total that choose each class, e.g., gas-fired, oil-fired, or gas instantaneous water heaters, is specified exogenously. Long-term market share elasticities have been assumed with respect to equipment price, operating expense, and income. Alternative efficiency levels are expected to lower operating expenses and increase equipment prices. The percentage changes in these quantities are used, together with the elasticities, to determine changes in market share resulting from imposed efficiency levels. Higher equipment prices will decrease market shares, while lower operating expense will increase market shares. The net result depends on the efficiency level selected and associated equipment price and operating expense.

Usage Behavior

For some products, changing the operating expense results in changes in usage behavior. For ranges and ovens, these elasticities are assumed to be non-zero.

Energy Consumption Calculations

The energy consumption per appliance for each end use and fuel by house type and vintage (existing or new) is the UEC. The corresponding energy consumption for all households is the consumption per appliance times the number of households of that type and vintage, times the fraction of households that owns that appliance.

Aggregate energy consumption is obtained from summations over intermediate results. For example, national electricity consumption for ranges and ovens in a particular year is the sum, over house types, classes, and vintages, of the electricity consumption of all ranges and ovens. National residential electricity consumption in that year is the sum of electricity consumption over all end uses.

Assumptions in the Analysis

The Consumer Analysis assumes that decisions on the purchase and use of appliances depend on operating expenses, household income, and appliance prices. Manufacturers are projected to respond to the demand for more efficient products by incorporating technologically feasible and cost-effective design options in new units. Forecasts of population growth, housing starts, personal income, and energy prices from published sources are utilized. Justifications for the most important assumptions in the Consumer Analysis are listed below.

Assumption	*Justification*
• Occupied households will increase from 93	The *Annual Energy Outlook 1995* projects annual growth

million in 1990 to 131 million in 2030.

of 1.0%, 0.6%, and 0.3% for single family, multifamily, and mobile homes, respectively, from 1993 to 2010.

- Housing starts are projected to be near constant for single family and mobile homes, but to increase from the current low levels for multifamily.

The *Annual Energy Outlook 1995* projects annual housing starts of 1.03 to 1.06 million for single family, from 1992-2010, of 0.17 to 0.50 million for multifamily, and 0.21 to 0.23 million for mobile homes.

- Real disposable personal income is projected to grow from $4.0 billion in 1990 to $8.8 billion in 2030 (in 1990 dollars). This corresponds to disposable income per household growing from $43,100 in 1990 to $66,400 in 2030.

The *Annual Energy Outlook 1995* projects growth in real disposable personal income for the nation as 2.0% per year from 1993 to 2010.

- Residential electricity prices are projected to increase from 8.40 cents/kWh in 1992 to 8.76 cents/kWh in 2010. Residential natural gas prices are projected to increase from $5.87/ MMBtu in 1992 to $6.92/MMBtu in 2010. Residential distillate prices are projected to increase from $6.86/ MMBtu in 1992 to $8.71/MMBtu in 2010.

The *Annual Energy Outlook 1995* projects annual growth of 0.3% for residential electricity prices from 1993 to 2010.

- Appliance purchase decisions are based on operating expenses, as well as on equipment price.

Research on equipment sales for competing alternatives and on historical efficiency choices indicates that operating expenses are significant variables.

- Manufacturers are projected to respond to consumer demand for energy efficiency. Engineering designs that are technologically feasible and attractive to purchasers are assumed to be available.

Industry is competitive and historically has responded to changes in consumer demand.

- The lifetimes of appliances are projected to remain the same as empirically observed in the past, independent of energy efficiency.

Retirement functions are based on reconciliation of historical appliance stocks and shipments. To date, efficiency improve-ments have occurred without any apparent effect on reliability.

Data Sources

The LBNL-REM takes the range of possible energy efficiencies of new equipment from the Engineering Analysis. The purchase price of these products is derived from the factory cost supplied by the Engineering Analysis and adjusted for manufacturer and dealer markups in the Manufacturer Analysis. Historical housing stocks and starts are from U.S. Department of Commerce, Bureau of the Census. Projected energy prices, household incomes, and housing stocks and starts are from U.S. Department of Energy, *Annual Energy Outlook 1995*.

Model Outputs

The principal outputs from the LBNL-REM for each year are:

- National energy consumption by end use and fuel;
- Per-unit equipment price and operating expense by product;
- Total residential energy consumption by fuel;
- Projected annual shipments of residential appliances; and
- Differences in these quantities between a base case and each efficiency level case.

These outputs are provided annually (or for selected years) and cumulatively for the period 1999-2030. Energy savings from alternative energy efficiency levels are provided annually to the end of the period. Net present value (NPV) of alternative efficiency levels is evaluated for each regulated product.

Cost-Benefit Analysis

The costs and benefits of the alternative efficiency levels from a national perspective are quantified by calculating a net present value. The NPV is the sum of discounted savings in operating expenses minus the sum of discounted increases in equipment prices.

DOE has determined that 7% real is the appropriate discount rate for calculating societal NPV. The NPV of alternative efficiency levels is also calculated at consumer discount rates of 4% and 10% as sensitivity analyses.

Different assumptions about technology choice are invoked when calculating energy savings of efficiency levels on the one hand, and when calculating the net present benefit of efficiency levels on the other. Energy savings are the net of any adjustments households make in changing their technology or fuel choice or from using appliances differently. For example, if, after implementing new efficiency levels, a regulated product captures larger market shares (without displacing consumption of another fuel), then the net energy savings will be diminished. The energy savings are calculated as the net result of implementing new efficiency levels, accounting for such secondary effects as shifts in market share.

NPV excludes these secondary effects. Base case purchase behavior, without market share changes, is assumed in calculating the NPV, because any market share shift reflects the consumer's judgment that change is worth more than the direct energy savings associated with keeping market share constant. NPV is calculated from per unit changes in equipment and operating costs, multiplied by efficiency level case shipments. If the NPV was calculated without normalizing to shipments, the results would be erroneous: if implementing new efficiency levels caused decreased purchase of a product, this would appear as an economic benefit, namely less money spent on purchasing and use of the appliance,[5] and if implementing new efficiency levels caused an increase in purchases, this would be counted incorrectly as a cost, when it actually reflects consumers' preference for the post-efficiency level product.

3.3.3 LBNL Manufacturer Analysis Model (LBNL-MAM)

Conceptual Approach

The Manufacturer Impact Analysis estimates both the short- and long-run impacts of alternative efficiency levels on profitability (return on equity) and many other variables for each industry under consideration. All computations used in this analysis are carried out by the Manufacturer Analysis Model (LBNL-MAM). The LBNL-MAM is a spreadsheet composed of thirteen modules. It consists of the earlier LBL-Manufacturer Impact Model (LBL-MIM) along with Version 1.2 of the Government Regulatory Impact Model (GRIM) developed by the Arthur D. Little Consulting Company under contract to the Association of Home Appliance Manufacturers (AHAM), the Gas Appliance Manufacturers Association (GAMA), and the Air-conditioning and Refrigeration Institute (ARI). Figure 3.3 displays inputs to LBNL-MAM and their interactions. In addition to computing estimated values for the above-mentioned descriptive variables, the LBNL-MAM also computes standard errors for each by explicitly evaluating the standard errors in the estimates of input variables and then using Monte Carlo simulations.

Measures of Impact

Three types of long-run impacts are analyzed: 1) profitability, 2) growth, and 3) competitiveness. To do this, the following six measures of impact are tracked for the industry: 1) shipments, 2) price, 3) revenue, 4) net income, 5) return on equity (ROE), and 6) industry net present value (NPV).

---

[5] Without normalization, the greatest economic benefit would be obtained by efficiency levels that resulted in no future purchases of the product. Then, no money would be spent on purchasing the product, or on operating expenses, and the value of the savings would equal the amount of money that would have been spent without implementing the efficiency levels. Clearly, this would be a misrepresentation of the NPV of alternative efficiency levels.

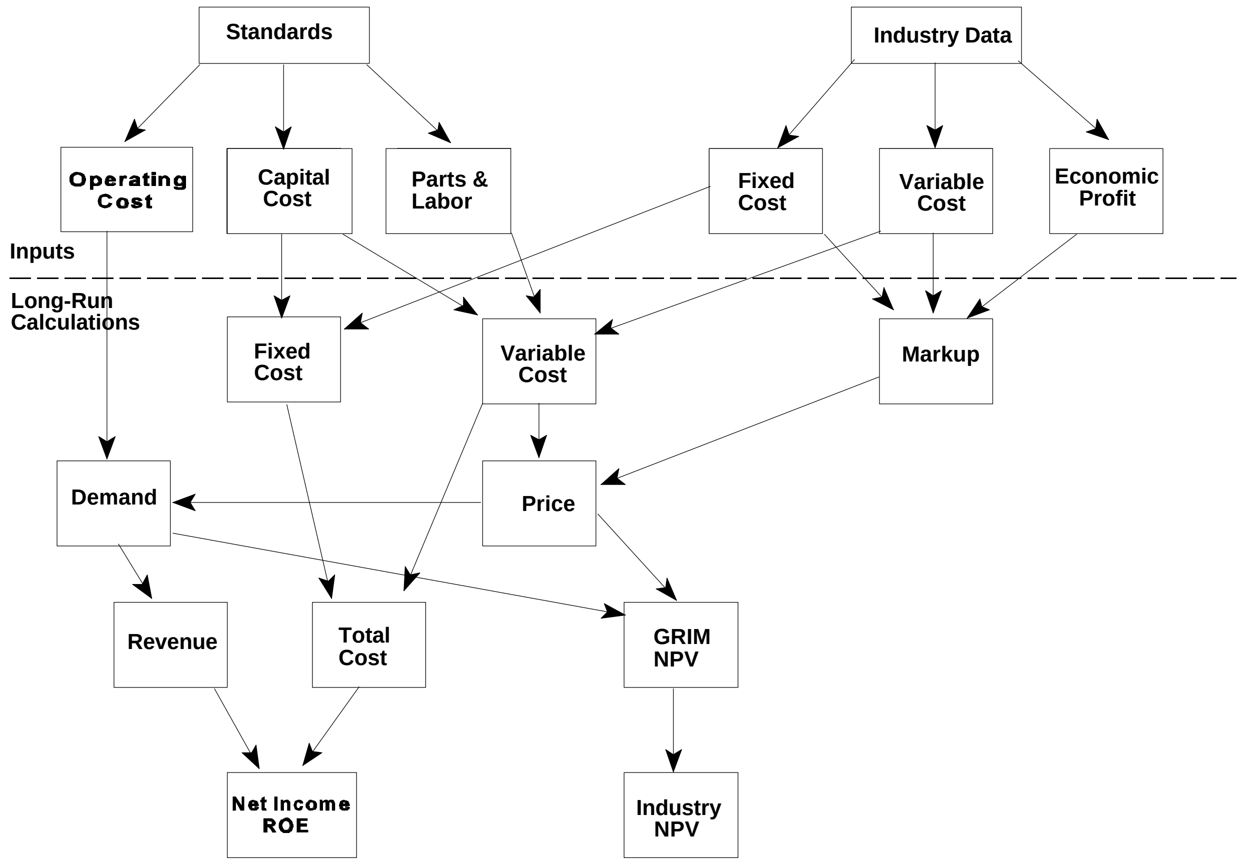


Figure 3.3 Conceptual Approach to the Manufacturer Analysis Model

ROE is the primary measure of profitability, although gross margin, return on assets, and return on sales are also reported. Changes in assets and revenue are the measures of growth (positive or negative). Because both of the industries analyzed are in an historical process of consolidation, any decrease in ROE will tend to hasten this process; thus, ROE also provides an indication of the impact of efficiency levels on competitiveness. Industry NPV is theoretically identical to ROE but has been included to provide additional insight into the impact of implementing new efficiency levels.

A short-run calculation is also made. If the long-run calculation indicates a decrease in sales, the predicted price is reduced by an amount determined by the industry's observed behavior during historical downturns in sales. The adjusted price is used to calculate the other measures of impact.

Description of the LBNL-MAM

Although LBNL-MAM examines many aspects of an industry, its most important role is to compute the effect on profits and industry net present value of a cost increase caused by implementing alternative efficiency levels. To accomplish this, the model first estimates how much of the cost increase is passed on in the form of higher prices. (An accompanying effect is the decrease in operating expense due to imposed efficiency levels, which makes the product more desirable to the consumer and, thus, increases demand for the product.) Then, it estimates how this price increase and the accompanying reduction of operating expense influence demand. Finally, given the new price and level of demand, it computes a new level of profit. These calculations use estimated long-run costs. The LBNL-MAM makes an additional calculation to correct for any short-run difficulties the industry may have in achieving its long-run markup and also estimates the impact of alternative efficiency levels on industry net present value.

It is important to note from the start that the model does not assume perfect competition, nor does it assume that the level of profit will remain unchanged. The results of the model depend entirely on the input values.

The basic behavior of the model can be understood only in light of the following standard economic consideration. In the long run, an increase in *fixed costs will not be passed on* via a price increase except when it is sufficient to cause some firms to leave the industry.[6] This result is derived from the assumption that firms act individually to maximize profits and from the definition of fixed costs as those that are not proportional to output. The mathematical derivation is given in Appendix C of this volume.

A second influence on profits is the change in purchases resulting from both the change in price and the change in operating expense. These tend to offset each other because price increases lower quantity demanded, and increased efficiency increases demand (by lowering operating expense). The LBNL-MAM takes these effects into account through the use of two demand elasticities which play an important role in determining the outcome and are therefore examined more closely in the sensitivity analysis.

Assumptions in the Analysis

This section begins with a series of short discussions of different aspects of the modeling procedure that require careful interpretation (such as "long-run variable cost") or simplifying assumptions. This is followed by a list of more detailed assumptions.

The long-run costs. The LBNL-MAM requires input of long-run costs. A firm is in long-run equilibrium when it has optimal productive capacity. Thus, during a recession (when firms experience excess capacity), firms are not in long-run equilibrium, and the theory of price as a markup over long-run costs may not apply. Long-run fixed costs are those that remain unchanged when a firm moves from one long-run equilibrium to another; they do not include capital costs that are proportional to output. The latter are considered long-run variable (marginal) costs and are marked up and passed on. To the extent that costs are not strictly proportional to output, but decrease on average with quantity produced, there are fixed costs. Also, a cost that does not depend on the scale of production, i.e., an engineering cost, is a long-run fixed cost.

---

[6] When firms leave the industry, the latter becomes less competitive and the remaining firms can increase their markup over variable costs, thus, indirectly covering their increased fixed costs.

Use of "typical" firm. The analysis estimates the impact of the efficiency levels by using "typical" firms. A typical firm is a hypothetical firm that is described by industry-average values. Each one is modeled as if it produced only products of the industry being analyzed. This procedure is justified by the observation that real firms generally are organized into autonomous divisions, each of which produces a different type of appliance and one of which generally corresponds to the industry being modeled. Also, these divisions are generally run on a profit-and-loss basis similar to a firm. It is not feasible to analyze inter-divisional interactions within real firms.

Aggregation. Generally, it has been impossible to obtain data on cross-elasticities of the various product lines within an industry. Therefore, data for the various products are aggregated before the markup is computed and applied. However, once the aggregate calculations have been made, individual prices are computed for the various classes of products.

How alternative efficiency levels are implemented in the model. A change in energy efficiency levels affects the inputs to the model in three distinct ways. In general, the implementation of stricter efficiency levels will require additional investment, will raise production costs, and will affect revenue through both price and demand.

The most obvious investment induced by the implementation of new efficiency levels is the purchase of new plants and equipment. This cost is first evaluated from engineering data, and then amortized by taking into account the life of the investment, the date at which it is made, tax laws, and the appropriate cost of funds. An additional, and sometimes larger, investment takes place as the old inventory is replaced with more expensive new units. The model assumes that the ratio of inventory to revenue remains unchanged; in this way both changes in quantity sold and unit value are taken into account. A third form of investment tracked by the LBNL-MAM is the change in the demand for cash that accompanies a change in revenues.

Financial inputs. Several simplifying assumptions are used in the process of generating inputs for the LBNL-MAM. First, all firms within a particular industry segment (e.g., large manufacturers of water heaters) are assumed to have the same cost structure. Second, it is assumed that financial data collected for the parent company are representative of the specific product division being studied. These data come from publicly available sources such as Value Line, Standard and Poor's, Moody's, and company reports.

Impact Analysis: An Overview

The next section provides a general discussion of the methods of the impact analysis together with some cautions about interpreting the results.

The significance of long-run impacts and how they are analyzed are discussed below. These impacts are most important simply because they will either persist or be so severe as to cause a restructuring of the industry. The meaning and analysis of short-run impacts are also discussed. Additionally, the various types of sensitivity analysis performed on the model's results are discussed. This analysis is crucial for understanding the accuracy and reliability of the model's predictions, and includes the use of alternative scenarios, sensitivity checks on individual inputs, and Monte Carlo simulations involving the random selection of all control inputs.

3.3.3.1 Long-Run Impact Analysis

The heart of the model is the long-run impact analysis. It assumes that enough time has passed for any changes in demand to have been accommodated by changes in the industry's productive capacity. Thus, in the long-run, capacity, or capital stock, is variable. Because capital is sometimes thought to be the only fixed cost, it might seem that fixed costs would be zero in the long run. This is not the case. For the purpose of price determination, whenever there are returns to scale, there are, effectively, fixed costs. This means that if the cost of meeting alternative efficiency levels is less than proportional to plant capacity, there are fixed costs. Design costs would typically fall into this category. See Appendix C of this volume for a more detailed discussion of the long run.

The fraction of increased costs of production (due to more stringent efficiency levels) that manufacturers are able to pass on is determined by the nature of the cost, i.e., whether it is fixed or variable, the price elasticity of demand, and the consumer discount rate as seen by the price-setting firm. Once the price increase has been determined, it and the operating expense decrease (obtained from engineering data) are used with the price elasticity of demand and the discount rate to determine the change in sales. These mechanisms are presented in Figure 3.4, which displays the most basic economic forces analyzed by the LBNL-MAM.

As shown in Figure 3.4, the two cost changes do not translate directly into price changes. Instead, the reduction in operating costs makes the appliance more desirable, thereby shifting the demand curve out (e.g., an increase in production costs changes the marginal cost curve). Together, these determine price and the number of units shipped (quantity). Price and quantity, together with production costs, determine net income (profit), and these, together with changes in capital stock (not shown), determine ROE.

The LBNL-MAM simulates the implementation of alternative efficiency levels as follows. For each product, a set of engineering designs is specified. For each design, the engineering analysis provides a per-unit cost, a one-time capital cost, and an energy usage. The two costs effectively determine the production costs used in Figure 3.4 and the energy usage determines the operating expense. The LBNL-MAM calculates a weighted average of the two costs and the energy usage for the relevant engineering designs. The weights used correspond to the relative numbers of shipments for each engineering design as determined by LBNL-REM.

Another and more subtle point is that markup is determined by price elasticity, and because life-cycle-cost elasticity is constant, price elasticity changes with a change in either price or operating expense. This change in markup can have an important impact on ROE.

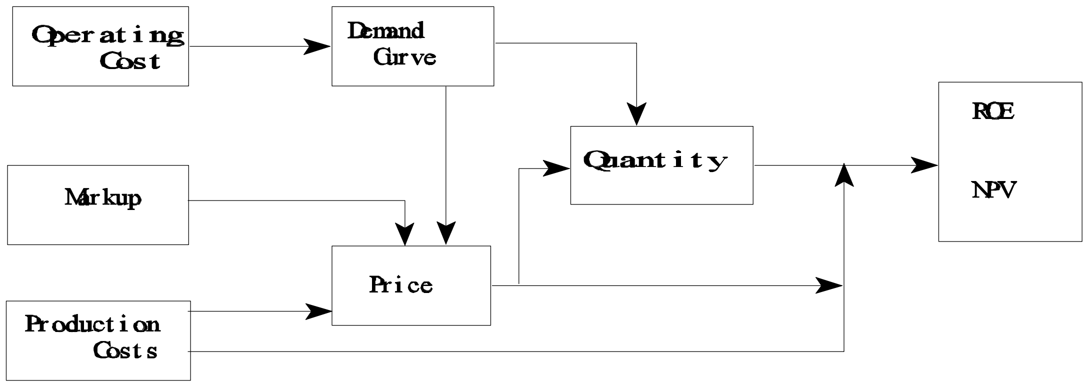


Figure 3.4 How Alternative Efficiency Levels Cause a Change in ROE and NPV

The markup discussed here is a markup over economic variable costs, which is a broader category than the typical business definition of variable costs. The manufacturer markup listed in the model and this volume is used only to calculate the baseline model price (calculated by multiplying the baseline manufacturer cost by the manufacturer markup). This is called the calibration case in LBNL-MAM. The manufacturer markup listed is not used in calculating the manufacturer prices for the base case or the alternative efficiency levels. In these cases, the manufacturer price is calculated from the economic markup[7] which, as described above, is dependent on elasticities, discount rates, and price and operating expense changes. Thus, prices at different efficiency levels do not exactly reflect the manufacturer cost times the manufacturer markup.

Typical results of an analysis of an alterantive efficiency level at a particular level might be the following: wholesale price increases 10%, sales decline 2%, revenue increases 8%, net income increases 12%, and ROE increases 0.5%. Associated with each of these numbers is a standard error. The errors might be as follows: 4% on price, 1% on sales, 4% on revenue, 10% on net income, and 1.5% on ROE. To interpret the prediction for ROE, one could then conclude (by checking a table of the normal distribution) that there is about a 69% chance that ROE will increase, and a 31% chance that it will decrease. One could also conclude that the chance of profits declining by more than 2% is only 2.3%.

---

[7] For a thorough description of how markups are derived and used in LBNL-MAM, see Appendix C of this volume.

3.3.3.2 Short-Run Impacts

In the shortest run, capacity is fixed; however, the short run of interest is, at the shortest, approximately three years. During this time, some change in capacity may occur, and demand, apart from the change induced by implementing new efficiency levels, will change. Demand for both types of appliance is projected to grow by approximately 2% during the three years, so, to that extent, it will alleviate any tendency toward excess capacity resulting from imposed efficiency levels.

In order to simplify the analysis and to take a cautious approach, the analysis has ignored the ability of the industry to actively or passively adjust its capacity relative to demand. The estimated short-run effect is what would happen if the industry converted, as a result of efficiency levels being implemented, all of its present capacity, and if the demand curve did not shift except as an indirect consequence of imposed efficiency levels.

The short-run analysis is based on the analogy between a change in demand caused by imposed efficiency levels and one caused by the business cycle. The business cycle periodically presents the industry with a fairly sharp decrease in demand that is much greater than the decrease predicted for any of the efficiency levels. This demand shortfall seems to present all of the opportunities for price competition that would accompany a shortfall resulting from a change in efficiency levels. Data for the last few business cycles (18 years) have been analyzed to determine the ratio between the decline in demand (industry-wide) and the induced decline in price.

If, for example, the long-run prediction is for a decline in demand of 2%, then, using the above figure, the short-run price could be predicted to be 0.06% (0.03 × 2%) lower than the long-run price. Actually, this is just a first approximation, and the model does better, as follows: the short-run price response factor (SRPR) of 0.03 means that the short-run price will be 0.06% lower than predicted with the long-run price formula if the actual decline in demand is 2%. This is different from the long-run prediction of a 2% decline, because the short-run price fall will keep the long-run demand fall from fully materializing. Thus, in the short run, the actual fall in demand will be less than the long-run prediction of 2%, and the actual fall in price will be greater than the long-run prediction, but not by a full 0.06%. Short-run demand and price must be determined simultaneously, which occurs in the short-run module of LBNL-MAM.

Short-run prices, profit levels, and other variables will gradually, over a period of several years, approach their long-run values. How long this will take depends on the industry, on the fact that the implementation of new efficiency levels is announced three or four years in advance, and on how fast (and if) the demand for the product is growing.

3.3.3.3 Industry Net Present Value Analysis

In this analysis, the LBNL-MAM was modified to include an analysis of the impacts of alternative efficiency levels on industry net present value. Beginning in late 1990, a number of trade associations[8] contracted with the Arthur D. Little consulting firm to develop a model they named the Government Regulatory Impact Model (GRIM). Given exogenously-supplied price, shipments, and cost inputs, the GRIM provides an analysis of efficiency levels on industry net present value (NPV). Theoretically, NPV provides an alternate measure of impact that is identical to industry ROE that has been historically used by the LBNL-MAM.

In response to the industry's concerns, the LBNL-MAM has been modified to include all the programming code from the latest version of the GRIM that is available.[9] The GRIM has been integrated as a separate module within the LBNL-MAM and generates the industry net present value analysis given price, shipments, and cost inputs from LBNL-MAM. For a detailed explanation of the GRIM module and its integration with the LBNL-MAM, please refer to Appendix C herein.

3.3.3.4 Sensitivity Analysis

Both because of the nature of the information required and the desire of sources to protect proprietary information, many of the data used by the model represent uncertain estimates. Therefore, the effect of these uncertainties on the accuracy of the model's predictions is analyzed. Two types of questions need to be answered. First, how does a particular input variable contribute to the uncertainty of the outputs? Second, how uncertain is the estimate of a particular output variable?

Sensitivity charts

The model's sensitivity to inputs is measured by the impact of a change of one standard error (S.E.) in the input variable. This analysis is presented only for the impact of input variables on ROE; this standardizes and simplifies the process. The results are displayed in a sensitivity chart, an example of which is given and explained below (Table 3.2).

---

[8] Association of Home Appliance Manufacturers, Gas Appliance Manufacturers Association, and Air-conditioning and Refrigeration Institute.

[9] GRIM Version 1.2 dated 1 March 1993; received from AHAM in March 1993.

Table 3.2 Sensitivity of ROE to 1 S.E. Change in Control Variables

Scenario = Primary

Control Variables			Efficiency Levels				
Name	Value	Changed	1	2	3	4	5
IPE	-0.300	-0.690	0.06%	0.07%	0.15%	-1.65%	-4.27%
RD	50.00%	114.96%	0.00%	0.15%	0.22%	1.32%	2.81%
ECC	0.068	0.075	0.00%	0.00%	0.00%	-0.01%	-0.04%
EP	0.008	0.018	-0.01%	-0.01%	-0.02%	0.07%	0.15%
FCA	0.098	0.157	0.00%	0.00%	-0.01%	0.06%	0.13%
F1X	0.200	0.348	-0.09%	-0.10%	-0.14%	-0.17%	-0.30%
CC.N	0.394	0.480	-0.02%	-0.03%	-0.04%	-0.07%	-0.16%
dVC.N	5.124	6.872	0.00%	0.01%	0.01%	0.05%	0.01%

Table 3.2 lists the sensitivities of ROE to the control panel inputs defined below:

1. IPE = industry price elasticity
2. RD = consumer discount rate
3. ECC = firm's real equity cost of capital
4. EP = firm's economic profit
5. FCA = percentage of a firm's costs that are fixed before the implementation of new efficiency levels
6. F1X = percentage of one-time costs (i.e., costs that are induced by implementing new efficiency levels) that are fixed
7. CC.N = estimate of one-time capital costs induced by alternative efficiency levels
8. dVC.N = increase in variable costs necessary to reach an efficiency level

Note that for CC.N and dVC.N the change of one standard error from the mean is applicable for efficiency level 2 only. These two variables are dollar values rather than percentages, and thus their value and the change in one standard error are different at each efficiency level.

To construct the table, each control variable is first set to its normal value. Next, one at a time, each is increased in absolute value by one standard error and the change in profit is recorded. Then the variable is returned to its normal value and the next variable is tested. The matrix in the table lists the percentage point change in ROE as a result of the change of one standard error in the variable's value. The change in ROE is listed for each control panel variable and at each efficiency level being analyzed.

Since each variable has its own standard error, the sensitivity reported in the table measures both how sensitive the model is to a change in the variable, and how uncertain the variable's value is. Note that the change in profit is simply the difference between long-run ROE and base case ROE. Note also that, as expected, increasing the absolute values of some variables increases ROE and, for other variables, decreases ROE.

The comparison of the various inputs' contributions to the uncertainty in ROE focuses attention on the parts of the model that should be examined most closely to determine their accuracy and on the parts where improvement in the certainty of input variables would have the greatest payoff. Because of the differences in the sensitivities among input variables, it will generally be found that one to three of the inputs will dominate the model's uncertainty, in the sense that perfecting all the rest of the inputs would make only a negligible difference to the model's accuracy.

Alternative Scenarios

For each appliance class and hypothetical efficiency level, hundreds of different scenarios are run for the Monte Carlo analysis described in a following section. However, a few scenarios that involve different demand elasticities are singled out for special attention.

If the reader wishes to estimate some other scenario not reported here, he or she can often simply use the sensitivity charts. To do this, first look up how sensitive ROE is to a one standard deviation change in the control variables that are changed by the proposed scenario. Then estimate by how many standard deviations the desired scenario variables differ from the primary scenario control variables and calculate a proportional change in ROE. Lastly, add the changes in ROE resulting from the different variables. This method should be reasonably accurate for changes in the control variables that are likely to be of interest.

Uncertainty of Outputs (Monte Carlo Analysis)

Output uncertainty is most directly addressed by the Monte Carlo analysis. This analysis assigns an uncertainty to each of the nine control-panel input variables and then chooses a value for each based on this uncertainty. The model is then solved using these randomly chosen variables. All of the important outputs are tabulated on the Monte Carlo page of the model. These outputs are changes from the base case of price, shipments, revenue, net income, long-run ROE, and short-run ROE. Next, new values of the input variables are drawn from the same distribution. The model is run again and the new outputs recorded. This cycle can be repeated as many as 400 times (or more). After a sufficient number of runs, the mean and standard deviations of each output variable are computed.

The standard deviations of the Monte Carlo output variables are the best estimate of the true uncertainty of the model's predictions. However, this does not mean they are absolutely reliable because they are based on estimates of the uncertainty of the inputs, and these are often not based on something as objective as the standard error of a regression coefficient. In short, if the uncertainty in the inputs is misperceived, the estimate of uncertainty in the outputs cannot be relied upon. Nonetheless, the standard errors generated by the Monte Carlo procedure are useful for the interpretation of the LBNL-MAM outputs.

Assumptions in the Analysis

Justifications for the most important assumptions of the Sensitivity Analysis are listed below.

Assumption	*Justification*
• Firms maximize revenues minus economic costs (R-EC), where EC includes the cost of equity and all taxes.	This follows from the assumptions of standard economic theory, in which firms are rational profit maximizers.
• The life-cycle-cost elasticity of demand experienced by a single firm is constant. This means that price elasticity will tend to decrease with operating cost. Note also that since price elasticity is finite, firms have market power.	There is no reason to assume that life-cycle-cost elasticity either increases or decreases with cost; thus, constancy is the base assumption.
• Costs are assumed to have two compo-nents: one fixed, and one proportional to quantity.	A linear cost function approximates any smooth curve over a small region; since quantity changes very little with new efficiency levels, the linear approximation should be adequate.
• Assets are assumed to be a linear function of sales.	Same as previous justification.
• The debt-to-equity ratio remains constant while the firm finances any investment necessary to meet any imposed efficiency levels.	Firms attempt to maintain a relatively constant overall debt-to-equity ratio, which they believe is optimal. Although specific new expenditures (such as those induced by new efficiency levels) may be financed primarily by debt or by equity, in the long run, the debt-to-equity ratio will be restored to its desired value.

Assumption	*Justification*
• The additional costs of parts, materials, and labor are assumed to be long-run marginal costs.	These costs are proportional to production except for cases in which there are discounts for large quantity purchases. Industry sources state that at the scales of production under consideration, these discounts are very nearly exhausted.
• A percentage (that varies from industry to industry) of capital costs are long-run fixed costs.	Although industry informants have stated that one-time capital costs will be proportional to the production capacity of the plant in question, it seems inevitable that there will be some associated engineering costs that are not. These will be long-run fixed costs.
• Any fall in demand caused by implementing new efficiency levels (because of a price increase) will affect prices in the industry by the same amount as a normal fall in demand experienced during the business cycle.	To the extent that a normal demand short-fall reduces the firm's short-run marginal cost, the demand decrease caused by implementing new efficiency levels will be indistinguishable. The crucial assumption here is that the business cycle does not influence the consumers' elasticity of demand. There is no evidence one way or the other on this.

Outputs of the LBNL-MAM

The LBNL-MAM tracks six essential output variables, with emphasis on ROE. The other five variables are 1) industry NPV, 2) price, 3) sales, 4) revenue, and 5) net income. Base case and short- and long-run values of these variables are reported on the control panel. In addition, LBNL-MAM constructs an output table that shows the long-run values of the variables at each of the efficiency levels under consideration. LBNL-MAM also produces a simplified income statement. As part of its algorithm, it calculates the markup from manufacturers' costs to consumer purchase price. The purchase price is used in the calculation of price-efficiency curves, the life-cycle-cost curves, and the calculation of payback periods, and throughout the LBNL-REM.

All of these values are estimates that necessarily reflect some uncertainty. Estimates of these uncertainties and identification of their sources comprise another set of model outputs. Under each estimate of one of the five main output variables, the output table displays that variable's change from its base level and the standard error of the estimate of that change. The LBNL-MAM also computes the effect on ROE of a one-standard-deviation change in each of the control variables. This is reported for each efficiency level in a sensitivity chart, designed to help discover the source of uncertainty in the output variables.

Data Sources

The LBNL-MAM uses data that characterize both a particular industry and typical firms within that industry. Estimates of data are based on information from five general sources: 1) the Engineering Analysis, 2) the Consumer Analysis, 3) industry consultants, 4) public financial data, and 5) industry profiles. A detailed discussion of model inputs appears in Appendix C of the product-specific discussion of ranges and ovens (Volume 2).

3.3.4 Appliance Standards Environmental and Utility Model (ASEUM)

The two analyses used in the prior appliance standards rulemakings, the Utility Impact Model and the Environmental Analysis have been integrated in one new model, the Appliance Standards Environmental and Utility Model (ASEUM). By calculating utility avoided costs and lost revenues, ASEUM provides marginal electricity costs to be used in evaluating the societal benefits of alternative energy efficiency levels. ASEUM also quantifies impacts on the electric utility industry's need for new generating capacity. Appendix E of this volume contains more information on the model and data used to perform these calculations.

ASEUM adopts the standard industry convention that the financial value of electricity savings to an electric utility can be broken down into fuel cost savings and capacity cost savings. The sum of the two is usually called avoided cost. The fuel cost element measures variable production costs avoided by reduced electrical demands, valued at marginal input fuel costs. The capacity cost measures the value of reduced loads during system peak periods; that is, the reduced requirement to have capacity available to meet peak demand. This saving is often valued at the cost of a combustion turbine, which is usually considered the lowest cost capacity available. This convention is explained in Appendix E. ASEUM calculates the avoided cost rate per kWh of energy saved. These values are used to calculate societal benefits from reduced electricity consumption.

ASEUM calculates avoided energy costs based on a disaggregation of the national generation fuel mix to the ten National Electric Reliability Council (NERC) regions and a simplified load duration curve (LDC) for each region. No attempt is made to segment the demand by region, but rather the electricity demand loss is assumed proportional. The fraction of the electricity that would have to be generated at the margin from oil and gas is calculated from total regional oil and gas generation and a simplified LDC. Projected utility natural gas and coal prices, weighted by the oil and gas marginal fraction and the non-oil and gas marginal fraction, respectively, are used to calculate utility marginal energy costs during the forecast period.

The avoided-capacity cost calculation in the model is based on a conservation load factor (CLF) for the energy savings attributable to the efficiency level, as well as the cost of a combustion turbine. A CLF is defined as the average load savings of a conservation measure (in kW) divided by its peak-load savings. The peak savings are averaged over an on-peak period from 0800 to 2000. This wide on-peak period yields a conservative estimate for peak-load savings that accounts for coincidence with system peak demand.

The CLF is used to characterize the peak demand savings of a conservation measure. It is used to convert the capacity value of the alternative efficiency levels into a per kWh value described above. The analysis assumes that the load shapes of appliances do not change as these appliances are made more efficient.

The NERC forecasts of capacity requirements for each region are used to account for regional variations in reserve margin. If NERC predicts an adequate reserve margin in a region for a given future year, no reliability value is given to the peak load savings in the region.

The net revenue loss is equal to the difference between the revenue reductions and avoided costs. Revenue reduction is calculated by multiplying the change in electricity consumption by the average national residential rate. Avoided costs are calculated from the change in electricity consumption multiplied by the per-unit, avoided costs.

The inputs needed for the utility impact calculations include electricity savings, conservation load factors, utility fuel prices, average electricity prices, electricity generation by fuel type, and capacity need by NERC region. The outputs of the analysis are the reduction in the need for new generating capacity, the net change in revenues, and the avoided energy and capacity costs for an appliance per MMBtu of source energy. These marginal costs are used to calculate societal costs and benefits of implementing new efficiency levels.

Assumptions in the Analysis

Justifications for the most important assumptions in ASEUM are listed below. These assumptions include the shape of the regional LDCs, conservation factors that remain constant through the analysis, the regional distribution of energy savings, utility marginal costs, and the substance of NERC forecasts.

Assumption	*Justification*
• The analysis calculates the period during which oil and gas or coal are the marginal fuels for electricity generation based on a simplified LDC for each NERC region. It therefore assumes that this LDC accurately reflects the distribution of fuels on the margin.	There is little information by NERC region on which fuels are marginal. Since NERC supplies the total amount of fuel burned for generation, a method is needed to convert total generation into an estimate of marginal generation, and using an LDC is the usual way to derive such an estimate. Because most peak generating technologies, such as gas turbines, use light fuels, these fuels will be used by utilities to meet peak loads; hence, oil and gas are assumed to be at the top of the LDC. The other fuel assumed to appear on the margin is coal, since nuclear, hydro, and purchases from independent generators are usually base-loaded.
• Oil and gas fractions (OGFs) for each NERC region remain constant throughout the analysis period.	Constant OGFs are assumed to simplify computation. The OGFs are calculated using the simplified LDCs described above and by averaging NERC forecasts of the total amount of oil and gas generation for the years 1990 to 1995. There are no forecasts for the amount of oil and gas generation after 1995. Because these calculations are highly uncertain, and because no other forecasts are available, the analysis assumes constant OGFs.
• Energy savings accrue in each region in proportion to the region's consumption of heating, cooling, and baseload energy in 1980.	This approach is an approximation made necessary by insufficient information and for computational convenience. Information is available on average saturations and appliance efficiencies, by state, that can be aggregated to NERC regions.
• Utility marginal energy costs are calculated using the sum of utility natural gas and coal prices weighted by the oil and gas fraction and the non-oil and gas fraction, respectively. This approach assumes that all marginal generation has the same heat rate.	Different generating units have different heat rates, but the extent of this variation for utility generating systems in different NERC regions has not been calculated. A 34% energy conversion efficiency is typical for current generating units.

Assumptions	*Justification*
• The NERC forecasts of changes in adjusted reserve margin are accurate.	The NERC forecasts are widely accepted. They are the only forecasts of adjusted reserve margin at the regional level.

3.3.5 Life-Cycle Cost Analysis, Payback Period, and Cost of Conserved Energy

One measure of the effect of implementing new efficiency levels on consumers is the change in operating expenses as compared to the change in purchase prices. These changes are quantified by the difference in life-cycle costs (LCC) between the base and efficiency level cases for the appliance classes analyzed. The LCC is the sum of the purchase price and the operating expense discounted over the lifetime of the appliance. It is calculated at the average efficiency for each class in the year efficiency levels are imposed using real consumer discount rates of 2%, 6%, and 15%. The purchase price is based on the factory costs in the Engineering Analysis and includes a factory markup plus a distributor and retailer markup. Maintenance and installation costs are included, when appropriate. The operating expense is calculated using the unit energy consumption data in the LBNL-REM. Energy prices are taken from *Annual Energy Outlook 1995* and appliance usage are taken from the results of the LBNL-REM.

The life-cycle cost analysis also examines the payback periods (PBPs) and the cost of conserved energy (CCE) associated with the alternative efficiency levels. The PBP measures the amount of time it takes to recover additional investment in increased efficiency through lower operating costs. Numerically, it is the ratio of the increase in purchase price between the base and efficiency level cases to the decrease in annual operating expenditures. Both the numerator and denominator of this expression are evaluated at the average efficiency in the year new efficiency levels come into effect and at energy prices in that year. The CCE is the increase in purchase price amortized over the lifetime of the appliance, divided by the annual energy savings.

Details of these calculations may be found in Chapters 4 of the product-specific discussion of ranges and ovens (Volume 2).

3.3.6 Environmental Analysis

As mentioned in Section 3.3.4 above, the ASEUM model now conducts both the electric utility and environmental analyses. Further details of the environmental calculations and results can be found in the Environmental Assessment, which is included in this volume. The environmental calculations are quite straightforward. Reductions in energy use estimated by LBNL-REM are multiplied by emissions factors to estimate net emissions reductions.

The main environmental effects of electricity generation and distribution on air and water quality result from emissions of sulfur dioxide (SO_2), nitrogen oxides (NO_x), and carbon dioxide (CO_2). With the alternative efficiency levels lessening the need for electricity generation, in general, power plant emissions would be reduced. However, the case of SO_2 is complicated by the emissions cap provision of the 1991 Clean Air Act Amendments. In the case of this pollutant, the reduction in emissions reported should be interpreted as reduced demand for emissions. Physical emissions of SO_2 will most likely not change, although the price of emission allowances should be lower than the case absent the imposition of new efficiency levels. The ASEUM model also estimates the effect of implementing new efficiency levels on the three emissions resulting from in-house combustion.

The numerous other, but more minor, effects of power generation, such as water pollution, land-use effects, etc., are not covered in the analysis of appliance energy efficiency levels. The net effect of an appliance energy efficiency level on such environmental problems are just too small to be measurable.

The multipliers used in this Technical Support Document are derived from a report that accompanied the 1991 NES (6). Estimation of multipliers over future periods is not as straightforward as it may seem. Our reasonable expectation is of improved emission controls over time and the effectiveness of these improvements must be forecast. In addition, future restrictions on emissions of greenhouse gases could have a major impact on CO_2 emissions. Table 3.3 shows some sample emission factors. As is clear, the forecast emission factor for SO_2 falls dramatically as the provisions of the Clean Air Act become effective. The factor for NO_x falls, but less dramatically, while the CO_2 emissions, which have no currently known feasible abatement strategy, fall modestly.

Table 3.3 Emissions Factors for Power Generation

Year	SO_2 *g/kWh*	NO_x *g/kWh*	CO_2 *g/kWh*
2000	3.463	2.578	964.2
2010	2.550	2.216	977.5
2020	1.639	1.897	973.2
2030	0.951	1.169	952.1

Clearly, the approach used in this analysis assumes that the generation avoided will be similar Is thisin its environmental effects to average generation. That is, no effort is made to conduct a marginal rather than average analysis, even though the fraction of time that a certain fuel is a marginal fuel will not be the same as its share of overall generation. For residential air conditioning and cooking, this is a reasonable assumption. Generation will be reduced at all times of the year and coal and gas will both be marginal for some of the time.

Table 3.4 shows the emissions factors used for in-house emissions, which are assumed fixed over the forecast period.

Table 3.4 Emissions Factors for In-House Emissions

Year	SO_2		NO_x		CO_2	
	Gas	Oil	Gas	Oil	Gas	Oil
2000	0	134.6	45.1	55.9	47291	72485

3.4 SENSITIVITY ANALYSIS

Sensitivity studies are performed to determine how changes in technical and operational parameters affect key engineering and economic indicators used in the evaluation of appliance energy efficiency levels. This makes it possible to place bounds on the uncertainty in the results of the analysis and to gain an understanding of which variables are most important in producing these results. Sensitivity analyses are developed in a series of distinct steps. For each computer model in the analysis, critical input parameters are identified and reasonable ranges of variation are determined. The sensitivity of the model to changes in the value of each important parameter is then estimated by running the model for the base case and efficiency level cases. The significance of the results is assessed in terms of the magnitude of change in each model's outputs.

Sensitivity runs are made with the LBNL-REM to explore the effects of uncertainty in the equipment and operating cost of the products being analyzed. The costs of the baseline unit as well as the incremental costs of design options are varied. Other sensitivity runs examine alternative efficiency trends in the absence of implementing new efficiency levels.

Sensitivity analysis of the results of the LBNL-MAM is conducted mainly from a sensitivity chart that reports the sensitivity of ROE to each of the nine control variables. Because the LBNL-MAM is a non-linear model, the effects of these input uncertainties may not be additive. A Monte Carlo analysis addresses this problem by computing standard errors, which are displayed in the output table. For each control variable, the Monte Carlo section randomly picks a value near the best estimate of its true value. As a result, the outputs of Monte Carlo vary from run to run. After finishing a batch of runs (typically 100 to 400), the LBNL-MAM calculates means and standard deviations for the five main output variables.

The results of the sensitivity analyses are examined to extract two types of information. First, the base case runs of the model are analyzed to determine the sensitivity of the forecasts to exogenous variables and assumptions. Second, the sensitivity analysis of the impacts of alternative efficiency levels is performed by examining the differences between the base and efficiency level cases. A variable that affects the two cases similarly will have little effect on the impact of imposed efficiency levels, even though it might have a significant effect on the absolute forecasts. The primary interest in the second type of sensitivity analysis is in variables and assumptions that affect the two cases differently.

The sensitivity analyses of the impacts of efficiency levels are discussed in Chapter 6 of the product-specific discussion of ranges and ovens.

REFERENCES

1. E. Hurst and J. Carney. 1978. *The ORNL Engineering-Economic Model of Residential Energy Use*, Oak Ridge National Laboratory, Oak Ridge, TN. ORNL/CON-24.

2. J.E. McMahon. 1987. "The LBL Residential Energy Model: An Improved Policy Analysis Tool," *Energy Systems and Policy*, vol. 10, no. 1, pp. 41-71.

3. U.S. Department of Energy (U.S. DOE). 1988. *Energy Conservation Program for Consumer Products: Advance Notice of Proposd Rulemaking and Request for Public Comments Regarding Energy Conservation Standards for Dishwashers, Clothes Washers, and Clothes Dryers*," Washington, D.C. Federal Register, vol. 53, no. 96, 17712-17721.

4. U.S. Department of Commerce, Bureau of the Census. 1983. *1980 Census of Population and Housing*. Washington, D.C. PC80-A1.

5. U.S. DOE, Energy PC80-1-A1 Information Administration. 1995. *Annual Energy Outlook 1995 with Projections to 2010*, Washington, D.C. DOE/EIA-0383(95), January

6. U.S. DOE, Energy Information Administration. 1991. *Improving Technology: Modeling Energy Futures for National Energy Strategy*. Service Report to the 1991 National Energy Strategy. Washington, D.C. SR/NES/90-01.

Volume 1 contains five chapters and five appendices:

Chapter 1 Executive Summary: presents an overview of the analysis.

Chapter 2 Introduction: outlines the structure of the document.

Chapter 3 Analytic Approach: summarizes the methodology used in the analysis; discusses the components of the analysis and their interrelationships; describes the models used, their data requirements, and their outputs; and identifies the primary assumptions of the analysis. This chapter also provides an overview of the methodology employed to examine the sensitivity of the results to changes in the key assumptions, parameters, and exogenous forecasts used in the analysis.

Chapter 4 Industry Profile: discusses appliance saturations, market shares, and industry structure.

Chapter 5 Development of Base Case Forecasts: discusses population projections, housing starts, commercial floorspace projections, and energy prices.

The appendices in Volume 1 cover the following topics:

Appendix A Methodology for uncertainty analysis of maximum technologically feasible energy efficiency.

Appendix B Overview of the forecasting model: structure of the LBNL Residential Energy Model (LBNL-REM) program. The principal components of the model are discussed and the component interrelationship is explained. In Volume 2, Appendices B describe and define the inputs to the model specific to each respective end use.

Appendix C Overview of Manufacturer Analysis Model (LBNL-MAM): outlines how an industry profile of the manufacturing firms affected is constructed; describes how the effects on appliance manufacturers of imposing efficiency levels by product are quantified; defines the results of the analysis in terms of changes in gross margin, return on sales, return on equity, return on assets, total assets, and labor requirements; and presents the method for conducting a sensitivity analysis of the results.

Appendix D Maintenance costs are derived for several components common to more than one appliance type.

Appendix E Electric utility impact modeling.

Environmental Assessment: Quantifies impacts of alternative efficiency levels on emissions of carbon dioxide, nitrogen oxides, and sulfur oxides.

Volume 2 contains detailed analyses corresponding to kitchen ranges and ovens.

Chapter 1 Engineering Analysis: contains detailed energy use and cost information.

Chapter 2 Base Case Forecasts: describes national forecasts of energy consumption, efficiency of new units, units installed in households, and annual appliance sales in the absence of new regulations.

Chapter 3 Projected National Impacts of Alternative Efficiency Levels: discusses the choice of efficiency levels to be analyzed and the projected impacts of each efficiency level. The chapter summarizes the energy savings by fuel and product; the sales, average efficiencies, purchase costs, and operating costs of new and replacement appliances; and the net present benefit of the alternative efficiency levels.

Chapter 4 Life-Cycle Costs and Payback Periods: describes the effects of imposed efficiency levels on individual purchasers and users of appliances. It compares the life-cycle cost of appliances and other measures of consumer impact with and without implementing new efficiency levels.

Chapter 5 Impacts of Alternative Efficiency Levels on Manufacturers: describes the analysis methodology, short- and long-run impacts, and sensitivity analysis.

Chapter 6 Impact of Alternative Efficiency Levels on Electric Utilities: describes the effects of imposed efficiency levels on the electric utility industry, focusing on marginal costs of electricity, generating capacity growth, changes in regional capacity and energy demand, and changes in utility revenues and costs.

Chapter 7 Environmental Effects: describes changes induced by the implementation of new efficiency levels in emissions of oxides of carbon, sulfur, and nitrogen from combustion of fossil fuels for electricity generation and in homes.

Appendices A through C contain more detailed information on the models and databases used in the economic analysis of kitchen ranges and ovens.

Appendix A Energy Use and Cost Data: provides a breakdown of the costs for each design option. This appendix also includes additional information pertinent to the Engineering Analysis.

Appendix B Forecasting Model (LBNL-REM): gives a detailed description of the data used to calculate consumer impacts. The input data stream for the base case runs is shown and changes to the input data for the efficiency level cases are indicated.

Appendix C Manufacturer Impact Analysis: provides a detailed description of the model to estimate financial impacts of the imposition of efficiency levels on the manufacturers of covered products. The appendix shows the structure of the model, the data sources used, and detailed outputs of base case, efficiency level case, and sensitivity analysis runs.

prices, and life-cycle cost curves are constructed for each class. The payback periods associated with each incremental change in efficiency are also calculated.

The Consumer Analysis focuses on national energy savings and economic impacts on consumers up to the year 2030. It forecasts efficiencies and sales of new appliances by class, as well as appliance usage levels in response to changes in projected energy prices and incomes. These results are used to project energy use and consumer expenditures on fuel and equipment. The net present value of the alternative efficiency levels are computed by discounting the differences in the time streams of these expenditures in the "with" and "without" efficiency level cases.

The Manufacturer Impact Analysis estimates the overall impact of imposing new of amended efficiency levels on manufacturers. The analysis examines long-run impacts on 1) profitability, 2) growth, and 3) competitiveness. To do this, two measures of impact are tracked for the industry as a whole and for any segments that may exist: 1) return-on-equity (ROE) and 2) net income. ROE provides the primary measure of profitability; gross margin, return-on-assets (ROA), and return-on-sales (ROS) are also reported. The analysis also shows total assets, shipments, average prices, and revenues. Assets and income are the measures of growth (positive or negative).

The Industry Impact Analysis analyzes two short-run impacts as well. First, the ability of the industry as a whole and of specific segments of the industry to make the one-time investments required to meet the new efficiency levels is examined. Second, if implementing new efficiency levels result in decreased sales for the particular industry being analyzed, the analysis examines the possibility of price-cutting while the industry is adjusting to a lower sales volume.

The Life-Cycle Cost Analysis evaluates the impacts on individual consumers by determining the changes in life-cycle cost resulting from the imposition of the energy efficiency levels.

The Utility Analysis focuses on revenue changes, avoided costs, and reductions in peak electric loads. Utility-avoided costs represent the marginal value of lower fuel consumption as well as the marginal value of lower investment in new generating plants. Reduction in peak loads can lead to deferring the construction of new generating capacity. Because fuel costs and the need for additional capacity are region-specific, the Utility Analysis is conducted on a regional basis.

The Cost-Benefit Analysis provides a picture of the sum total of all the analyses, so that the impacts of the efficiency levels may be viewed not just as components but on a much larger scale.

Finally, the Environmental Assessment measures the main environmental effects (reduced particulate emissions) resulting from the alternative efficiency levels' effect on reduced electricity and fuel demand. This assessment is completed for each appliance and for each alternative efficiency level.

LIST OF TABLES

LIST OF FIGURES