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EIA Model Documentation

INDUSTRIAL SECTOR DEMAND MODULE OF THE NATIONAL ENERGY MODELING SYSTEM

January 1997

Office of Integrated Analysis and Forecasting
Energy Information Administration
U.S. Department of Energy
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1. Introduction

Purpose of this Report

This report documents the objectives, analytical approach, and development of the National Energy Modeling System (NEMS) Industrial Demand Model. The report catalogues and describes model assumptions, computational methodology, parameter estimation techniques, and model source code.

This document serves three purposes. First, it is a reference document providing a detailed description of the NEMS Industrial Model for model analysts, users, and the public. Second, this report meets the legal requirement of the Energy Information Administration (EIA) to provide adequate documentation in support of its models (*Public Law 94-385, section 57.b2*). Third, it facilitates continuity in model development by providing documentation from which energy analysts can undertake model enhancements, data updates, and parameter refinements as future projects.

Model Summary

The NEMS Industrial Demand Model is a dynamic accounting model, bringing together the disparate industries and uses of energy in those industries, and putting them together in an understandable and cohesive framework. The Industrial Model generates mid-term (up to the year 2015) forecasts of industrial sector energy demand as a component of the NEMS integrated forecasting system. From the NEMS system, the Industrial Model receives fuel prices, employment data, and the value of industrial output. Based on the values of these variables, the Industrial Model passes back to the NEMS system estimates of consumption by fuel types.

The NEMS Industrial Model estimates energy consumption by energy source (fuels and feedstocks) for 9 manufacturing and 6 nonmanufacturing industries. The manufacturing industries are further subdivided into the energy-intensive manufacturing industries and non-energy-intensive manufacturing industries. The energy-intensive industries are modeled through the use of a detailed process flow accounting procedure, whereas the non-energy-intensive, as well as the nonmanufacturing industries, are modeled through econometrically based equations. The industrial model forecasts energy consumption at the four Census region levels; energy consumption at the Census division level is allocated by using SEDS data.

Each industry is modeled as three components consisting of the process/assembly component (PA), the buildings component (BLD), and the boiler/steam/cogeneration component (BSC). The BSC component satisfies steam demand from the PA and BLD components. In some industries, the PA component produces byproducts that are consumed in the BSC component. For the energy-intensive industries, the PA component is separated into the major production processes or end uses.

Archival Media

The model has been archived on IBM RISC 6000 magnetic tape storage as part of the National Energy Modeling System production runs used to generate the Annual Energy Outlook 1997. It is archived as File 1 on Verbatim tape, 8mm-DL 112M, serial number 1046G112.

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Organization of this Report

Chapter 2 of this report discusses the purpose of the NEMS Industrial Demand Model, detailing its objectives, input and output quantities, and the relationship of the Industrial Model to the other modules of the NEMS system. Chapter 3 of the report describes the rationale behind the Industrial Model design, providing insights into further assumptions utilized in the model. Chapter 4 reports model sensitivities. Chapter 5 details the model structure. The first section in Chapter 5 provides an outline of the model. The second section in Chapter 5 provides a description of the principal model subroutines, including the key computations performed and key equations solved in each subroutine.

The Appendices to this report provide supporting documentation for the Industrial Model. Appendix A lists and defines the common variables used in the Industrial Model in Tables A1-A11. The same variable names are used in the text of the documentation. Table A12 provides a brief description of the subroutines used in the model. Appendix B is a bibliography of data sources and background materials used in the model development process. Appendix C consists of a model abstract. Appendix D lists the input data and estimation methods for deriving the input data.

2. Model Purpose

Model Objectives

The NEMS Industrial Demand Model was designed to forecast industrial energy consumption by fuel type and Standard Industrial Classification (SIC). The Industrial Model generates mid-term (up to the year 2015) forecasts of industrial sector energy demand as a component of the NEMS integrated forecasting system. From the NEMS system, the Industrial Model receives fuel prices, employment data, and the value of output for industrial activity. All dollar values are expressed in 1987 dollars. Based on the values of these variables, the Industrial Model passes back to the NEMS system estimates of fuel consumption for seventeen main fuels (including feedstocks and renewables) for each of 15 SIC industry groups. The Industrial Model forecasts energy consumption at the four Census region levels; energy consumption is allocated to the Census division level based on SEDS data.

The NEMS Industrial Model is an annual energy forecasting model; as such, it does not model seasonal variations in fuel demand or fuel prices. The model was designed primarily for use in applications such as the *Annual Energy Outlook* and other applications that examine mid-term energy-economy interactions.

The model can also be used to examine various policy, environmental, and regulatory initiatives. For example, energy consumption per dollar of output is, in part, a function of energy prices. Therefore, the effect on industrial energy consumption of policies that change relative fuel prices can be analyzed endogenously in the model.

To a lesser extent, the Industrial Model can endogenously analyze specific technology programs or energy standards regulations. The model distinguishes among the energy-intensive manufacturing industries, the non-energy-intensive manufacturing industries, and the non-manufacturing industries. Energy consumption in the non-energy-intensive industries is modeled econometrically. Consequently, the Industrial Model does not currently have the capability to model technologies or processes for these industries.

A process flow approach, represented by their major production processes or end uses, is used to model the energy-intensive industries. This approach provides considerable detail about how energy is consumed in that particular industry. Even using this approach, however, the process flows are modeled at a high degree of aggregation. Therefore, technologies or processes at the same level of aggregation as the model can be endogenously analyzed by changing the relevant unit energy consumption values for those technologies or processes. For example, the model can analyze changes at the level of a blast furnace or a pulping process. To model technologies or processes at a lower level of aggregation, off-line analysis can be performed, and the results incorporated into the model through the use of engineering judgment.

Interaction with Other NEMS Models

Table 1 shows the Industrial Model inputs from and outputs to other NEMS modules. Note that all inter-module interactions must pass through the integrating module.

Table 1. Interaction With Other NEMS Modules

INPUTS	From Module
Controlling information (iteration count, present year, number of years to be modeled, convergence switch, etc.)	System
Electricity prices	Electricity Market Module
Natural gas prices	Natural Gas T & D
Steam coal prices Metallurgical coal prices	Coal Supply
Distillate oil prices Residual oil prices LPG prices Motor gasoline prices Petrochemical feedstock prices Asphalt and road oil prices Other petroleum prices	Petroleum Market Module
Value of output Employment	Macro
Refinery consumption of: Natural gas Steam coal Distillate oil Residual oil LPG Still gas Petroleum coke Other petroleum Purchased Electricity	Petroleum Market Module
Lease and Plant Natural Gas Consumption	Natural Gas Transmission and Distribution Module

Table 1. Interaction with Other NEMS Modules, cont.

OUTPUTS	To Module
Industrial consumption of: Purchased electricity Natural gas Steam coal Metallurgical coal Net coal coke imports Distillate oil Residual oil LPG Motor gasoline Kerosene Petrochemical feedstocks Still gas Petroleum coke Other petroleum	Supply Modules
Consumption of renewables: Biomass Hydropower Solar/wind/geothermal/etc.	System
Nonutility generation: Cogeneration of electricity Electricity sales to the grid and own use	Electricity Market Module

3. Model Rationale

Theoretical Approach

Introduction

The NEMS Industrial Model can be characterized as a dynamic accounting model, because its architecture attempts to bring together the disparate industries and uses of energy in those industries, and put them together in an understandable and cohesive framework. This explicit understanding of the current uses of energy in the industrial sector is used as the framework from which to base the dynamics of the model.

One of the overriding characteristics in the industrial sector is the heterogeneity of industries, products, equipment, technologies, processes, and energy uses. Adding to this heterogeneity is that the industrial sector includes not only manufacturing, but also agriculture, mining, and construction. These disparate industries range widely from highly energy-intensive activities to non-energy-intensive activities. Energy-intensive industries are modeled at a disaggregate level so that changes in composition of the products produced will not significantly offset accounting of energy consumption. Other industrial modeling approaches have either lumped together these very different activities across industries or users, or they have been so disaggregate as to require extensive resources for data development and for running the model.

Modeling Approach

A number of considerations have been taken into account in building the industrial model. These considerations have been identified largely through experience with the current and previous EIA models and with various EIA analyses, through communication and association with other modelers and analysts, and through literature review. The primary considerations are listed below.

- The industrial model incorporates three major industry categories, consisting of energy-intensive manufacturing industries, non-energy-intensive manufacturing industries, and nonmanufacturing industries. The level and type of modeling and the attention to detail is different for each.

- Each industry is modeled as three separate but interrelated components, consisting of boilers/steam/cogeneration (BSC), buildings (BLD) and process/assembly (PA) activities.

- The model uses a vintaged capital stock accounting framework that models energy use in new additions to the stock and in the existing stock. The existing stock is retired based on retirement rates for each industry.

- The energy-intensive industries are modeled with a structure that explicitly describes the major process flows or major consuming uses in the industry.

- Technology penetration at the level of major processes in each energy-intensive industry is based upon engineering judgment.

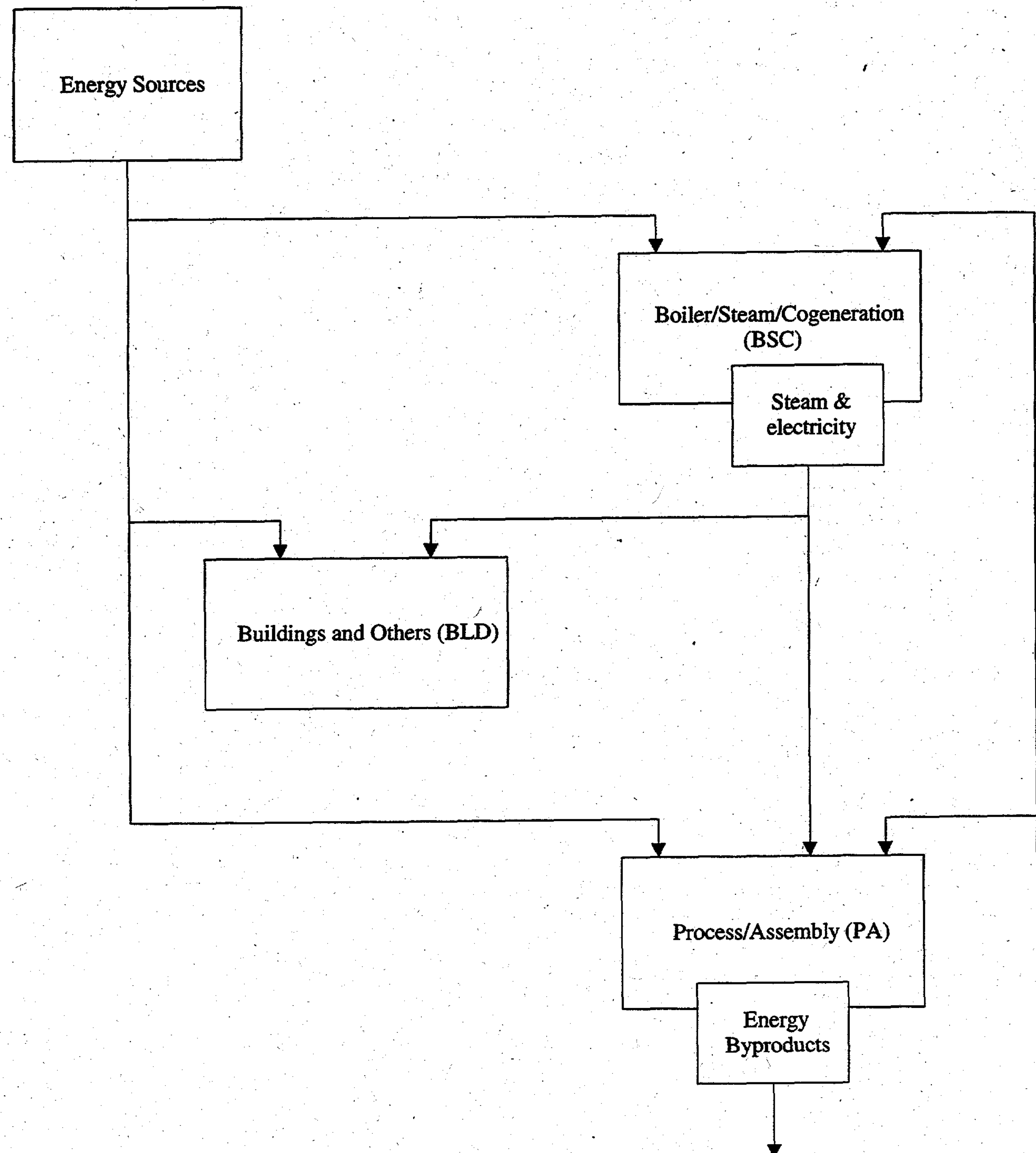
- The model structure accommodates several industrial sector activities including: fuel switching, cogeneration, renewables consumption, recycling and byproduct consumption. The principal model calculations are performed at the four Census region levels and aggregated to a national total.

Fundamental Assumptions

The industrial sector consists of a wide variety of heterogeneous industries. The Industrial Model classifies these industries into three groups by Standard Industrial Classification (SIC) - energy-intensive industries, non-energy-intensive industries, and non-manufacturing industries. There are eight energy-intensive manufacturing industries; seven of these are modeled in the industrial model. These are as follows: food and kindred products (SIC 20); paper and allied products (SIC 26); bulk chemicals (SICs 281, 282, 286, and 287); glass and glass products (SICs 321, 322, and 323); hydraulic cement (SIC 324); blast furnaces and basic steel products (primarily SICs 331, 332, etc.); and primary aluminum (primarily SICs 3334, 3341, 3353, 3354, 3355, etc.). Petroleum refining (SIC 2911) is modeled in detail in a separate module of NEMS, and the projected energy consumption is included in the manufacturing total. The forecast for Oil and Gas (SIC 1311) lease and plant and cogeneration consumption are exogenous to the Industrial model, but endogenous to the NEMS modeling system.

Each industry is modeled as three separate but interrelated components consisting of the process/assembly component (PA), the buildings component (BLD) and the boiler/steam/cogeneration component (BSC). (See Figure 1). The BSC component satisfies the steam demand from the PA and BLD components. For the energy-intensive industries, the PA component is broken down into the major production processes or end uses.

Figure 1. Industrial Model Components



The flow of energy among the three industrial model components follows the arrows. Energy consumption in the NEMS Industrial Model is primarily a function of the level of industrial economic activity. Industrial economic activity in the NEMS system is measured by the dollar value of output produced by each SIC industry group. The value of output for the Industrial Model by SIC is provided by the NEMS MACRO Module. As the level of industrial economic activity increases, the amount of energy consumed to produce the relevant industrial products typically increases at a slower rate.

The amount of energy consumption reported by the Industrial Model is also a function of vintage of the capital stock that produces the output. It is assumed that new vintage stock will consist of state-of-the-art technologies that are relatively more energy efficient than the average efficiency of the existing capital stock. Consequently, the amount of energy required to produce a unit of output using new capital stock is less than that required by the existing capital stock. The energy intensity of the new capital stock relative to 1991 capital stock is reflected in the parameter of the Technology Possibility Curve estimated for each of the energy-intensive industries. These curves are based on engineering judgment of the likely future path of energy intensity changes.

The energy intensity of the existing capital stock also is assumed to decrease over time, but not as rapidly as new capital stock. The decline is due to retrofitting and replacement of equipment due to normal wear and tear. The net effect is that over time the amount of energy required to produce a unit of output declines. Although total energy consumption in the industrial sector is projected to increase, overall energy intensity is projected to decrease.

Energy consumption in buildings is assumed to grow at the same rate as employment in that industry.[1] Energy consumption in the BSC is assumed to be a function of the steam and electricity requirements of the other two components.

Industry Disaggregation

Table 2 identifies the industry groups to be modeled in the industrial sector along with their Standard Industrial Classification[2] (SIC) code coverage. These industry groups have been chosen for a variety of reasons. The primary consideration is the distinction between energy intensive groups (or large energy consuming industry groups) and non-energy-intensive industry groups. The energy-intensive industries are modeled more in detail, with aggregate process flows. The

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[1]Note that manufacturing employment generally falls in a typical *Annual Energy Outlook* forecast. As a result, buildings' energy consumption falls over time. Given this situation, we have assumed there is no additional consumption decline due to efficiency increases.

[2]The Standard Industrial Classification (SIC) codes have been modified at various points in time, leading to occasional difficulties with tracking specific industries over time. In general this is not a problem, but does lead to some difficulties with matching some databases, including the National Energy Accounts.

industry categories are also to be as consistent as possible with the categories which are available from the Manufacturing Energy Consumption Survey (MECS).[3] Table 2 identifies 6 nonmanufacturing industries and 9 manufacturing industries. Within the manufacturing industries, the seven most energy-intensive are modeled in greater detail in the Industrial Demand Model. Refining (SIC 2911), also an energy-intensive industry, is modeled elsewhere in NEMS.

Table 2. Industry Categories

Energy-Intensive Manufacturing	**Nonmanufacturing Industries**
Food and Kindred Products (SIC 20)	Agricultural Production - Crops (SIC 01)
Paper and Allied Products (SIC 26)	Other Agriculture including Livestock (SIC 02, 07, 08, 09)
Bulk Chemicals (SIC 281, 282, 286, 287)	Coal Mining (SIC 12)
Glass and Glass Products (SIC 321, 322, 323)	Oil and Gas Mining (SIC 13)
Hydraulic Cement (SIC 324)	Metal and Other Nonmetallic Mining (SIC 10, 14)
Blast Furnaces and Basic Steel (SIC 331, 322)	Construction (SIC 15, 16, 17)
Primary Aluminum (SIC 3334)	
Nonenergy-Intensive Manufacturing	
Metals-Based Durables (SIC 34, 35, 36, 37, 38)	
Other Manufacturing (all remaining manufacturing SIC)	

SIC = Standard Industrial Classification.
Source: Office of Management and Budget, *Standard Industrial Classification Manual 1987* (Springfield, VA, National Technical Information Service).

Energy Sources Modeled

The NEMS Industrial Model estimates energy consumption by 15 SIC industries for 17 energy types. The major fuels modeled in the Industrial Model are:

- Electricity

[3] All of the two digit industries can be made consistent with the published tables in MECS, but the published MECS tables do not always have subcategories (below 2 digit) that add up to their industry total. Moreover, in cases where there are subcategories, MECS uses fairly specific 4-digit industry which is typically at a lower level of detail than that which is desired for the industrial model. This makes for some difficulty with coordination.

- Natural Gas
- Steam Coal
- Distillate Oil
- Residual Oil
- LPG for heat and power
- Other Petroleum
- Renewables
- Motor Gasoline

Other energy sources that are used in specific industries are also modeled:

- Natural Gas Feedstock
- Coking Coal (including net imports)
- LPG Feedstock
- Petrochemical Feedstocks
- Asphalt and Road Oil
- Still Gas
- Petroleum Coke
- Other Petroleum Feedstocks

In the model, byproduct fuels are always consumed before purchased fuels.

Key Computations

The key computations of the Industrial Model are the Unit Energy Consumption (UEC) estimates made for each SIC industry group. UEC is defined as the amount of energy required to produce one dollar's worth of output. The overall modeling approach posits a *putty/clay* process of investment to determining UECs. This means that before a piece of equipment or industrial process is installed, the factor inputs may be somewhat variable. Thus, the combination of energy and other factor inputs will be chosen to minimize costs (for a given output level) based on the current price expectations. However, after installation the capital has become clay, and factor proportions cannot be changed without additional investment. This characterization of the industrial expansion process leads to the notion that the existing capital stock has limited variation of input ratios of energy versus other factors, but when new capital is added the input ratios are more variable. In practice, the fuel use pattern typically is similar across vintages. Distinguishing between the characteristics of the process when new capital equipment is put into place and the characteristics of the process with existing capital equipment is done with a vintage-based accounting procedure.

The modeling approach incorporates technical change in the production process to achieve lower energy intensity. Autonomous technical change can be envisioned as a learning-by-doing process for existing technology. As experience is gained with a technology, the costs of production decline. Autonomous technical change is the most important source of energy-related changes in the industrial sector. The reason is that few industrial innovations are adopted solely because of their energy consumption characteristics; industrial innovations are adopted for a combination of factors. These factors include process changes to improve product quality, changes made to improve productivity, or changes made in response to the competitive environment. These strategic decisions are not readily amenable to economic or engineering modeling at the level of disaggregation in the Industrial Model.

Buildings Component UEC

Buildings are estimated to account for 6 percent of heat and power energy consumption in manufacturing industries.[4] Estimates of 1991 manufacturing sector building UEC's are presented in Table D1 in Appendix D. Energy consumption in industrial buildings is assumed to grow at the same rate as employment in that industry. This assumption appears to be reasonable since lighting and HVAC are used primarily for the convenience of humans rather than machines.

Process and Assembly Component UEC

The process and assembly component accounted for the largest share, 52 percent, of direct energy consumption for heat and power in 1991. Of the total, natural gas accounts for 52 percent and electricity accounts for 38 percent.

Estimation of the PA component UECs differs according to whether the industry is an energy-intensive industry or an energy non-intensive industry. UECs for the energy non-intensive industries are estimated using econometric techniques. For the energy-intensive industries, the econometric estimates are replaced by engineering data relating energy consumption to the product flow through the process steps in each industry. In addition, engineering judgment is also used to characterize autonomous change in the energy-intensive industries through the use of Technology Possibility Curves. Each of these methods is discussed in the following sections.

Fuel shares for process and assembly energy use in six of the energy-intensive manufacturing industries[5] are adjusted for changes in relative fuel prices. The six industries are food, paper, chemicals, glass, cement, and steel. In each industry, two logit fuel-sharing equations are applied to revise the initial fuel shares obtained from the process-assembly component. The resharing does not affect the industry's total energy use--only the fuel shares. The methodology adjusts

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[4] Computed from Energy Information Administration, *Manufacturing Consumption of Energy 1991*, DOE/EIA-0512(91) (Washington, DC, December 1994), Table 36. Note that byproduct and non-energy use of combustible fuels are excluded from the computation.

[5] Primary aluminum is excluded because it uses only electricity in the process and assembly component.

total fuel shares across all process stages and vintages of equipment to account for aggregate market response to changes in relative fuel prices.

The fuel share adjustments are done in two stages. The first stage determines the fuel shares of electric and nonelectric energy. The latter group excludes boiler fuel and feedstocks. The second stage determines the fossil fuel shares of nonelectric energy. In each case, a new fuel-group share, $NEWSHR_i$, is established as a function of the initial, default fuel-group shares, $DEFLTSHR_j$ and fuel-group price indices, $PRCRAT_i$. The price indices are the ratio of the current year price to the base year price, in real dollars. The formulation is as follows:

$$NEWSHR_i = \frac{DEFLTSHR_i * e^{(\beta_i - \beta_i * PRCRAT_i)}}{\sum_{j=1}^{N} DEFLTSHR_j * e^{(\beta_j - \beta_j * PRCRAT_j)}} \quad (1)$$

where:

$NEWSHR_i$ = New fuel-group share for fuel i, and

$DEFLTSHR_i$ = Default fuel-group share for fuel i,

The coefficients β_j are all assumed to be 1.

The form of the equation results in unchanged fuel shares when the price indices are all 1, or unchanged from their 1995 levels. The implied own-price elasticity of demand is about -0.2.

Non-Energy-Intensive Manufacturing UEC Estimation

Currently, non-manufacturing UEC estimation incorporates price-induced energy intensity changes and autonomous efficiency trends in a single equation. The resulting equation shows that the change in UEC results from a combination of autonomous and price-induced technical change. One process operates on the existing stock (or technology). It is expected that small but measurable efficiency gains can be obtained even with the existing technology. The other process operates through the incorporation of new technology and current price expectations in the production process.

The price-induced technical change can be represented as a function of price changes. The autonomous change is somewhat more problematical. However, one may argue that as equipment using the current technology undergoes maintenance and refurbishing that the tendency is to incorporate the latest version of the equipment being replaced. Usually, the latest versions consume energy somewhat differently. The autonomous trend can be represented as a function of cumulative output from existing technology. The resulting equation takes the following form:

$$\frac{UEC_{f,t}}{UEC_{f,1958}} = \alpha \left(\frac{P_{f,t}}{P_{f,1958}} \right)^{\beta_f} * \left(\frac{\sum_{i=1958}^{t-1} Q_i}{Q_{1958}} \right)^{\beta_2} \tag{2}$$

where:

$UEC_{f,t}$	=	Unit energy consumption for fuel *f* in year *t*,
$UEC_{f,1958}$	=	Unit energy consumption for fuel *f* in year 1958,
$P_{f,t}$	=	Price of fuel *f* in year *t*, in 1987 dollars,
$P_{f,1958}$	=	Price of fuel *f* in year 1958, in 1987 dollars,
Q_{1958}	=	Output in year 1958, in 1987 dollars,
Q_i	=	Output in year *i*.

The α parameter captures the effects of influences on the UEC that are not specified in the model.

In double log form, this formulation leads to estimated elasticities as follows:

$$LN\left(\frac{UEC_{f,t}}{UEC_{f,1958}} \right) = LN\ \alpha + \beta_f\ LN\left(\frac{P_{f,t}}{P_{f,1958}} \right) + \beta_2\ LN\left(\frac{\sum_{i=1958}^{t-1} Q_i}{Q_{1958}} \right) + \epsilon \tag{3}$$

The estimated β_f and β_2 would then represent the UEC elasticity for price-induced and autonomous change, respectively. The β_f are expected to be less than zero, but β_2 may be positive or negative. Similar UEC elasticities are estimated for natural gas, petroleum products, and coal.

The unit energy consumption values for metals-based durables and other non-intensive manufacturing industries are estimated using the implied fuel cost shares from a translog model. Assuming constant returns to scale, the translog cost function is specified as follows

$$\ln(c) = a_0 + \sum_{i=1}^{n} a_i \ln(w_i) + \frac{1}{2}\left[\sum_{i=1}^{n}\sum_{j=1}^{n} d_{ij}\ln(w_i)\ln(w_j)\right] + \ln(y) \tag{4}$$

where $d_{ij}=d_{ji}$ to insure symmetry. The optimal share for input I can be found by differentiating the (log) cost function with respect to the (log) price of the i'th fuel.

$$\frac{\partial \ln(c)}{\partial \ln(w_i)} = \frac{\partial c}{\partial w_i}\frac{w_i}{c} = \frac{x_i w_i}{c} = S_i = \alpha_i + \sum_{j=1}^{n} d_{ij}\ln(w_j) \tag{5}$$

where $\partial c/\partial w_i = x_i$ by Shephard's Lemma. Theory requires that the cost function be homogeneous of degree one in input prices. For the translog model this implies that

$$\begin{aligned} \sum_{i=1}^{n} \alpha_i &= 1 \\ \sum_{j=1}^{n} d_{ij} &= 0,\ i = 1,\dots,n \\ \sum_{i=1}^{n} d_{ij} &= 0,\ j = 1,\dots,n \end{aligned} \tag{6}$$

These conditions allow us to eliminate one equation, because its parameters can be inferred from equations (3). These equations were estimated using nonlinear optimization techniques in the Statistical Analysis System.

In the future, a similar Translog specification will be used for the non-manufacturing industries.

The baseline (1991) PA component UEC values for the non-manufacturing and the non-energy-intensive manufacturing industries are given in Appendix D, Table D2 and Table D3, respectively. The regression parameter estimates (β_f and β_2) for the non-manufacturing industries are given in Table D4 in Appendix D. Those fuels or non-manufacturing industries that do not appear in Table D4 are assumed to have constant UECs. The regression results for metals-based durables and other non-intensive manufacturing industries are located in Table D5 in Appendix D.

Energy-Intensive Industry UEC Estimation

For the seven most energy-intensive industries, energy consumption for the PA component is modeled according to the process flows in that industry. The industries are food and kindred products, paper and allied products, bulk chemicals, hydraulic cement, glass and glass products, blast furnaces and basic steel products, and primary aluminum. (Petroleum refining is also a major energy consuming industry but it is being modeled elsewhere in NEMS.)

To derive energy use estimates for the process steps, the production process for each industry was first decomposed into its major steps, and then the engineering and product flow relationships among the steps were specified. The process steps for the seven industries were analyzed according to one of the following methodologies:

Methodology 1. Developing a process flowsheet and estimates of energy use by process step. This was applicable to those industries where the process flows could be fairly well defined for a single broad product line by unit process step (paper and allied products, glass and glass products, hydraulic cement, blast furnace and basic steel products, and primary aluminum).

Methodology 2. Developing end use estimates by generic process units as a percentage of total use in the PA component. This was especially applicable where the diversity of end products and unit processes is extremely large (food and kindred products, and bulk chemicals).

In both methodologies, major components of consumption are identified by process for various energy sources:

- Fossil Fuels;
- Electricity (valued at 3412.0 Btu/Kwh);
- Steam; and
- Non-fuel energy sources.

The following sections present a more detailed discussion of the process steps and unit energy consumption estimates for each of the energy-intensive industries. The data tables showing the estimates are presented in Appendix D and are referenced in the text as appropriate. The process steps are model inputs with the variable name *INDSTEPNAME*.

Food and Kindred Products (SIC 20)

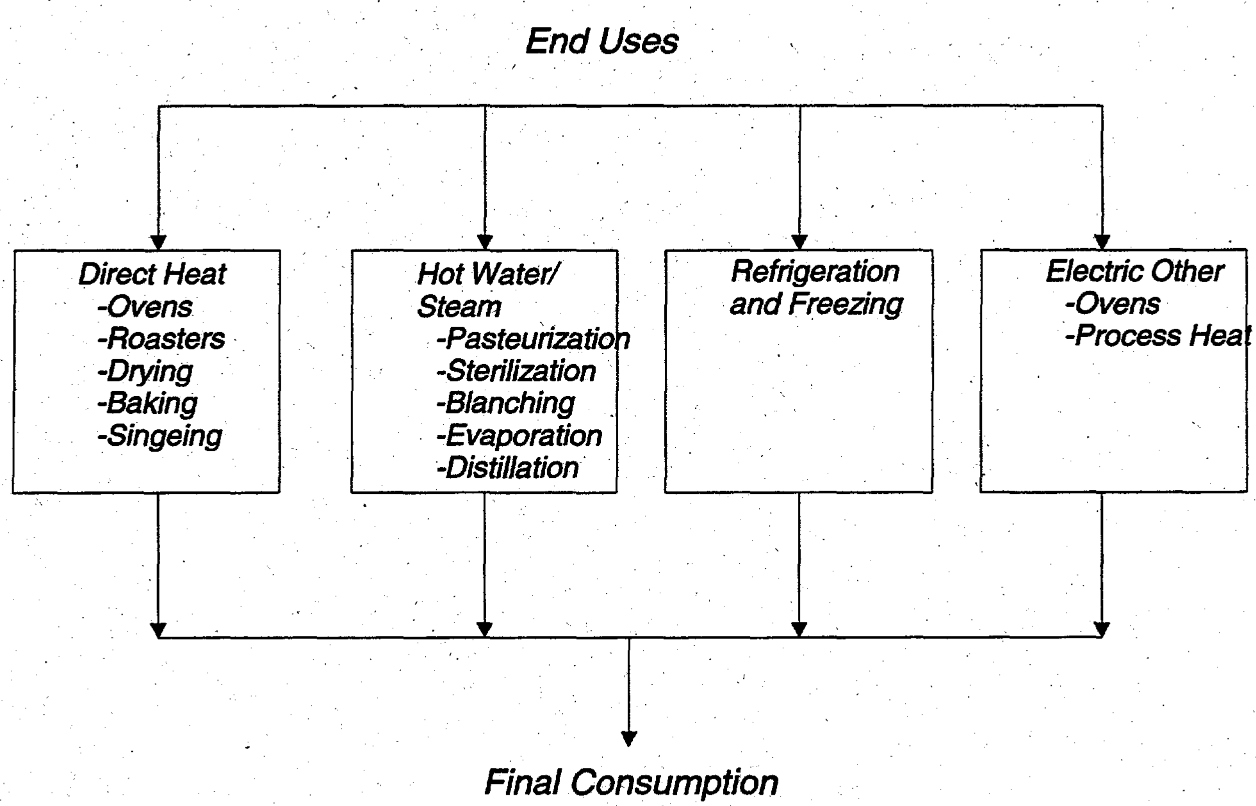
The food and kindred products industry accounted for 14 percent of manufacturing gross output in 1991.

The food and kindred products industry consumed approximately 956 trillion Btu of energy in 1991. Energy use in the food and kindred products industry for the PA Component was estimated on the basis of end-use in four major categories:

- Steam or hot water;
- Direct fuel used in a process such as in grain drying or directly fired ovens;
- Electrical energy used in refrigeration; and
- Other electrical energy.

Figure 2 portrays the PA component's end-use energy flow for the food and kindred products industry. The UECs estimated for this industry are provided in Table D6, Appendix D. Note that the steam/hot water use shown in the table represents the energy content of steam that is used in the industry sub-sector (i.e., boiler losses and efficiencies are not included in these tables). The dominant end-use was steam (and hot water), which accounted for 57 percent of the total energy consumption. Direct fuel use made up about 25 percent. Electric energy contributed 18 percent of the energy consumption.

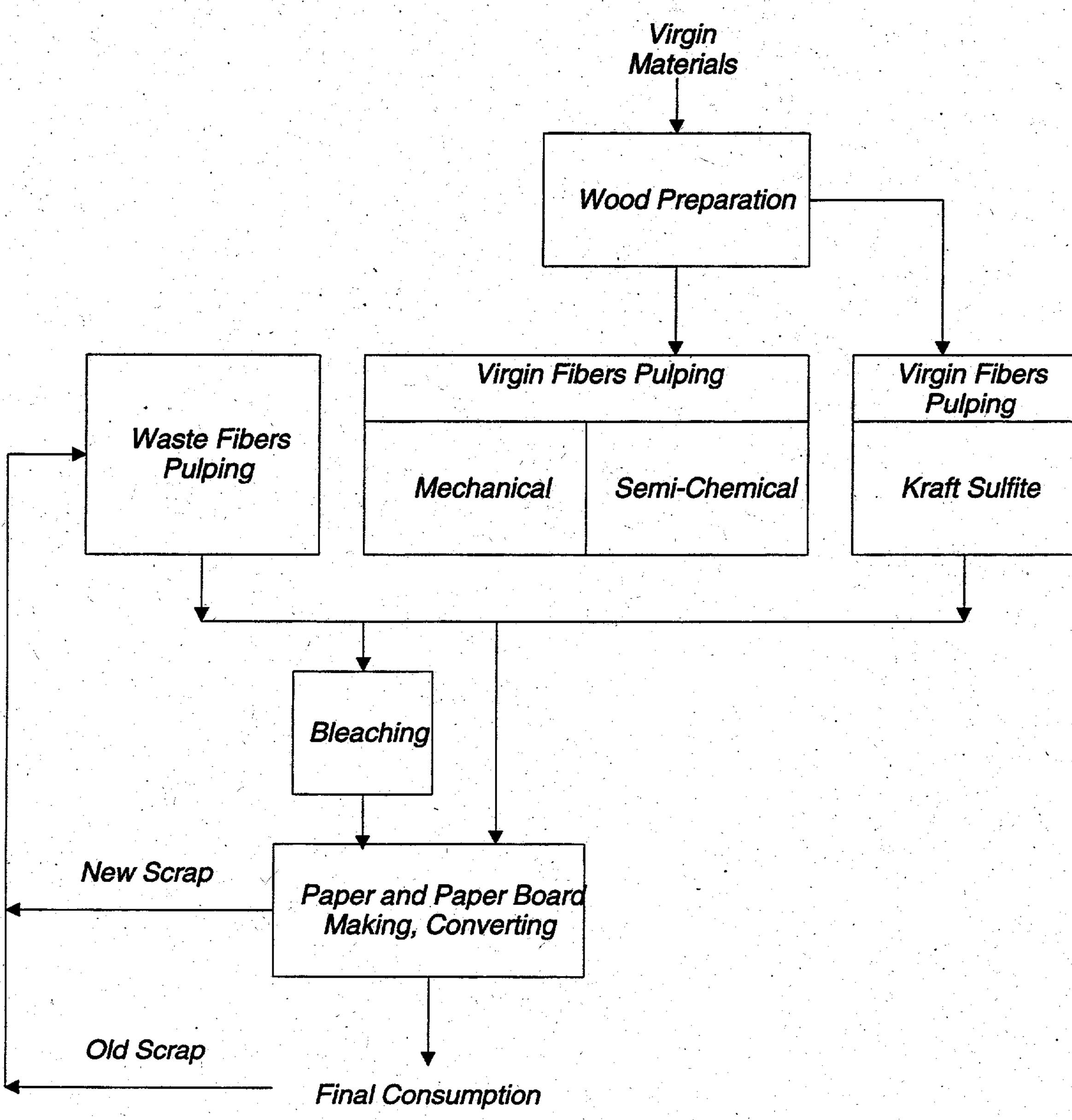
Figure 2. Food and Kindred Products End-Use Flow



Paper and Allied Products (SIC 26)

The paper and allied products industry's principal processes involve the conversion of wood fiber to pulp, and then paper and board to consumer products that are generally targeted at the domestic marketplace. Aside from dried market pulp, which is sold as a commodity product to both domestic and international paper and board manufacturers, the industry produces a full line of paper and board products. Figure 3 illustrates the major process steps for all pulp and paper manufacturing. The wood is prepared by removing the bark and chipping the whole tree into small pieces. Pulping is the process in which the fibrous cellulose in the wood is removed from the surrounding lignin. Pulping can be conducted with a chemical process (e.g., Kraft, sulfite) or a mechanical process. (In addition, a semi-chemical process is also available.) The pulping step also includes processes such as drying, liquor evaporation, effluent treatment and miscellaneous auxiliaries. Bleaching is required to produce white paper stock.

Figure 3. Paper and Allied Products Industry Process Flow



Paper and paperboard making takes the pulp from the above processes and makes the final paper and paper board products. The manufacturing operations after pulp production are similar for each of the paper end-products even though they have different desired characteristics imparted by the feedstocks (fibers furnished) and specific processes used. The processes in the papermaking step include papermaking, converting/packaging, coating/redrying, effluent treatment, and other miscellaneous processes.

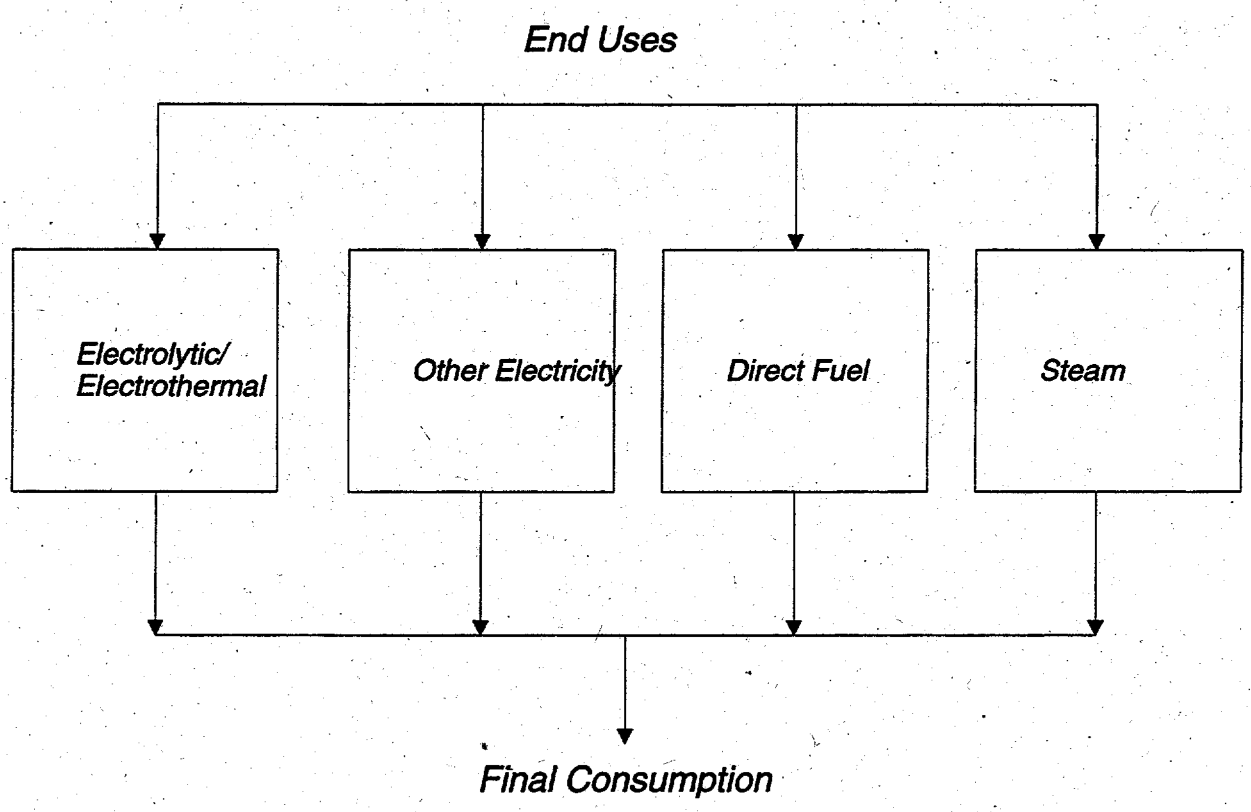
In 1991, a total of 81 million tons of paper and paperboard products were produced. The major paper products include woodfree printing paper, groundwood printing paper, newsprint paper, tissue paper and packaging paper. The major paper board products include kraft paperboard, corrugating medium and recycled paperboard. Of the total 81 million tons of product, 65 percent were produced from kraft chemical process, 5 percent from semi-chemical, 39 percent from waste fibers and 8 percent from mechanical (groundwood). The average unit energy consumption estimated for this industry is slightly over 27 million Btu/ton of final product. The unit energy use estimates for this industry are provided in Table D7, Appendix D. The largest component of this energy use is in the paper and paper board making process step and kraft pulping step, accounting for 40 percent each. Use of recycled paper as the feedstock for the waste fiber pulping step is taken into account. The regional distribution for each technology is shown in Table D13 in Appendix D.

Bulk Chemical Industry (SIC 281, 282, 286, and 287)

The bulk chemical sector is very complex. Industrial inorganics and industrial organics are the basic chemicals, while plastics, agricultural chemicals, and other chemicals are either intermediates or final products. The chemical industry is estimated to consume 25 percent (5 quadrillion Btu) of the total energy consumed in the industrial sector. This industry is a major energy feedstock user and a major cogenerator of electricity.

The complexity of the bulk chemical industry, with its wide variety of products and use of energy as both a fuel and feedstock, has led to an end-use modeling approach. The unit energy consumption in the PA component for the bulk chemical industry is shown in Table D8 in Appendix D. The end-uses for the industry is shown in Figure 4.

Figure 4. Bulk Chemical Industry End-Use Flow

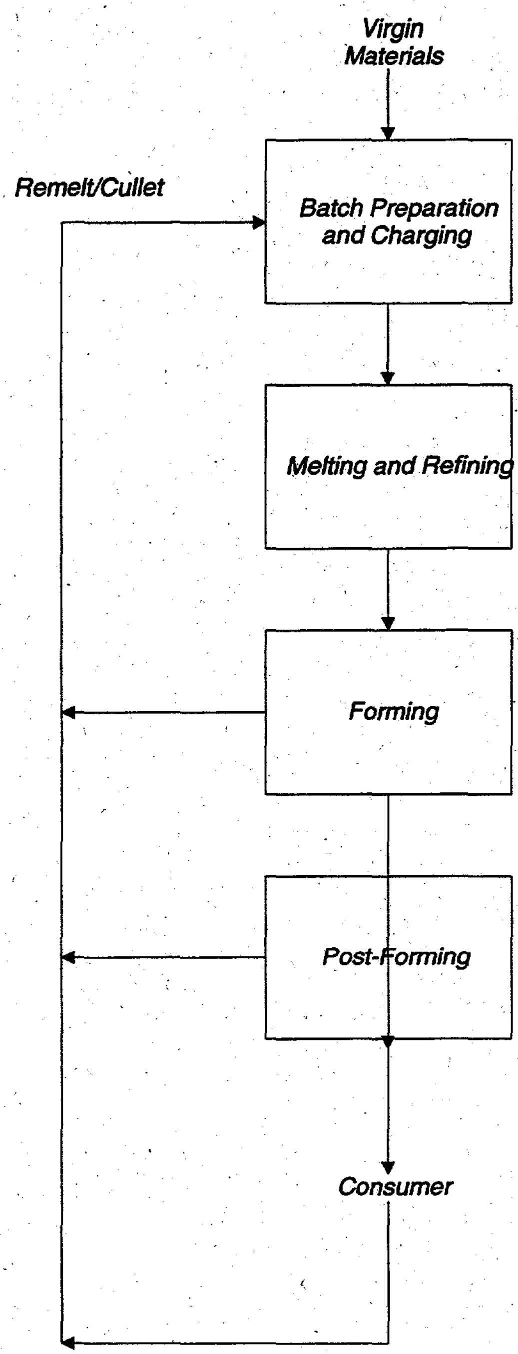


Glass and Glass Products Industry (SIC 321, 322, 323)

The energy use profile has been developed for the total glass and glass products industry, SIC 321, 322, and 323. The glass making process contains four process steps: batch preparation, melting/refining, forming and post-forming. Figure 5 provides an overview of the process steps involved in the glass and glass products industry. While scrap (cullet) and virgin materials are shown separately, this is done to separate energy requirements for scrap versus virgin material melting. In reality, glass makers generally mix cullet with the virgin material.
In 1991, the glass and glass product industry produced approximately 20 million tons of glass products. As noted by the Department of Commerce, about half of this was attributable to container glass.

The glass and glass product industry consumed approximately 226 trillion Btus of energy in 1991 as identified in the *1991 Manufacturing Consumption Survey*. This accounts for about one quarter of the total energy consumed in the stone, clay and glass industry. The fuel consumed is predominantly for direct fuel use; there is very little steam raising. This direct fuel is used mainly in furnaces for melting. Table D9 in Appendix D shows the unit energy consumption values for each process step.

Figure 5. Glass and Glass Products Industry Process Flow



Hydraulic Cement Industry (SIC 324)

The hydraulic cement industry uses raw materials from quarrying and mining operations which are sent through crushing and grinding mills and then converted to clinker in the clinker producing step. This clinker is then ground to produce cement. The industry produces cement by two major processes: the long-wet process and the dry process. The dry process is less energy-intensive than the wet process. As a result, it is assumed in the model that all new plants will be based on the dry process. Figure 6 provides an overview of the process steps involved in the hydraulic cement industry.

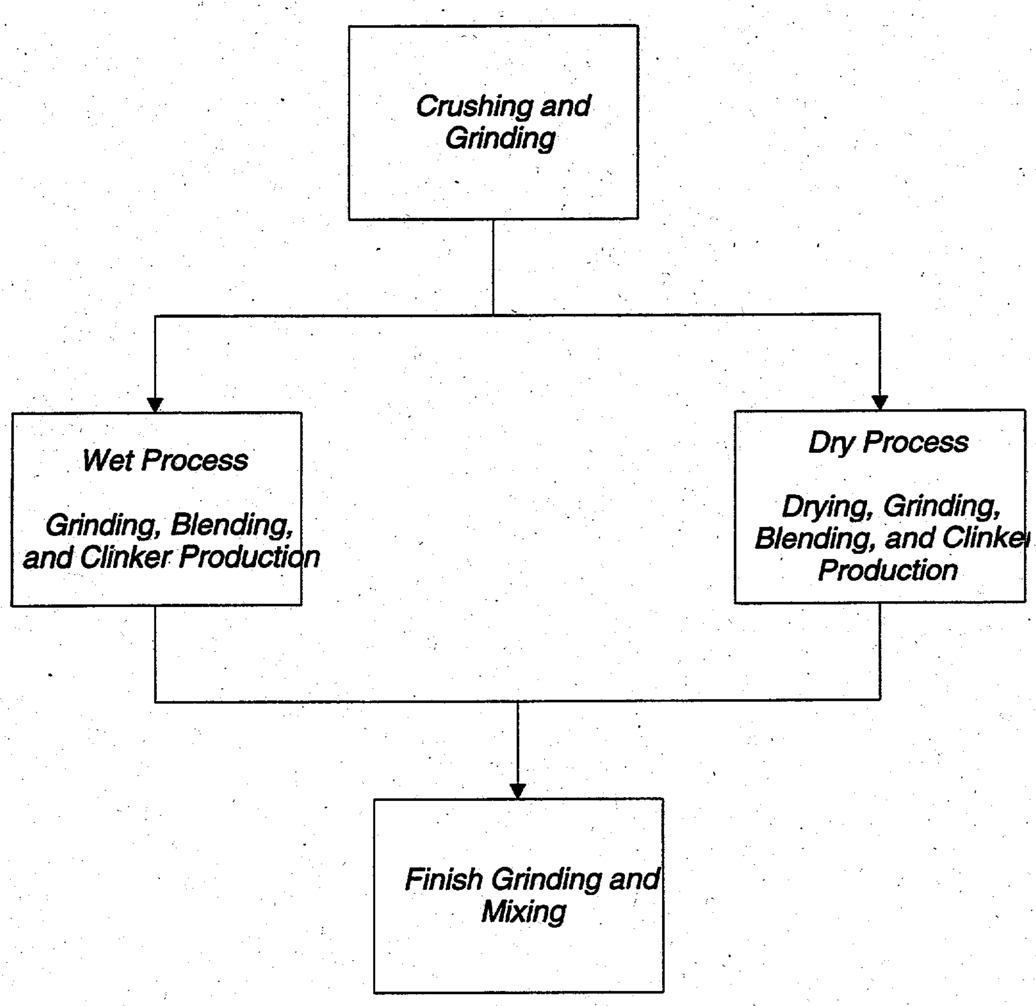
The Portland Cement Association reported that in 1991 the hydraulic cement industry produced 74 million tons of cement, of which 70 million or 95 percent was Portland cement with the remaining 4 million tons being masonry cement. Since cement is the primary binding ingredient in concrete mixtures, it is used in virtually all types of construction. As a result, the U.S. demand for cement is highly sensitive to the levels of construction activity. The wet process accounted for 37 percent of production, while the dry process accounted for about 63 percent.

The hydraulic cement industry exhibits one of the highest unit energy consumption values (MMBtu/dollar value of output) in the U.S. industrial sector. The industry consumed approximately 312 trillion Btu of energy in 1991 as identified in the *1991 Manufacturing Consumption Survey*. This accounts for 35 percent of the energy consumed in the stone, clay and glass industry. Direct fuel, used in clinker-producing kilns, accounted for 90 percent of the total energy consumption, with the remaining 10 percent attributed to electricity. The electricity consumed is used to operate crushing and grinding equipment, materials handling equipment, machine drives and pumps and fans.

The wet process requires significantly larger amounts of energy which can be largely attributed to fuels used to dry the feed. While wet grinding is known to require less energy than dry grinding, the entire wet process has longer kilns, requiring greater energy use than the dry process to drive them. Higher air flows, larger pollution control devices, and generally older facilities lead to slightly larger estimated electric energy use for the wet process.

The UEC values for each process in the hydraulic cement industry are shown in Table D10, Appendix D. As noted previously, it is assumed that all new hydraulic cement capacity will be based on the dry process. The regional distribution of hydraulic cement production processes is presented in Table D13 in Appendix D.

Figure 6. Cement Industry Process Flow



Blast Furnace and Basic Steel Products Industry (SIC 331, 332, etc.)

The blast furnace and basic steel products industry includes the following six major process steps:

Agglomeration;
Cokemaking;
Iron Making;
Steel Making;
Steelcasting; and
Steelforming.

Steel manufacturing plants can be divided into two major classifications: integrated and non-integrated. The classification is dependent upon the number of the above process steps that are performed in the facility. Integrated plants perform all the process steps, whereas non-integrated plants, in general, perform only the last three steps.

For the Industrial Demand Model, a process flow was developed to classify the above six process steps into the five process steps around which unit energy consumption values were estimated. Figure 7 shows the process flow diagram used for the analysis. The agglomeration step was not considered because it is not part of the SIC 33 (it is part of mining). Iron ore and coal are the basic raw materials which are used to produce iron. A simplified description of a very complex industry is provided below.

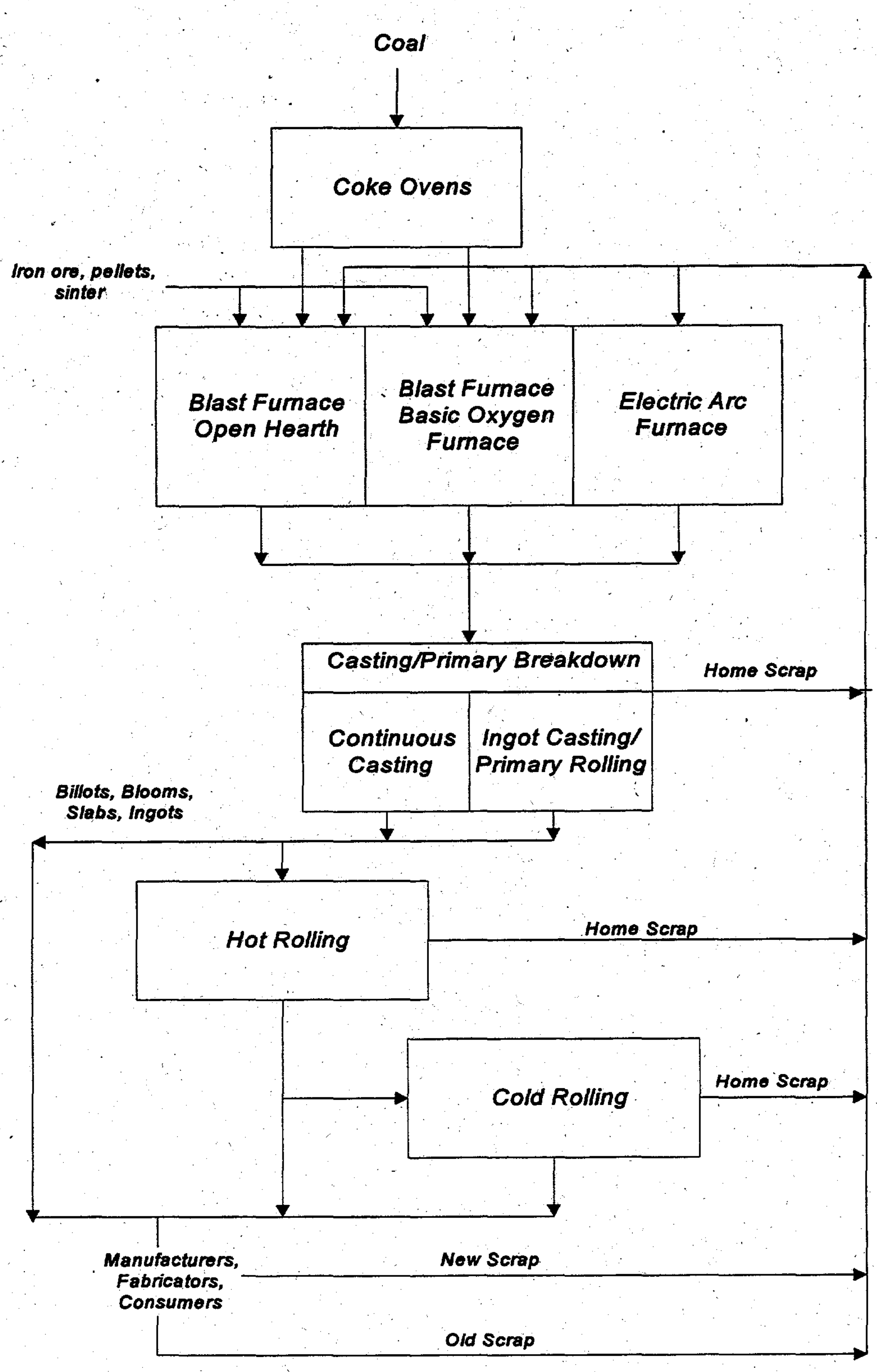
Iron is produced in the Blast Furnace (BF), which is then charged into a Basic Oxygen Furnace (BOF) or Open Hearth (OH) to produce raw steel. The OH is now becoming obsolete. However, it was used to some extent in 1991. The Electric Arc Furnace (EAF) is utilized to produce raw steel from an all scrap charge, sometimes supplemented with direct reduced iron (DRI) or hot briquetted iron (HBI).

The raw steel is cast into ingots, blooms, billets or slabs, some of which are marketed directly (e.g., forging grade billets). The majority is further processed ("hot rolled") into various mill products. Some of these are sold as hot rolled mill products, while some are further cold rolled to impart surface finish or other desirable properties.

In 1991, the U.S. steel industry produced nearly 100 million tons of raw steel utilizing the BF/OH, BF/BOF and the EAF. Taking process yields into account, the total shipments were approximately 85 million tons. The EAF accounted for almost 40 percent of the raw steel production, whereas the BF/BOF accounted for 55 percent and the BF/OH for 5 percent. Continuous casting was the predominant casting process whereas ingot casting is declining. Final products/ consumption were made up of hot rolled products (about 60 percent of the total) with the difference being cold rolled products along with a small amount of direct shipped ingot, billets, blooms, and slabs.

Table D11 in Appendix D summarizes UEC estimates by process step and energy type for the steel industry. The largest category for energy use is coal, followed by liquid and gas fuels. Coke ovens and blast furnace also generate a significant amount of byproduct fuels (denoted by a negative number in Table D11) which are used throughout the steel plant. For the integrated producers, it is assumed in the model that all new capacity additions will be the blast furnace/basic oxygen furnace technology and casting capacity additions will be the continuous type. The regional distribution of steel-making technologies is presented in Table D13, Appendix D.

Figure 7. Iron and Steel Industry Process Flow



Primary Aluminum Industry (SIC 3334)

The U.S. primary aluminum industry consists of two majors sectors: the primary aluminum sector, which is largely dependent on imported bauxite and alumina as raw materials; and the secondary sector, which is largely dependent on the collection and processing of aluminum scrap. The primary and secondary aluminum industries generally cater to different markets. Traditionally, the primary industry bought little scrap and supplied wrought products, including sheet, plate and foil. The secondary industry is scrap-based and supplies foundries that produce die, permanent mold, and sand castings. In the past decade, the primary producers have been moving aggressively into recycling aluminum, especially used beverage cans, into wrought products.

The primary aluminum industry modeled in the Industrial Model generally accounts for the energy used in SIC 3334, alumina refineries and primary aluminum smelters. In the future, the following SICs may also be explicitly accounted for:

SIC 3353: Aluminum sheet, plate, and foil;
SIC 3354: Aluminum extruded products;
SIC 3355: Aluminum rolling and drawing, n.e.c.; and
SIC 3341: Secondary Aluminum.

Domestic aluminum production plus aluminum ingot imports resulted in about 7.2 million tons of semi-fabricated product shipments from U.S. plants. Secondary (scrap-based) operations added another 1.25 million tons. Total shipments were about 8.5 million tons. The primary industry produced approximately 4.5 million tons of aluminum products in 1991.

The UEC estimates developed around the process steps shown in the process flow diagram are presented in Table D12 in Appendix D. As shown in the table, the alumina smelting process is the most energy-intensive of the four process steps. The primary form of energy used is electricity. The majority of the fuel for processing alumina and aluminum is used in kilns, furnaces and ovens. The regional distribution of smelters in the primary aluminum Industry is presented in Table D13 in Appendix D.

Technology Possibility Curves and Relative Energy Intensities

Future energy improvements were estimated for old (retrofit) and new processes/plants. The energy improvements for old plants as a group consist of gradual improvements due to housekeeping/energy conservation measures, retrofit of selected technologies, and the closure of older facilities leaving the more efficient plants in operation. The energy savings for old processes/plants were estimated using engineering judgment on how much energy conservation savings were reasonably achievable in each industry. The estimated annual energy savings values for energy conservation measures are modest (up to 0.5 percent per year).

Unit energy consumption values for the state-of-the-art (SOA) and advanced technologies were estimated. SOA technologies are the latest proven technologies that are available at the time there is a commitment made to build a new plant. These values were then compared to the unit energy consumption values for 1991 to develop a relative energy intensity (REI). Relative energy intensity is defined as the ratio of energy use in a new or advanced process compared to 1991 average energy use (see Table D14, Appendix D).

The savings shown in the appendix for the listed technologies represent savings over "average" 1991 energy use and SOA energy use. The latter increases are due to the gradual commercialization of advanced technologies. Advanced technologies are ones which are still under development and will be available at some time in the future. Where a range is shown for the savings, it was assumed that the lower end of the savings range would start to be realized in the beginning of the time frame, the midpoint of the savings would be realized at the end of the time frame, and the upper end of the savings range would not be realized until 10 or more years after the time frame shown. An energy savings range is most often given when multiple technologies will be becoming available in the future for the same process step or product line. The savings range represents engineering judgment of the most likely achievable savings. In these instances, it is uncertain which specific technologies will be implemented, but it is reasonably certain that at least one of these technologies or a similar technology is likely to be successful. It is also recognized that in some instances thermodynamic limits are being approached which will prevent further significant improvements in energy savings.

The improvement for new plants assumes the plant has been built with the SOA technologies available for that process. SOA technologies are the latest proven technologies that are available at the time there is a commitment made to build the plant. A second and often more important set of substantial improvements are often realized when **advanced technologies** become available for a certain process. Often one sees a number of technologies being developed and it is difficult to ascertain which specific technologies will be successful. Some judgment is necessary as to the potential for energy savings and the likelihood for such savings to be achieved. All the energy improvement values are based on 1991 energy usage.

Additionally, even SOA technologies and advanced technologies can at times be expected to show improvements once developed as the process is improved, optimal residence times and temperatures are found, and better energy recovery techniques are installed. Depending on the process, these are factored into the projections as slow improvements ranging from zero to about 0.5 percent/year. Old plants, however, are assumed to be able to economically justify some retrofits and for other reasons listed above, to show slow improvements over time in their unit energy use. Based on engineering judgment, it is assumed that by 2015, old processes (1991 stock) still operating can achieve up to 50 percent of the energy savings of SOA technology.

Thus, if SOA technology has an REI of 0.80, old processes in the year 2015 will have an REI of 0.90.

With a few exceptions (noted as appropriate in Appendix D), it was assumed that the REI for all energy sources decrease in proportion to the total. Thus, if the total REI for a new technology is 0.90, it was assumed that the relative energy intensity for natural gas, oil, coal, or electricity are all 0.9. When the new technology uses a very different energy mix than the existing technology, it is so noted.

The initial results for a process step in an industry consist of a scatter of points where the Y-axis is the REI and the X-axis is time from 1990 to 2015. Thus, the scatter might indicate that the REI is 0.9 in 1997, 0.8 in 1999, and 0.5 in 2007. As a convenience for modeling purposes, a least squares line was fitted through these points (using natural logarithms) so that the resulting slope coefficient (i.e., the TPC) could be used rather than a step function. (The TPCs are given in Table D14. However, since there is no particular meaning to measures of fit for this exercise, they are not given in Appendix D.)

Table D14 in Appendix D lists the REI's for old and new plants, by process step, for the seven energy-intensive industries. The REI is defined as the ratio of energy use in a new or advanced process compared to the 1991 old plant average energy use which has been normalized to a value of 1.0. The list of SOA and advanced technologies considered in the analysis is presented in Table D15, Appendix D.

Where the relative amounts of different energy sources changes with time, separate equations were estimated for each energy source. The procedure for calculating UECs over time includes establishing the energy sources used as a fraction of the total for each process step, as shown in Table D16 in Appendix D.

Boiler, Steam, Cogeneration Component

The boiler, steam, cogeneration (BSC) component consumes energy to meet the steam demands from the other two components and to provide internally generated electricity to the buildings and process and assembly components. The boiler component consumes fuels and renewable energy to produce the steam and, in appropriate situations, cogenerate electricity.

The boiler component is estimated to consume 40 percent of total manufacturing heat and power energy consumption.[6] Within the BSC component, natural gas accounts for 63 percent and coal 26 percent.

The steam demand and byproducts from the PA and BLD Components are passed to the BSC Component, which applies a heat rate and a fuel share equation to the boiler steam requirements to compute the required energy consumption.

The boiler fuel shares are calculated using a logit formulation. (Note that waste and byproduct fuels are excluded from the logit because they are assumed to be consumed first.) The equation is calibrated to 1991 so that the actual boiler fuel shares are produced for the relative prices that prevailed in 1991. The equation for each manufacturing industry is as follows:

$$ShareFuel_i = \frac{(P_i^{\alpha_i}\beta_i)}{\sum_{i=1}^{3} P_i^{\alpha_i}(\beta_i)} \qquad (7)$$

where the fuels are coal, petroleum, and natural gas. The P_i are the fuel prices; α_i are sensitivity parameters; and the β_i are calibrated to reproduce the 1991 fuel shares using the relative prices that prevailed in 1991. (The values in the equation are presented in Table D17.) The byproduct fuels are consumed before the quantity of purchased fuels is estimated. The boiler fuel shares are assumed to be those estimated using the 1991 MECS and exclude waste and byproducts.

Cogeneration (the generation of electricity and steam) has been a standard practice in the industrial sector for many years. The cogeneration model within the Industrial Model is an econometrically estimated equation that relates on-site electricity generation to industrial steam demand.

Parameter estimates for the cogeneration model are based on regressions from a panel of pooled time series and cross sectional data. The data source is EIA Form EI-867, consisting of data from approximately 400 cogenerators over the years 1989 to 1991. The regression results are presented in Table D18, Appendix D.

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[6] Computed from Energy Information Administration, *Manufacturing Consumption of Energy 1991*, DOE/EIA-0512(91) (Washington, DC, December 1994), Table 36. Note that byproduct and non-energy use of combustible fuels are excluded from the computation.

Assumptions

Capital Stock and Vintaging

Industrial energy consumption is affected by increased energy efficiency in new and old plants, the growth rate of the industry, and the retirement rate for old plants. The efficiency changes are captured in the TPCs and the rate of growth is given by the Macroeconomic module. (Retirement rates from the Census Bureau and vintaging information are very sketchy.) At present, the capital stock is grouped into three vintages: old, middle, and new. The old vintage consists of capital in production prior to 1991 and is assumed to retire at a fixed rate each year. Middle vintage capital is that which is added from 1991 through the lag of the forecast year. New production is added in the forecast years when existing production is less than the output forecasted by the NEMS Regional Macroeconomic Model. Capital additions during the forecast horizon are retired in subsequent years at the same rate as the pre-1991 capital stock. The retirement rates used in the Industrial Model for the various industries are listed in Table D19 in Appendix D.

Renewable Fuels

Renewable fuels are modeled in the same manner as all other fuels in the industrial model. Renewable fuels are modeled both in the PA component and the BSC component. The primary renewable fuels consumed in the industrial sector are pulping liquor, a byproduct of the chemical pulp process in the paper industry, and wood.

Recycling

With projected higher landfill costs, regulatory emphasis on recycling, and potential cost savings, recycling of post-consumer scrap is likely to grow. Projecting such growth, however, is highly dependent on assessing how regulations will be developed, the growth of the economy, and quality related issues dealing with recycled materials. Assumptions for recycling in the Paper and Allied Products and Blast Furnace and Basic Steel Products industries are shown in Table D20 in Appendix D.

Legislative Implications

The Energy Policy Act of 1992 (EPACT) and the Clean Air Act Amendments of 1990 (CAA) contain several implications for the industrial model. These implications fall into three categories: coke oven standards; efficiency standards for boilers, furnaces, and electric motors; and industrial process technologies. The industrial model assumes the leakage standards for coke oven doors do not reduce the efficiency of producing coke, or increase unit energy consumption. The industrial model uses heat rates of 1.25 (80 percent efficiency) and 1.22 (82 percent efficiency) for gas and oil burners respectively. These efficiencies meet the EPACT standards.

The standards for electric motors call for an increase of 10 percent efficiency. The industrial model incorporates a 10 percent savings for SOA motors increasing to 20 percent savings in 2015. Given the time lag in the legislation and the expected lifetime of electric motors, no further adjustments are necessary to meet the EPACT standards for electric motors. The industrial model incorporates the necessary reductions in unit energy consumption for the energy-intensive industries.

Several programs included in the Climate Change Action Plan (CCAP) target the industrial sector. Note that the potential impacts of the Climate Wise Program are also included in the CCAP impacts. The intent of these programs is to reduce greenhouse gas emissions by lowering industrial energy consumption. The Department of Energy (DOE) program offices estimated that full implementation of these programs would reduce industrial electricity consumption by 29 billion kilowatt-hours and non-electric consumption by 383 trillion Btu by 2000. However, since the energy savings associated with the voluntary programs in the CCAP largely duplicate savings that would have occurred in their absence since some of these programs were not fully funded, total CCAP energy savings were reduced. The *Annual Energy Outlook 1997* (*AEO97*) assumes that CCAP reduces electricity consumption by 16 billion kilowatt-hours and non-electric energy consumption by 90 trillion Btu. The non-electric energy is assumed to be steam coal.

For 2010, the DOE program offices estimated electricity savings of 81 billion kilowatt-hours and fossil fuel savings of 650 trillion Btu. For the reason cited above, these estimates were revised to 47 billion kilowatt-hours for electricity and 190 trillion Btu for fossil fuels. In this situation, carbon emissions would be reduced by about 10 million metric tons (2 percent) in 2010.

Fuel Switching

Because the Industrial Model produces annual projections, seasonal fuel switching is not considered. Most observable fuel switching is seasonal and is difficult or impossible to detect with annual data. In the BSC component, all natural gas consumption is interruptible, i.e., switchable. Presumably, most of the switching that occurs here is seasonal and unobservable with annual data and prices. Fuel switching is implemented in the model by allowing the share of fuels in existing boilers to shift based on the logit formulation discussed above.

Benchmarking

The Industrial Model energy demand forecasts are benchmarked to actual 1990 through 1994 State Energy Data System (SEDS) values to ensure that the model forecasts for these years coincide with the SEDS consumption data. The benchmark factors are based on the ratio of the SEDS value of consumption for each fuel to the consumption calculated by the model at the census division level.

4. Model Sensitivities

Solution Methodology

The solution methodology of the NEMS Industrial Module is a direct, one-pass, computation of linear and non-linear equations to develop the industrial module outputs such as quantity demanded by fuel type. Consequently, convergence within the NEMS Industrial Module is never an issue nor is it relevant since the solution algorithm within the industrial module is not iterative.

The module requires no estimate of the current-year solution to compute the solution to the NEMS Industrial Module. The current year solution is a function of lag year decision variables in addition to fixed inputs from NEMS such as macroeconomic output and fuel prices. This appendix contains a series of sensitivity analyses for the purpose of illustrating the behavior of the industrial module. These sensitivities illustrate how the module responds to changes in key module inputs on a one-at-a-time basis.

Although rigorous tests have not been performed to determine the maximal ranges and input interdependencies over which the module remains valid, the ranges used for the sensitivity analysis for this exercise provide an indication of ranges for which the module has proven to be valid. In addition, the sensitivity values were chosen to reflect price increases that have been historically experienced in the various markets for the fuel types considered for this study. It is important to note that care must be exercised in selecting the proper range, especially with inputs which are correlated so that the module produces plausible results.

Theoretical Considerations

Because of the direct (rather than iterative) solution algorithm and because all of the functions implemented in the NEMS Industrial Module code are continuous and differentiable in the domain of applicability of the model (that is, when "reasonable and consistent inputs" are provided to the model), the module always produces a unique solution. As previously mentioned, some of the inputs to the module may be correlated (as in certain macroeconomic inputs) and if inconsistent groups of such inputs or negative prices are chosen, then the module may produce results that are either difficult to interpret or erroneous. Thus, when the module is run in a stand-alone fashion, the user must be certain that the inputs are consistent and credible.

Examples of assumptions that will cause the module to produce uninterpretable results include:

- severely altering base year data, e.g., doubling the 1991 energy consumption for some or all industries,
- assuming unrealistic efficiency gains through penetration of presently unknown technologies, and

- modifying prices considerably in excess of variations historically experienced, such as quadrupling prices in one year.

Sensitivity Analysis

To examine the NEMS Industrial Module's behavior under a variety of situations, several module runs were made to test its sensitivity to altered values for key input variables. These runs were compared with a reference case that was created in a stand-alone run.[7] Although this stand-alone run was not based on the final results for the *Annual Energy Outlook 1997*, the final results do not differ significantly. The sections below describe the six major inputs and five outputs chosen for this exercise.

Input Variables

The seven input variables chosen for the sensitivity analyses were selected based upon their perceived importance in producing the Annual Energy Outlook forecasts. The seven variables and the magnitude of variation are given below.

Electricity, natural gas, steam coal, residual fuel oil, and distillate prices. Five prices for the major industrial fuels were each increased, one at a time, by 25 percent over their values in the stand-alone reference case in every year of the forecast (1997 through 2015).[8] Fuel prices affect the projected consumption levels through own and cross price elasticities. Note that these are essentially single-period elasticities. Consequently, they are not expected to vary over time (within limits of the NEMS convergence tolerance). The response to price changes is the result of the methodologies applied to estimating fuel shares in the energy intensive industries, energy non-intensive industries, and in the boiler, steam, cogeneration (BSC) component of the industrial module.

Technology Possibility Curve. The efficiency of new equipment plays an obvious and important role in determining the level of energy intensity for the industrial sector. As described in the text of this document, the assumed rate of energy intensity decreases is captured in the technology possibility curve (TPC) for the energy intensive industries. For this sensitivity analysis, the TPCs were increased by 25 percent relative to the stand-alone reference case beginning in 1997. It is expected that higher equipment efficiencies will cause both energy consumption and energy intensity to decline. This is illustrated by graphing the effect on total energy consumption over time.

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[7] Since energy demand for the refining industry and for lease and plant natural gas consumption in the oil and gas industry are modeled elsewhere in NEMS, the calculations exclude these demands.

[8] Note that for natural gas, both the firm and the interruptible prices were increased by 25 percent.

Output Variables

The sensitivities of five outputs were examined with respect to one-at-a-time variation of the above seven inputs. The five outputs chosen for examination were:

- the quantity demanded of electricity,
- the quantity demanded of natural gas,
- the quantity demanded of steam coal,
- the quantity demanded of residual fuel oil, and
- the quantity demanded of distillate oil.

Table 3 provides the fuel price elasticities (the percent change of the output divided by the percent change of the input) of the selected output variables with respect to the selected input variables. Figure 8 displays the own price elasticity for the five fuel price variations. Table 4 provides the elasticities of total energy consumption with respect to technology and retirement rates. These elasticities do vary over time. This variation can be seen in Figure 9 which displays the variation in energy consumption for the technology and retirement scenarios.

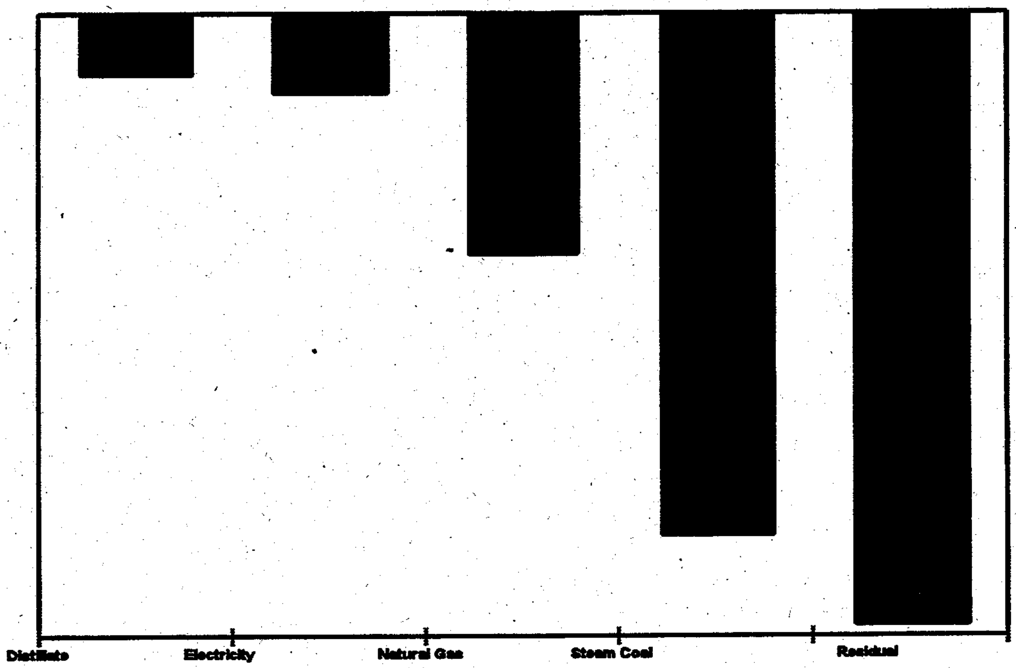
Table 3. Fuel Price Elasticities

	Own and Cross Elasticities in 2015				
Inputs	Electricity	Natural Gas	Coal	Residual	Distillate
Electricity	-0.074	0.092	0.605	0.080	0.017
Natural Gas	0.496	-0.229	1.087	0.346	0.014
Steam Coal	0.021	0.061	-0.499	0.151	0.023
Residual	0.236	0.036	0.650	-0.587	0.012
Distillate	0.247	0.002	0.57 8	0.044	-0.055

Table 4. Other Elasticities

	Total Delivered Energy			
Inputs	2000	2005	2010	2015
Technology	-0.02	-0.04	-0.07	- 0.09
Retirement	-0.016	-0.036	-0.05	-0.05

Figure 8. Own Price Elasticities



Price Responsiveness

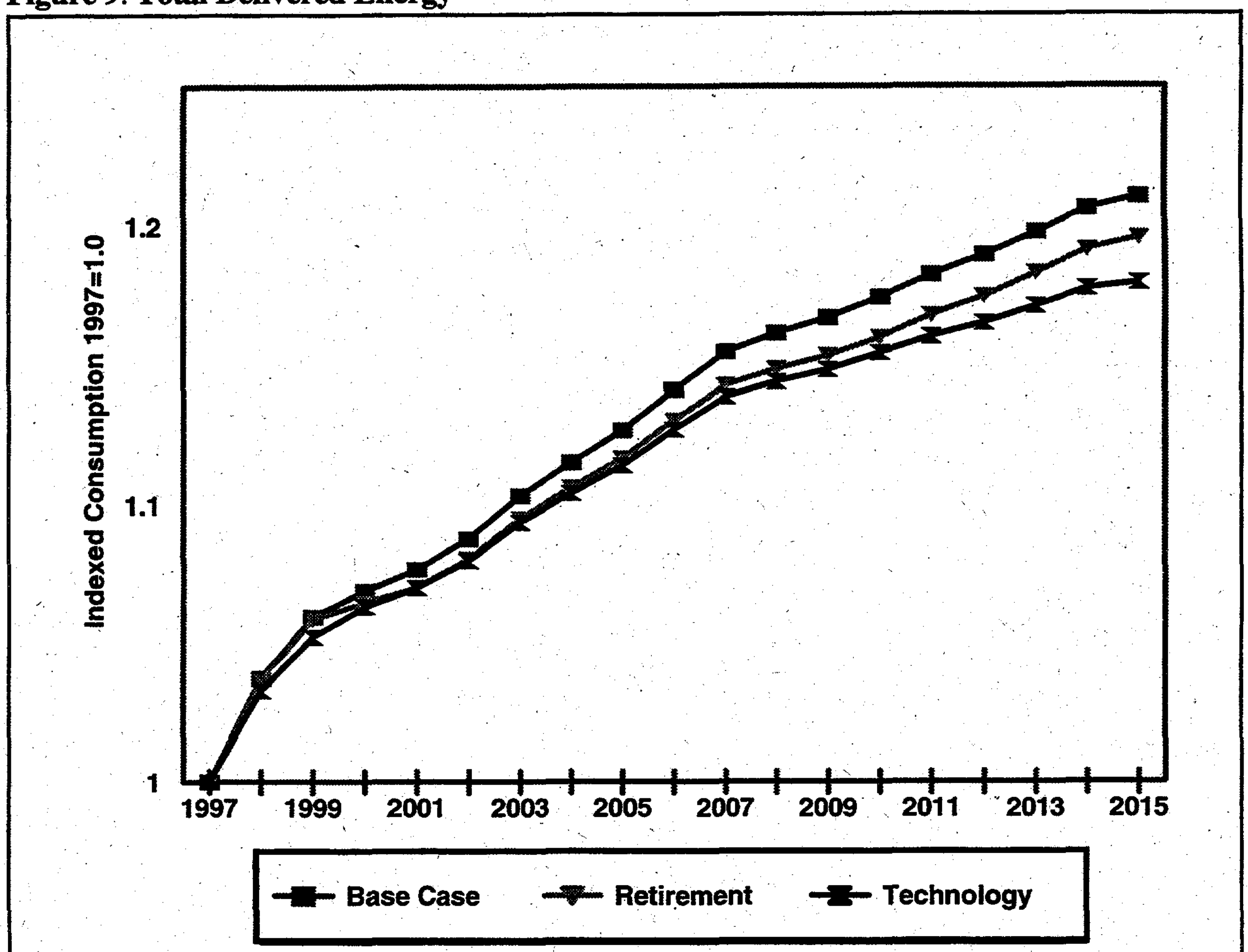
As shown on Table 3, the NEMS Industrial Module exhibits fuel own-price elasticities for 2015 ranging from -0.587 for residual oil to -0.055 for distillate. The price elasticities observed in the industrial model are generally constant over time because the model incorporates no dynamic methodology for estimation based upon past prices or expectations about future prices.

Generally, the cross price elasticities are positive as expected but do not show symmetry. This result is due to the varying econometric methods used for estimating fuel shares for the energy intensive industries, energy non-intensive industries, and the boiler, steam, cogeneration component in the industrial module. Further, since the elasticity results represent an aggregation of diverse processes and industries, these quantities do not reflect a price response of a particular type of equipment. In principle, the cross elasticities represent varying usages for equipment that consumes different fuels and not fuel switching in any one type of equipment.

Responsiveness to Technology Penetration and Retirement Rate Changes

The results of this technology penetration and retirement rate sensitivity scenario is independent of any price effects on technological change over time in the industrial model. As shown in Figure 9, increased technology penetration and retirement rates result in an expected increase in the elasticity of demand for total delivered energy over time. In this scenario, a 25 percent increase in the technology penetration rate and a 25 percent increase in equipment retirement rates results in a 2.25 percent and 1.24 percent decline in total energy intensity respectively, relative to the stand-alone reference case.

Figure 9. Total Delivered Energy



5. Model Structure

Outline of Model

Table 5 presents the solution outline for the NEMS Industrial Demand Model. The following section provides an overview of the solution outline for the model.

Subroutines and Equations

This section provides the solution algorithms for the Industrial Model. The order in which the equations are presented follows the logic of the FORTRAN source code very closely to facilitate an understanding of the code and its structure. In several instances, a variable name will appear on both sides of an equation. This is a FORTRAN programming device that allows a previous calculation to be updated (for example, multiplied by a factor) and re-stored under the same variable name.

IND

IND is the main industrial subroutine called by NEMS. This subroutine retrieves data for gross output for both the manufacturing and non-manufacturing industries from the NEMS Macroeconomic (MACRO) model. Employment is also obtained from the MACRO model for each non-agricultural industry. Prices for the various fuels as well as the previous year's consumption are obtained from NEMS COMMON blocks. For the first model year, consumption is obtained from the *State Energy Data System 1994* (SEDS). Because data for the industrial model are available only for the four Census regions, the energy prices obtained from NEMS, available for each of the nine Census divisions, are combined using a weighted average of the fuel prices as shown in the following equation for the first model year. A similar weighted average is used for all other fuels and model years. However, the previous year's consumption is used rather than SEDS consumption.

Table 5. Outline of Industrial Module

Industrial Module Solution Outline

I. First Year: Initialize Data

- A. RCNTL: Read Control Options
- B. REXOG: Assign exogenous macroeconomic and energy price variables that come from NEMS.
- C. IEDATA: Read ENPROD file with industry production parameters, base year industrial output, UECs, elasticities and other coefficients;
- D. RSTEO: Read Short Term Energy Outlook File with last available history data and national projections for the next two years.

II. Industry Processing:

Loop through each of 14 industry groups, including 6 non-manufacturing, 7 energy intensive and 2 energy non-intensive manufacturing industries. For each industry, loop through each of 4 census regions

- A. RDBIN: Read memory management file with previous year's data for this industry, region
- B. CALPROD: Compute revised productive capacity and throughput by process/assembly step and vintage; implement retirement and vintaging assumptions.
- C. CALCSC: Conservation Supply Curve: Evaluate changes in UECs based on Technological Possibility Curves (TPCs) or econometric estimates, depending on the industry.
  - 1. CALCSC1: Holds UECs constant for alternate Translog Approach in energy-intensive non-manufacturing
  - 2. CALCSC2: Apply CSC function and reset UECs
  - 3. CALCSC3: Apply ADL TPC Approach.
- D. CALPRC: Evaluate price-induced changes in UECs based on energy prices, elasticities.
  - 1. CALPRC1: Holds UECs constant
  - 2. CALPRC2: Apply constant own-price elasticity to UECS
  - 3. CALTLOG: Revises UECs based on translog function relating factor cost shares to relative energy prices.
- E. CALBYPROD: Calculate consumption of byproduct fuels
- F. CALPATOT: Compute consumption of energy in the process assembly component
  - 1. INDPALOG: Optionally, adjust fuel shares for process-assembly industries using a 2-stage logit equation. First year, read spreadsheet file (INDPALOG.WK1) with logit coefficients
    - a. CALPALOG: evaluate logit shares for a given industry and a given set of fuels, given changes in energy prices since the base year.
- G. CALBTOT: Compute consumption of energy in the buildings component
- H. CALGEN: Compute electricity generation for sale and internal use by prime mover and fuel.
- I. CALSTOT: Compute Energy consumption in the Boiler-Steam-Cogeneration (BSC) component
- J. WRBIN: Write memory management file with data on this industry, region
- K. INDTOTAL: Accumulate total energy consumption for the industry

III. National Sums:

- A. NATTOTAL: Accumulate total energy consumption over all industries
- B. CONTAB: Accumulate aggregates for non-manufacturing heat and power

IV. WEXOG: Apply exogenous adjustments and assign values to global variables

- A. SEDS Benchmarking:
  - 1. SEDS years (through 1994): calculate regional benchmark factors as the ratio of actual consumption to model consumption for each fuel in four Census regions.
  - 2. Post SEDS Years (1995-on): Optionally, multiply model consumption by the SEDS benchmark factors.
- B. Disaggregate energy consumption from 4 Census regions to 9 Census Divisions using shares from SEDS
- C. Calibrate regional energy consumption to match the latest year of national-level history data (from the STEO file).
- D. STEO Benchmarking:
  - 1. STEO years: calculate national benchmark factors as the ratio of model consumption for each fuel to the STEO forecast for each fuel.
  - 2. Post-STEO years: Optionally, over the period 1998 to 2000, multiply model consumption by the STEO benchmark factors.
- E. Assign final results to NEMS variables

$$PRCX_{elec,r} = \frac{\sum_{d=1}^{NUM_r} DPRCX_{elec,r} \; x \; QSELIN_{d,1990}}{\sum_{d=1}^{NUM_r} QSELIN_{d,1990}} \tag{8}$$

where:

$PRCX_{elec,r}$	=	Price for electricity in Census region r,
NUM_r	=	Number of Census divisions in Census region r,
$DPRCX_{elec,d}$	=	Price of electricity in Census division d, and
$QSELIN_{d,1990}$	=	SEDS consumption of electricity in Census division d in 1990.

IND calls two subroutines: ISEAM, the subroutine that guides the industrial model calculations, and WEXOG, the subroutine that reports the results back to NEMS.

ISEAM

ISEAM controls all of the industrial model calculations. It opens external files for debugging, binary files for restarting on successive iterations and forecast years, and the input data files. In the first model year and only on the first iteration, ISEAM calls RCNTRL to read runtime parameters file. ISEAM then calls REXOG to read in exogenous inputs on each model run. For the first model year, ISEAM calls the following subroutines for each Census region within each industry: IEDATA, CALBYPROD, CALPATOT, CALBTOT, CALGEN, CALSTOT, and INDTOTAL. After the forecast for the last Census region for a particular industry has been calculated, the following two subroutines are called to compute totals: NATTOTAL and CONTAB. After the first model year, ISEAM calls two subroutines, RDBIN to read the restart files, and MODCAL to carry out model calculations. After all model calculations have been completed, ISEAM calculates industry totals and saves information to the restart files in the subroutine WRBIN. Finally, after each industry has been processed, ISEAM calls the subroutine INDCGN to report industrial cogeneration estimates to NEMS.

Subroutine RCNTRL

RCNTRL reads data from the input file INDRUN. This file contains internal control variables for the industrial model. Data in this file are based on user defined parameters consisting of indicator variables for subroutine tracing, debugging, writing summary tables, options to calculate model sensitivities, and benchmarking options. This file also contains the number of industries to be modeled and the industrial input file name.

Subroutine REXOG

REXOG prepares exogenous data obtained from the NEMS MACRO model for use in the industrial model. Dollar value of output and employment are aggregated over the appropriate Census divisions to obtain data at the Census region level. Employment data is obtained from NEMS at the two digit SIC level. Therefore, for some industries, employment data must be shared out between industries at the same two digit SIC level. In particular, the chemical industry (SIC 28) is grouped into bulk chemicals (SICs 281, 282, 286, and 287) and other chemical. Employment for the petroleum industry must be shared out between refining and all other petroleum. The stone, clay, and glass industry and the primary metals industry also require sharing out of employment data.

Subroutine IEDATA

IEDATA stands for Industrial Enprod Data where enprod is the name of the industrial input data file. This routine consists of many subprograms designed to retrieve industrial input data. The call order of these routines is consistent with the data structure of the model. Most of these subroutines perform no calculations and are simply listed with a description of their function.

The routines are as follows:

<u>IRHEADER</u>

Get industry and region identifier numbers, base year value of output, physical to dollar output conversion factor, base year steam demand, and cumulative output 1958-1991.

The ratio of physical output to 1990 value of output for five of the energy-intensive industries is calculated (food and bulk chemical industries are excluded). This constant ratio is applied to value of output in subsequent years.

$$PHDRAT_i = \frac{PHYSICAL_i}{PRODVX_{i,r}} \qquad (9)$$

where:

$PHDRAT_i$	=	Ratio of physical units to value of output for industry *i*,
$PHYSICAL_i$	=	Physical units of output for industry *i*, and
$PRODVX_{i,r}$	=	Value of output for industry *i* in Census region *r*.

If the Unit Energy Consumption (UEC) is in physical units, then the following equation is used.

$$PRODX_{i,r} = PHDRAT_i \; x \; PRODVX_{i,r} \tag{10}$$

where:

$PRODX_{i,r}$	=	Output in physical units for industry *i* in Census region *r*,
$PHDRAT_i$	=	Ratio of physical units to value of output in industry *i*, and
$PRODVX_{i,r}$	=	Value of output for industry *i* in Census region *r*.

If the UEC is in dollar units, then the following equation is used.

$$PRODX_{i,r} = PRODVX_{i,r} \tag{11}$$

where:

$PRODX_{i,r}$	=	Value of output for industry *i* in Census region *r*, and
$PRODVX_{i,r}$	=	Value of output for industry *i* in Census region *r*.

IRSTEPDEF

Get production throughput coefficients, process step retirement rates, and other process step flow information. The latter includes process step number, number of links, the process steps linked to the current step, physical throughput to each process step, the retirement rate, and process step name.

Note that only the energy-intensive industries have steps. However, two industries, food and kindred products and bulk chemicals, do not have linkages among steps because the steps represent end-uses (e.g., refrigeration and freezing in the food and kindred products industry). As a result, the downstep throughput for food and kindred products and bulk chemicals is equal to 1. A linkage is defined as a link between more than one process step. For example, in the paper and allied products industry, the wood preparation process step is linked to the virgin fibers pulping process step. The down-step throughput is the fraction of total throughput for an industry at a process step if it is linked to the final consumption. If the process step is linked to another process step, then the down-step throughput is the fraction of the linked process step plus the fraction of final consumption. The following example illustrates this procedure.

Figure 3 above shows the process flow for the paper and allied products industry. The algebraic representation is as follows:

Let:

$Y_1 \equiv$ Number of tons of paper to be produced.
$Y_2 \equiv$ Number of tons of material to go through the bleaching process.
$Y_3 \equiv$ Number of tons of material to go through the waste fiber pulping process.
$Y_4 \equiv$ Number of tons of material to go through the mechanical pulping process.
$Y_5 \equiv$ Number of tons of material to go through the semi-mechanical pulping process.
$Y_6 \equiv$ Number of tons of material to go through the Kraft pulping process.
$Y_7 \equiv$ Number of tons of material to go through the wood preparation process.

Then, we have the following:

$Y_1 =$ Some value of output, in tons (from the MACRO Module).
$Y_2 = 0.443\ Y_1$
$Y_3 = 0.164\ Y_1 + 0.164\ Y_2$
$Y_4 = 0.068\ Y_1 + 0.068\ Y_2$
$Y_5 = 0.037\ Y_1 + 0.037\ Y_2$
$Y_6 = 0.424\ Y_1 + 0.424\ Y_2$
$Y_7 = 0.998\ Y_4 + 0.998\ Y_5 + 0.998\ Y_6$

If according to the Pulp and Paper Association that $Y_1 = 81$ million tons of paper was produced in 1991, then $Y_2 = 36$, $Y_3 = 19.2$, $Y_4 = 79.5$, $Y_5 = 43.25$, $Y_6 = 49.6$, and $Y_7 = 172.4$.

The papermaking process is as follows. We need 172 million tons of output from the wood preparation process and 19 million tons of output from the waste fiber pulping process. Of the 172 million tons of material, 79 million tons flow through mechanical pulping, 43 million tons into semi-mechanical pulping, and 50 million tons into the Kraft pulping process. 36 million tons from the sum of output of the waste fiber, mechanical, semi-mechanical, and Kraft pulping processes goes through the bleaching process. This 36 million tons along with the remainder of the output from each process goes to the final stage in papermaking.

Physical throughput is obtained for two vintages, old and new. Old vintage is considered to be any capital installed in 1990 or earlier. Middle vintage includes installations from 1991 to the lag of the current forecast year. New vintage includes any capital installed in the current forecast year.

The following subroutines collect data from the input files:

IRBEU
: Get building energy use data including lighting, heating, ventilation, and air conditioning.

IRBSCBYP
: Get byproduct fuel information for the boiler/steam/cogeneration component. These data consist of fuel identifier numbers of steam intensity values.

IRBSFUEL
: Get boiler fuel share values for coal, oil, and natural gas. Biomass data is retrieved in the IRBSCBYP routine and is assumed to have a constant share of boiler fuel throughout the forecast.

IRCOGEN
: Get cogeneration information which includes prime mover heat rates, total generation and capacity from 1990 through the current survey year, and planned capacity.

IRSTEPBYP
: Get byproduct data for process and assembly component. These data consist of fuel identifier numbers and heat intensity values.

IRSTEPDAT

Get process step data for the energy intensive industries. These data consist of fuel identifier numbers, base year unit energy consumption values, and technology penetration coefficients.

IFINLCALC

Calculate initial year values for process step production throughput for the energy intensive industries.

If the current process step is linked to final consumption (i.e., if there are no intermediate steps between the current step and final output), then the following equation is used:

$$PRODSUM_{s,l} = PRODFLOW_{old,s,l} \times PRODX_{i,r} \qquad (12)$$

where:

$PRODSUM_{s,l}$	=	Amount of throughput used at process step s through link l,
$PRODFLOW_{old,s,l}$	=	Down-step throughput to process step s linked by link l for old vintage, and
$PRODX_{i,r}$	=	Output for industry i in Census region r.

Note that PRODFLOW is a parameter that represents the relative production throughput to a subsequent production step in the energy-intensive industries. The linkage parameter indicates which production step is involved.

If the current process step is linked to one or more intermediate process steps, then the following equation is used:

$$PRODSUM_{s,l} = PRODFLOW_{old,s,l} \times PRODCUR_{total,IP} \qquad (13)$$

where:

$PRODSUM_{s,l}$	=	Amount of throughput used at process step s through link l,
$PRODFLOW_{old,s,l}$	=	Down-step throughput to process step s linked by link l for old vintage, and

$PRODCUR_{total,IP}$ = Current production at process step *IP* linked to process step *s* through link *l* for all vintages.

In either case, the total production at each process step is determined through the following equation:

$$PRODCUR_{total,s} = \sum_{l=1}^{NTMAX_s} PRODSUM_{s,l} \tag{14}$$

where:

$PRODCUR_{total,s}$ = Current production at process step *s* for all vintages,

$NTMAX_s$ = Number of links at process step *s*, and

$PRODSUM_{s,l}$ = Amount of throughput used at process step *s* through link *l*.

Subroutine CALBYPROD

The industrial model consumes all byproduct fuels prior to purchasing any fuels. This subroutine calculates the energy savings or the current location on the technology possibility curve (TPC) based on the current year's industry production and the previous year's industry production for each process step, fuel, and old and new vintage as shown in the following equation. Currently, only the paper and allied products industry has a TPC for byproducts. For all other industries the UEC remains unchanged.

$$BYPCSCCUR_{v,f,s} = \left[\frac{PRODCUR_{total,s}}{PRODLAG_{total,s}}\right]^{BYPCSC_{v,f,s}} \tag{15}$$

$BYPCSCCUR_{v,f,s}$ = Current energy savings for byproduct fuel *f* at process step *s* for vintage *v*,

$PRODCUR_{total,s}$ = Current production at process step s for all vintages,

$PRODLAG_{total,s}$ = Lagged production at process step s for all vintages, and

$BYPCSC_{v,f,s}$ = Byproduct technology possibility curve coefficient for byproduct fuel f at process step s for vintage v.

The energy savings for middle vintage is a weighted average (by production) of the current year's energy savings for new vintage and the previous year's energy savings for middle vintage.

$$BYPCSCCUR_{mid,f,s} = \frac{(PRODCUR_{new,s} \times BYPCSCCUR_{new,f,s}) + (PRODCUR_{mid,s} \times BYPCSCLAG_{mid,f,s})}{PRODCUR_{new,s} + PRODCUR_{mid,s}} \tag{16}$$

where:

$BYPCSCCUR_{mid,f,s}$ = Current energy savings for byproduct fuel f at process step s for mid vintage,

$PRODCUR_{new,s}$ = New production at process step s,

$BYPCSCCUR_{new,f,s}$ = Current energy savings for byproduct fuel f at process step s for new vintage,

$PRODCUR_{mid,s}$ = Existing production at process step s for mid vintage, and,

$BYPCSCLAG_{mid,f,s}$ = Lagged location on the byproduct technology possibility curve for byproduct fuel f at process step s for middle vintage.

CALBYPROD calculates the rate of byproduct energy produced for each process step, fuel, and vintage shown in the following equation. This value is based on the previous year's rate of production and the current energy savings for each vintage.

$$BYPINT_{v,f,s} = BYPINTLAG_{v,f,s} \times BYPCSCCUR_{v,f,s} \tag{17}$$

where:

$BYPINT_{v,f,s}$ = Rate of byproduct energy production for byproduct fuel f at process step s for vintage v,

$BYPINTLAG_{v,f,s}$ = Lagged rate of byproduct energy production for byproduct fuel f at process step s for vintage v, and

$BYPCSCCUR_{v,f,s}$ = Current energy savings for byproduct fuel f at process step s for vintage v.

The byproduct rate of production is used to calculate the quantity of byproduct energy produced by multiplying total production at the process step by the production rate.

$$BYPQTY_{v,f,s} = PRODCUR_{v,s} \times BYPINT_{v,f,s} \tag{18}$$

where:

$BYPQTY_{v,f,s}$ = Byproduct energy production for byproduct fuel f at process step s for vintage v,

$PRODCUR_{v,s}$ = Production at process step s for vintage v, and

$BYPINT_{v,f,s}$ = Rate of byproduct energy production for byproduct fuel f at process step s for vintage v.

The byproduct rate of production is then converted from millions of Btu to trillions of Btu. Byproduct production is subdivided into three categories: main fuels, intermediate fuels, and renewable fuels.

Byproduct production for each group of fuels is determined by summing byproduct production over the individual process steps for each fuel and vintage as shown below for main byproduct fuels. The equations for intermediate and renewable fuels are similar.

$$ENBYPM_{f,v} = \sum_{s=1}^{MPASTP} BYPQTY_{v,f,s} \tag{19}$$

where:

$ENBYPM_{f,v}$ = Byproduct energy production for main byproduct fuel f for vintage v,

$MPASTP$ = Number of process steps, and

$BYPQTY_{v,f,s}$ = Byproduct energy production for byproduct fuel f at process step s for vintage v.

Subroutine CALPATOT

CALPATOT calculates the total energy consumption from the process and assembly component. In the first model year, this subroutine calls CALINTER to calculate an intercept term for further use in the non-manufacturing econometric equations. Note that CALINTER does not apply to the manufacturing industries.

Energy consumption at each process step is determined by multiplying the current production at that particular process step by the unit energy consumption (UEC) for that process step. Energy consumption is calculated for each fuel and vintage using the following equation.

$$ENPQTY_{v,f,s} = PRODCUR_{v,s} \times ENPINT_{v,f,s} \tag{20}$$

where:

$ENPQTY_{v,f,s}$ = Consumption of fuel f at process step s for vintage v,

$PRODCUR_{v,s}$ = Production at process step s for vintage v, and

$ENPINT_{v,f,s}$ = Unit energy consumption of fuel f at process step s for vintage v.

Four energy products that are used for non-fuel purposes are modeled differently. These products are asphalt and road oil, liquid petroleum gas feedstocks, petrochemical feedstocks, and natural gas feedstocks. For the construction industry, the consumption of asphalt and road oil for all model years after 1990 is determined through the following equation.

$$ENPQTY_{v,asp,s} = ENPINT_{v,asp,s} \times PRODZERO_{v,s} + 0.375 \times \left[PRODCUR_{v,s} - PRODZERO_{v,s}\right] \tag{21}$$

where:

$ENPQTY_{v,asp,s}$ = Consumption of asphalt and road oil at process step s for vintage v,

$ENPINT_{v,asp,s}$ = Unit energy consumption of asphalt and road oil at process step s for vintage v,

$PRODZERO_{v,s}$ = 1990 production at process step s for vintage v for the construction industry, and

$PRODCUR_{v,s}$ = Production at process step s for vintage v.

For all years after 1990, feedstock consumption in the bulk chemical industry is computed as shown below for natural gas feedstocks. Equations for liquid petroleum gas feedstocks and petrochemical feedstocks are similar.

$$ENPQTY_{v,ngf,s} = ENPINT_{r,g,f} \times PRODZERO_{v,s} + 0.25 \times (PRODCUR_{v,s} - PRODZERO_{v,s}) \quad (22)$$

where:

$ENPQTY_{v,ngf,s}$ = Consumption of natural gas feedstock at process step s for vintage v,

$ENPINT_{v,ngf,s}$ = Unit energy consumption of natural gas feedstock at process step s for vintage v,

$PRODZERO_{v,s}$ = 1990 production at process step s for vintage v for the construction industry, and

$PRODCUR_{v,s}$ = Production at process step s for vintage v.

Consumption of each fuel is converted to trillions of Btu. Energy consumption is subdivided into main fuels, intermediate fuels, and renewable fuels. Main fuels include the following:

- electricity,
- core and non-core natural gas,
- natural gas feedstocks,
- steam coal,
- coking coal (including net coke imports),
- residual oil,
- distillate oil,
- liquid petroleum gas for heat and power,
- liquid petroleum gas for feedstocks,
- motor gasoline,
- still gas,
- petroleum coke,
- asphalt and road oil,
- petrochemical feedstocks,
- other petroleum feedstocks, and

- other petroleum.

Intermediate fuels include the following:

- steam,
- coke oven gas,
- blast furnace gas,
- other byproduct gas,
- waste heat, and
- coke.

Renewable fuels include the following:

- hydropower,
- biomass--wood,
- biomass--pulping liquor,
- geothermal,
- solar,
- photovoltaic,
- wind, and
- municipal solid waste.

Energy consumption for the three fuel groups is determined for each fuel by summing over the process steps as shown below for main fuels. The equations for intermediate and renewable fuels are similar.

$$ENPMQTY_f = \sum_{s=1}^{MPASTP} ENPQTY_{total,f,s} \tag{23}$$

where:

$ENPMQTY_f$	=	Consumption of main fuel f in the process/assembly component,
$MPASTP$	=	Number of process steps, and
$ENPQTY_{total,f,s}$	=	Consumption of fuel f at process step s for all vintages.

Energy consumption for coke imports is calculated as the difference between coke consumption and coke production. In the current industrial model, coke is consumed only in the blast furnace/basic oxygen furnace process step in the blast furnace and basic steel products industry. Coke is produced only in the coke oven process step in the blast furnace and basic steel products industry. The equation for net coke imports is shown below.

$$ENPMQTY_{coke} = ENPIQTY_{coke} - \left[PRODCUR_{total,co} \; x \; \frac{24.8}{10^6} \right] \tag{24}$$

where:

$ENPMQTY_{coke}$	=	Consumption of coke imports in the process/assembly component,
$ENPIQTY_{coke}$	=	Consumption of coke in the process/assembly component,
$PRODCUR_{total,co}$	=	Current production at the coke oven process step for all vintages, and
$24.8/10^6$	=	Conversion factor, where there are 24.8 million Btu per short ton of coke converted to trillion Btu.

Subroutine CALINTER

CALINTER calculates an intercept term used to calculate unit energy consumption (UEC) by an econometric approach for certain fuels within the non-manufacturing industries. The intercept calibrates projected consumption for the base year to actual consumption. For each fuel, an intercept term is calculated in CALINTER based on the UEC, cumulative output, own-price elasticities, and cross price elasticities. The purpose of the intercept term is to calibrate the results for the first model year. The intercept term is calculated for old vintage in the following equation. The intercept for new vintage is assumed to equal the intercept for old vintage. An intercept term is not required for middle vintage calculations.

$$EINTER_{old,f,s} = \frac{ENPINT_{old,f,s}}{[CUMOUT91]^{BCSC_{old,f,s}} \; x \; \prod_{t=1}^{11} [WPRC_t]^{BELAS_{old,f,s,t}}} \tag{25}$$

where:

$EINTER_{old,f,s}$	=	Intercept at process step s for fuel f for old vintage,
$ENPINT_{old,f,s}$	=	Unit energy consumption of fuel f at process step s for old vintage,

$CUMOUT91$ = Cumulative output through the year 1991,

$BCSC_{old,f,s}$ = Energy savings coefficient at process step s for fuel f and old vintage,

$WPRC_t$ = Price for fuel t in 1987 dollars, and

$BELAS_{old,f,s,t}$ = Own price elasticity at process step s for fuel f for old vintage, and cross price elasticity at process step s for fuel f and fuel t for old vintage.

Subroutine CALBTOT

CALBTOT calculates the total energy consumption for buildings. The energy consumption for buildings is calculated for two building uses, lighting and HVAC. Total energy consumption is determined for electricity, natural gas, and steam by multiplying industry employment by the building unit energy consumption as shown in the following equation.

$$ENBQTY_{e,f} = EMPLX_{i,r} \; x \; ENBINT_{e,f} \tag{26}$$

where:

$ENBQTY_{e,f}$ = Consumption of fuel f for building end use e,

$EMPLX_{i,r}$ = Employment for industry i in Census region r, and

$ENBINT_{e,f}$ = Unit energy consumption of fuel f for building end use e.

Subroutine CALGEN

Calculates total steam used to co-generate electricity. The total steam demand is computed by summing steam demand from buildings and steam demand from the process and assembly component. Using an estimated regression equation, total co-generated electricity is determined from the total steam demand and is calibrated to the current year EIA-867 estimate of total generation. When EIA-867 estimates are not available the model applies the industry growth in output to determine current year estimate. After total generation is calculated, total cogeneration capability is determined using standard conversion factors, and an offline estimate of capacity utilization. Prime mover estimates for cogeneration and cogeneration capability for own use and sales to the grid are computed using prime mover shares and own use generation and sales to the grid generation shares based on EIA-867 survey data.

The following equation calculates the total demand for steam.

$$STEMCUR = ENBQTY_{hvac,steam} + ENPIQTY_{steam} \tag{27}$$

where:

$STEMCUR$	=	Total steam demand,
$ENBQTY_{hvac,steam}$	=	Consumption of steam for HVAC, and
$ENPIQTY_{steam}$	=	Consumption of steam in the process/assembly component.

Total electricity generation is based on an econometric equation that relates electricity generation to steam demand (the regression parameters are in Appendix D). To utilize the regression parameters, an intercept term must be calculated on the first call to CALGEN. This intercept is the natural log of the ratio of current year total generation based upon EIA-867 survey data to the predicted value for the current year based on the regression parameters.

$$GINTER = \ln\left[\frac{GNTOTAL}{STEMCUR^{GSTEAM}}\right] \tag{28}$$

where:

$GINTER$	=	Intercept term for electricity generation,
$GNTOTAL$	=	Current year total generation of electricity,
$STEMCUR$	=	Total steam demand for the current year, and
$GSTEAM$	=	Steam demand coefficient.

Electricity generation is then determined through the equation shown below based on the intercept term and an estimated parameter for steam demand.

$$ELGEN_{total} = e^{GINTER} \times STEMCUR^{GSTEAM} \tag{29}$$

where:

$ELGEN_{total}$	=	Electricity generation for all prime movers,
$GINTER$	=	Intercept for electricity generation,
$STEMCUR$	=	Total steam demand, and
$GSTEAM$	=	Steam demand coefficient.

Generation of electricity is converted from Btu to megawatt hours. Capacity for electric generation is determined from total generation of electricity and an assumed capacity utilization rate based on EIA-867 survey data. The following equation calculates capacity for electric generation.

$$ELCAP = \frac{ELGEN_{total} \times 10^9}{.64 \times 3412.0 \times 365.25 \times 24.0} \tag{30}$$

where:

$ELCAP$	=	Capacity for electricity generation,
$ELGEN_{total}$	=	Electricity generation from all prime movers,
$.64$	=	Assumed utilization rate is .64
3412.0	=	Conversion factor, 3412.0 Btu per kilowatt-hour,
365.25	=	Number of days per year,
24.0	=	Number of hours per day, and
10^9	=	Conversion factor to convert to megawatts.

Capacity by prime mover is calculated using shares computed based on EIA-867 survey data.

Electricity generation for own use is calculated by using the own use share of electricity generation from the EIA-867 survey data.
Electricity generation for own use is then calculated from the following equation.

$$ELOWN = ELGEN_{total} \times (1 - GRDSHRG_{inddir,indreg}) \tag{31}$$

where:

$ELOWN$	=	Electricity generation for own use,
$ELGEN_{total}$	=	Electricity generation from all prime movers, and
$GRDSHRG_{inddir,indreg}$	=	Industry grid share value.

Electricity generation for sales to the grid is calculated similarly. Electricity generation is calculated for each of the four prime movers based on the share of total generation for each prime mover as shown below for gas turbines.

$$ELGEN_{m} = ELGEN_{total} \times GTSHR_{indreg} \tag{32}$$

where:

$ELGEN_{m}$	=	Electricity generation from prime mover *m*,
$ELGEN_{total}$	=	Electricity generation from all prime movers, and
$GTSHR_{indreg}$	=	Share of generation for prime mover gas turbine.

Generation for steam turbine and internal combustion engine is calculated similarly.

Total industrial cogeneration sales to the grid, own use, and total capacity are incremented as the processing of each industry is completed.

Subroutine CALSTOT

CALSTOT calculates total fuel consumption in the BSC component. Fuel consumption for non-steam turbines is calculated by multiplying electricity generation by internal combustion engines and combustion turbines by the appropriate heat rates. These estimates are then augmented by adding an incremental amount of fuel consumption based on EIA-867 survey data estimates of total cogeneration fuels consumption. The equation for internal combustion engines is presented below and a similar equation is used for combustion turbines. (Note that $ELGEN_{ICE}$ is calculated in CALGEN where it is one of the prime movers.) CALSTOT also calls the subroutine FUELBOIL. FUELBOIL calculates total fuel consumption in boilers and steam turbines.

$$ICEFUEL = ELGEN_{ice} \times \frac{GENEQPHTRT_{ice}}{3412.0} \tag{33}$$

where:

$ICEFUEL$ = Fuel consumption for electricity generation from internal combustion engines,

$ELGEN_{ice}$ = Electricity generation from internal combustion engines,

$GENEQPHTRT_{ice}$ = Heat rate for internal combustion engines, and

3412.0 = Conversion factor to convert from Kwh to Btu.

Fuel consumption in steam turbines and boilers is calculated in the subroutine FUELBOIL called by CALSTOT. The four fuels considered for cogeneration are coal, oil, natural gas, and renewables/other. It is assumed that all coal and renewables consumed for cogeneration are consumed in steam turbines. Internal combustion engines are assumed to consume only distillate oil, and all combustion turbines use natural gas. The following equation is the computation of consumption of distillate oil for cogeneration. The equations for the other fuels are similar.

$$CGFUEL_{oil,total,r} = STFUEL_{oil} + ICEFUEL \tag{34}$$

where:

$CGFUEL_{oil,total,r}$ = Consumption of distillate oil for cogeneration of electricity for all uses in Census region r,

$STFUEL_{oil}$ = Consumption of distillate oil in steam turbines, and

$ICEFUEL$ = Distillate consumption for electricity generation from internal combustion engines.

The total fuel consumption for cogeneration is shared between generation for own use and sales to the grid based on the proportion of total generation allotted to each use. The following equation calculates fuel consumption for own use generation. Fuel consumption for sales to the grid is calculated similarly.

$$CGFUEL_{f,own,r} = CGFUEL_{f,total,r} \times (1 - GRDSHRG_{inddir,indreg}) \qquad (35)$$

where:

$CGFUEL_{f,own,r}$	=	Consumption of fuel f for cogeneration of electricity for own use in Census region r,
$CGFUEL_{f,total,r}$	=	Consumption of fuel f for cogeneration of electricity for all uses in Census region r,
$GRDSHRG_{inddir,indreg}$	=	Calculated sales to the grid share value.

Total industrial fuel use for cogeneration is incremented after each industry is processed.

Subroutine FUELBOIL

FUELBOIL calculates total fuel consumption in boilers and steam turbines. An average intensity, shown below, is determined from boiler fuel shares and the unit energy consumption to generate steam.

$$AVGINT = \sum_{f=1}^{IFSMAX} BSSHR_f \times ENSINT_f \qquad (36)$$

where:

$AVGINT$	=	Average intensity,
$IFSMAX$	=	Number of fuels consumed in the BSC component,
$BSSHR_f$	=	Share of total fuel consumption in the BSC component for fuel f, and
$ENSINT_f$	=	Intensity of fuel f in the BSC component.

The quantity of steam generated by byproduct fuels is determined by dividing the byproduct energy produced by the unit energy consumption for each main, intermediate, and renewable fuel.

$$BYPSTM = \sum_{f=1}^{IFSBYPM} \frac{BYPBSCM_f}{BYSINT_f} + \sum_{f=1}^{IFSBYPI} \frac{BYPBSCI_f}{BYSINT_f} + \sum_{f=1}^{IFSBYPR} \frac{BYPBSCR_f}{BYSINT_f} \qquad (37)$$

where:

$BYPSTM$	=	Amount of steam generated from all byproduct fuels,
$IFSBYPM$	=	Number of byproduct main fuels,
$BYPBSCM_f$	=	Byproduct consumption of main fuel f in the BSC component,
$BYSINT_f$	=	Intensity for byproduct fuel f consumed in the BSC component,
$IFSBYPI$	=	Number of byproduct intermediate fuels,
$BYPBSCI_f$	=	Byproduct consumption of intermediate fuel f in the BSC component,
$IFSBYPR$	=	Number of byproduct renewable fuels, and
$BYPBSCR_f$	=	Byproduct consumption of renewable fuel f in the BSC component.

The following equation calculates the quantity of steam to be generated from purchased fuels. The quantity of steam to be generated from purchased fuels is the difference between the amount of steam consumed in boilers and the amount of steam generated from all byproduct fuels.

$$STEMCURF = STEMCUR - BYPSTM \qquad (38)$$

where:

$STEMCURF$	=	Amount of steam to be generated from purchased fuels,
$STEMCUR$	=	Total steam demand, and
$BYPSTM$	=	Amount of steam generated from all byproduct fuels.

The total quantity of fuel consumed to generate steam is calculated below from the total steam demand from purchased fuels, the average intensity, and boiler fuel shares.

$$ENSQTY_f = STEMCURF \times AVGINT \times BSSHR_f \qquad (39)$$

where:

$ENSQTY_f$	=	Consumption of fuel *f* to generate steam,
$STEMCURF$	=	Amount of steam to be generated from purchased fuels,
$AVGINT$	=	Average intensity, and
$BSSHR_f$	=	Share of total fuel consumption in the BSC component for fuel *f*.

The amount of fuel consumed in the BSC component must be adjusted to exclude the amount of diesel used in internal combustion engines as shown in the following equation. A similar equation exists to exclude natural gas consumed in combustion turbines.

$$ENSQTY_f = ENSQTY_f - ICEFUEL \qquad (40)$$

where:

$ENSQTY_f$	=	Consumption of fuel *f* to generate steam, and
$ICEFUEL$	=	Fuel consumption for electricity generation from internal combustion engines.

The amount of each fuel and byproduct consumed in steam turbines is determined by fuel shares, total generation from steam turbines, and the heat rate for steam turbines. The following equation calculates the fuel consumption in steam turbines. A similar equation exists for byproduct fuel consumption in steam turbines.

$$STFUEL_f = \left[\frac{ENSQTY_f}{\sum_{f=1}^{IFSMAX} ENSQTY_f + \sum_{f=1}^{IFSBYP} BYSQTY_f} \right] \times ELGEN_{st} \times \frac{GENEQPHTRT_{st}}{3412.0} \qquad (41)$$

where:

$STFUEL_f$	=	Consumption of fuel *f* in steam turbines,
$ENSQTY_f$	=	Consumption of fuel *f* to generate steam,

IFSMAX	=	Number of fuels consumed in the BSC component,
IFSBYP	=	Number of byproducts consumed in the BSC component,
$BYSQTY_f$	=	Consumption of byproduct fuel *f* in the BSC component,
$ELGEN_{st}$	=	Electricity generation from steam turbines,
$GENEQPHTRT_{st}$	=	Heat rate for steam turbines, and
3412.0	=	Conversion factor to convert from kilowatt hours to Btu.

Subroutine INDTOTAL

The consumption estimates derived in the PA, BSC, and BLD components are combined in INDTOTAL to produce an overall energy consumption figure for each industry. The consumption estimates include byproduct consumption for each of the main, intermediate, and renewable fuels. Only electricity, natural gas, and steam include consumption from buildings. For all fuels except electricity, the following equation is used.

$$QTYMAIN_{f,r} = ENPMQTY_f + ENBQTY_{total,f} + ENSQTY_f + BYPBSCM_f \tag{42}$$

where:

$QTYMAIN_{f,r}$	=	Consumption of main fuel *f* in Census region *r*,
$ENPMQTY_f$	=	Consumption of main fuel *f* in the PA component,
$ENBQTY_{total,f}$	=	Consumption of fuel *f* for all building end uses,
$ENSQTY_f$	=	Consumption of fuel *f* to generate steam, and
$BYPBSCM_f$	=	Byproduct consumption of main fuel *f* to generate electricity from the BSC component.

Consumption of electricity is defined as purchased electricity only, therefore, electricity generation for own use is removed from the consumption estimate.

$$QTYMAIN_{elec,r} = ENPMQTY_{elec} + ENBQTY_{total,elec} - ELOWN \tag{43}$$

where:

$QTYMAIN_{elec,r}$	=	Consumption of purchased electricity in Census region r,
$ENPMQTY_{elec}$	=	Consumption of electricity in the PA component,
$ENBQTY_{total,elec}$	=	Consumption of electricity for all building end uses, and
$ELOWN$	=	Electricity generated for own use.

Subroutine NATTOTAL

After processing all four Census regions for an industry, NATTOTAL computes a national industry estimate of energy consumption. This subroutine also computes totals over all fuels for main, intermediate, and renewable fuels. Total consumption for the entire industrial sector for each main, intermediate, and renewable fuel is determined by aggregating as each industry is processed as shown in the following equation.

$$TQMAIN_{f,r} = \sum_{i=1}^{INDMAX} QTYMAIN_{f,r} \tag{44}$$

where:

$TQMAIN_{f,r}$	=	Total consumption for main fuel f in Census region r,
$INDMAX$	=	Number of industries, and
$QTYMAIN_{f,r}$	=	Consumption of main fuel f in Census region r.

Subroutine CONTAB

CONTAB is responsible for reporting consumption values for the energy-intensive industries and energy consumption for heat and power for non-energy-intensive industries. Energy consumption for manufacturing heat and power is computed by summing total consumption of each fuel over all the manufacturing industries. The consumption for heat and power will include consumption from the energy-intensive industries. The following fuels are considered for manufacturing heat and power: electricity, natural gas except for feedstock and lease and plant gas, steam coal, coking coal, net coke imports, residual oil, distillate oil, liquid petroleum gas, still gas, petroleum coke, other petroleum and total renewables. The following equation calculates consumption of main fuels for manufacturing heat and power. A similar equation exists for renewable fuels.

$$TMANHP_f = \sum_{i=7}^{INDMAX} \sum_{f=1}^{NUM_{fg}} QTYMAIN_{f,total} \tag{45}$$

where:

$TMANHP_f$	=	Total manufacturing consumption of fuel *f* for heat and power,
$INDMAX$	=	Number of industries,
NUM_{fg}	=	Number of fuels in fuel group *fg*, and
$QTYMAIN_{f,total}$	=	Consumption of main fuel *f* in all Census regions.

Energy consumption for non-manufacturing heat and power is considered separately from the manufacturing industries. Fuels considered for non-manufacturing heat and power include: electricity, natural gas, steam coal, residual oil, distillate oil, liquid petroleum gas, motor gasoline, renewables and other petroleum. A consumption table is also produced for miscellaneous feedstocks. All industries are included here and the following fuels are considered: natural gas feedstocks, liquid petroleum gas feedstocks, asphalt and road oils, petrochemical feedstocks, lubes and waxes, and other petroleum feedstocks.

A consumption table for each of the energy-intensive industries is produced in CONTAB. Consumption figures are reported for each of the fuels used in each particular industry. There is a total renewables fuel group for each energy-intensive industry. The equation below calculates consumption of main fuels in the food and kindred products industry. All other energy-intensive industries have similar equations.

$$TFOODCON_f = \sum_{f=1}^{NUM_{fg}} QTYMAIN_{f,total} \tag{46}$$

where:

$TFOODCON_f$	=	Total consumption of fuel *f* in the food and kindred products industry,
NUM_{fg}	=	Number of fuels in fuel group *fg*, and

$QTYMAIN_{f,total}$ = Consumption of main fuel *f* for all Census regions.

Subroutine WRBIN

WRBIN writes data for each industry to a binary file. Two different binary files are created. The first contains variables and coefficients that do not change over years, but change over industries. This binary file also contains data that do not change over years, but change over processes. The second binary file contains data that change from year to year.

Subroutine INDCGN

Calculates aggregate industrial total cogeneration and cogeneration capacity, for own use and sales to the grid by fuel and census division. Aggregate industrial total cogeneration fuel consumption for own use and sales to the grid by census division is also calculated. These quantities are reported to NEMS cogeneration variables.

The equation below calculates aggregate cogeneration capacity for sales to the grid by division and fuel based on EIA-867 survey data.

$$CAPGW_{cdiv,fuel,sales} = CAP867_{cdiv,year,ind,fuel} \times SHARE_{pm,cdiv,year,ind,fuel} \times IGRIDSHR_{cdiv,year,ind} \tag{47}$$

where:

$CAPGW_{cdiv,fuel,sales}$ = Existing or planned capacity for cogeneration of electricity for sales to the grid for census division and fuel,

$CAP867_{cdiv,year,ind,fuel}$ = EIA-867 capacity by census division, year, industry, and fuel,

$SHARE_{pm,cdiv,yr,ind,fuel}$ = EIA-867 share of fuel by prime mover PM, census division, year, and industry,

$IGRIDSHR_{cdiv,yr,ind}$ = EIA-867 sales-to-the-grid share of capacity in census division, year, and industry

The capacity for own use is calculated similarly.

Calculate EIA-867 total industrial generation by division and fuel for sales to the grid.

$$GENGWH_{cdiv,fuel,sales} = \sum_{cdiv=1,9} \sum_{fuel=1,6} \sum_{pm=1,3} \sum_{ind=1,15} SICGEN_{cdiv,yr,ind} \quad (48)$$

$GENGWH_{cdiv,fuel,sales}$	=	Total generation by census division, fuel, and own use/sales to the grid.
$SICGEN_{cdiv,yr,ind,fuel,pm,sales}$	=	EIA-867 based generation by census division, year, fuel, prime mover, and own use sales to the grid.

Generation for sales to the grid is calculated similarly.

Total industrial consumption by division and fuel is calculated from the EIA-867 survey data.

$$DIVFUEL_{cdiv,fuel,sales} = OTHFUEL_{cdiv,fuel,sales} \quad (49)$$

where:

$DIVFUEL_{cdiv,fuel,sales}$	=	Industrial variable holding aggregate total industrial cogeneration fuel consumption by division, fuel, and sales to the grid and own use
$OTHFUEL_{cdiv,fuel,sales}$	=	Variable holding the cogeneration fuel consumption calculated based on EIA-867 aggregate total generation by fuel, prime mover, and census division, multiplied by appropriate heat rates,

where:

$$OTHFUEL_{cdiv,fuel,sales} = \sum_{cdiv=1,9} \sum_{pm=1,3} SICGEN_{cdiv,yr,ind,pm,sales} \; x \; RATE_{pm} \quad (50)$$

where:

$RATE_{pm}$	=	Heat rate for prime mover *pm*.

Industrial cogeneration fuel consumption for own use is calculated similarly.

Subroutine WEXOG

WEXOG stands for write industrial calculated quantities to NEMS exogenous variables. Prior to assigning values to the NEMS variables, total industrial fuel consumption quantities are computed. These values are then calibrated or benchmarked to the *State Energy Data System* (SEDS) estimates for each data year, and thereafter are calibrated to the *Short Term Energy Outlook* (STEO) forecast year estimates. The calibration factors are multiplicative for all fuels which have values greater than zero and are additive otherwise.

The equation for total industrial electricity consumption is below. All other fuels have similar equations with refinery consumption and oil and gas consumption included only where appropriate.

$$BMAIN_{fuel,region} = TQMAIN_{fuel,region} + QELRF_{region} \tag{51}$$

The equation for total industrial natural gas consumption is:

$$BMAIN_{fuel,region} = TQMAIN_{fuel,region} + QNGRF_{region} + CGOGQ_{sales,region} + CGOGQ_{own,region} + NONTRAD_{region,fuel} \tag{52}$$

$BMAIN_{ng,r}$	=	Consumption of natural gas in Census region *r*,
$TQMAIN_{f,r}$	=	Consumption of natural gas fuel *f* in Census region *r*,
$QNGRF_{r,y}$	=	Natural gas consumed by petroleum refining industry in Census division *r* in year *y*, and
$CGOGQ_{sales,region}$	=	Consumption of natural gas from cogeneration of electricity for sales to the grid in enhanced oil recovery in Census region and year.
$CGOGQ_{own,region}$	=	Consumption of natural gas from cogeneration of electricity for own use in enhanced oil recovery by Census region year.

Total industrial consumption for other fuels is calculated similarly.

SEDS benchmark factors are calculated as follows:

$$SEDSBF_{fuel,region} = \frac{SEDS4_{fuel,region}}{BMAIN_{fuel,region}} \qquad (53)$$

where:

$SEDSBF_{fuel,region}$	=	Current SEDS data year benchmark factors
$SEDS4_{fuel,region}$	=	Current SEDS data year consumption aggregated from the division level by fuel to the region level by fuel
$BMAIN_{fuel,region}$	=	Total industrial fuel consumption by fuel and region

SEDS benchmark factors are then multiplied by the total industrial consumption value as follows:

$$BENCH_{fuel,region} = SEDSBF_{fuel,region} \ x \ BMAIN_{fuel,region} \qquad (54)$$

STEO benchmark factors are calculated as follows:

$$STEOBF_{fuel} = \frac{STEO_{fuel,year}}{\sum_{fuel} \sum_{region} BENCH_{fuel,region}} \qquad (55)$$

where:

$STEOBF_{fuel}$	=	STEO benchmark factor by fuel which equals each fuels share of the total SEDS benchmarked industrial consumption. Note that these factors are applied post SEDS data years.
$STEO_{fuel,year}$	=	Total third quarter STEO consumption by fuel for each forecast year.

$BENCH_{fuel,region}$ = Benchmarked total industrial fuel consumption.

The STEO factors are applied to the SEDS industrial benchmarked consumption values as follows:

$$BENCH_{fuel,region} = STEOBF_{fuel} \times BENCH_{fuel,region} \tag{56}$$

STEO benchmark factors are faded to zero beginning in the first year after the STEO forecast year until four years post STEO forecast.

The shares for renewable fuels, calculated through the following equation, are based on the value of output from the paper and lumber industries since most renewable fuel consumption occurs in these industries.

$$DSRENW_{f,d} = \frac{OUTIND_{13,d} + OUTIND_{11,d}}{\sum_{d=1}^{NUM_r} (OUTIND_{13,d} + OUTIND_{11,d})} \tag{57}$$

where:

$DSRENW_{f,d}$ = Share of output for renewable fuel f in Census division d,

$OUTIND_{13,d}$ = Gross value of output for the paper and allied products industry in Census division d,

$OUTIND_{11,d}$ = Gross value of output for the lumber and wood products industry in Census division d, and

NUM_r = Number of Census divisions in Census region r.

The benchmark factor for biomass is computed as follows.

$$BENCHFAC_{bm,d} = \frac{BIOFUELS_d}{\sum_{f=2}^{3} DQRENW_{f,d}} \tag{58}$$

where:

$BENCHFAC_{bm,d}$ = Benchmark factor for biomass in Census division d,

$BIOFUELS_d$ = Consumption of biofuels in Census division d, and

$DQRENW_{f,d}$ = Consumption of renewable fuel f in Census division d, and

$$DQRENW_{f,d} = TQRENW_{f,region} \times DSRENW_d \tag{59}$$

where:

$TQRENW_{f,r}$ = Industrial total consumption of renewable fuel f in Census region r, and

$DSRENW_{f,d}$ = Share of output for renewable fuel f in Census division d,

Adjust total industrial consumption for Climate Change Action Plan effects. There are assumed fossil fuel savings (CCAPFOS) and electricity savings (CCAPKWH) for 2000 and 2010. All fossil fuel savings are assumed to be in steam coal use. Savings increase gradually up to year 2010, and remain constant thereafter. Total savings are calculated and are then shared out at the census division level.

Fossil fuel, i.e., coal, savings are calculated as:

$$CCAPCL_{total} = CCAPFOS_1 + .1 * (CCAPFOS_2 - CCAPFOS_1) * NGYRS \tag{60}$$

where:

$CCAPCL_{total}$ = Total reduction in coal consumption due to climate change action plan.

CCAPFOS = Assumed fossil fuel savings for a base year 1=2000 and 2=2010.

NGYRS = Number of years past year 2000 up to year 2010.

Electricity savings are calculated similarly.

Benchmarked consumption values are then passed into the appropriate variables for reporting to NEMS. The following equation calculates consumption of electricity. Equations for other fuels are similar.

$$QELIN_{cdiv,year} = BENCH_{elec,region} \ x \ SEDSHR_{elec,region,cdiv} \tag{61}$$

where:

$QELIN_{cdiv,year}$	=	Industrial consumption of electricity in Census region and year,
$BENCH_{elec,region}$	=	Consumption of electricity in Census *region*, and
$SEDSHR_{elec,region,cdiv}$	=	SEDS census region share of electricity in census division.

The following two equations represent the consumption of core and non-core natural gas.

$$QGFIN_{cdiv,year} = \left[BENCH_{ngas,region} \ x \ SEDSHR_{ngas,region,region}\right] x \left[\frac{TQMAIN_{cng,region} + TQMAIN_{fds,region}}{BMAIN_{ngas,region}}\right] \tag{63}$$

where:

$QGFIN_{cdiv,year}$	=	Industrial consumption of core natural gas in Census division *cdiv* and *year*,
$BENCH_{ngas,region}$	=	Benchmarked consumption of total natural gas in Census region *region*,
$SEDSHR_{ngas,region,cdiv}$	=	SEDS census region share of natural gas in census division *cdiv*,
$TQMAIN_{cng,region}$	=	Consumption of core natural gas in Census region *region*,
$TQMAIN_{fds,region}$	=	Consumption of feedstock natural gas in Census region *region*, and

$BMAIN_{ngas,region}$ = Total unbenchmarked consumption of natural gas in Census region *region*.

$$QGIIN_{cdiv,year} = QNGIN_{ngas,cdiv} - QGFIN_{cdiv,year} \tag{63}$$

where:

$QGIIN_{cdiv,year}$ = Industrial consumption of non-core natural gas in Census division *cdiv* by year,

$QNGIN_{ngas,cdiv}$ = Consumption of natural gas in Census division *cdiv*,

$QGFIN_{cdiv,year}$ = Industrial consumption of core natural gas in Census division *cdiv* by year.

Industrial consumption of biomass is calculated in the following equation.

$$QBMIN_{d,y} = \left[\sum_{f=2}^{3} DQRENW_{f,d}\right] + \left[\sum_{u=1}^{2} CGOGQ_{d,y,bm,u}\right] + QBMRF_{d,y} \tag{64}$$

where:

$QBMIN_{d,y}$ = Industrial consumption of biomass in Census division *d* in year *y*,

$DQRENW_{f,d}$ = Consumption of renewable fuel *f* in Census division *d*,

$CGOGQ_{d,y,bm,u}$ = Consumption of biomass from cogeneration of electricity for use *u* in enhanced oil recovery in Census division *d* in year *y*, and

$QBMRF_{d,y}$ = Biomass consumed by petroleum refining industry in Census division *d* in year *y*.

Consumption of total renewables is calculated through the following equation. Currently, only biomass is nonzero.

$$QTRIN_{d,y} = QHOIN_{d,y} + QBMIN_{d,y} + QGEIN_{d,y} + QSTIN_{d,y} + QPVIN_{d,y} \qquad (65)$$

where:

$QTRIN_{d,y}$	=	Industrial consumption of total renewables in Census division d in year y,
$QHOIN_{d,y}$	=	Industrial consumption of hydropower in Census division d in year y,
$QBMIN_{d,y}$	=	Industrial consumption of biomass in Census division d in year y,
$QGEIN_{d,y}$	=	Industrial consumption of geothermal in Census division d in year y,
$QSTIN_{d,y}$	=	Industrial consumption of solar thermal in Census division d in year y,
$QPVIN_{d,y}$	=	Industrial consumption of photovoltaic in Census division d in year y,
$QWIIN_{d,y}$	=	Industrial consumption of wind in Census division d in year y, and
$QMSIN_{d,y}$	=	Industrial consumption of municipal solid waste in Census division d in year y.

Currently, only biomass (including pulping liquor) and hydropower are implemented in the model.

Variables pertaining to industrial cogeneration of electricity including generation for own use and sales to the grid, capacity, and fuel consumption are also passed to the appropriate NEMS variables. Cogeneration data from the refining and oil and gas industries are included in the industrial cogeneration data passed to NEMS as shown in the following equation for capacity. Similar equations are used to incorporate refining and oil and gas cogeneration for own use and sales to the grid as well as fuel consumption.

$$CGINDCAP_{d,y,f,u,pl} = CAPGW_{d,f,u,pl} \qquad (66)$$

where:

$CGINDCAP_{d,y,f,u,pl}$ = Industrial capacity for cogeneration for use u using fuel f in Census division d in year y,

$CAPGW_{d,f,u,pl}$ = Capacity for cogeneration of electricity for use u using fuel f in Census division d,

Total consumption is calculated below.

$$CGINDQ_{d,y,f,u} = DIVFUEL_{d,f,u} \tag{67}$$

where:

$CGINDQ_{d,y,f,u}$ = Industrial consumption of fuel f for cogeneration of electricity for use u in Census division d in year y,

$DIVFUEL_{d,f,u}$ = Consumption of fuel f for cogeneration of electricity for use u in Census division d,

Consumption values for manufacturing heat and power must be augmented by fuels purchased for refineries before passing to NEMS as shown in the following equation.

$$MANHP_{elec,y} = TMANHP_{elec} + QELRF_{d,y} \tag{68}$$

where:

$MANHP_{elec,y}$ = Consumption of electricity for manufacturing heat and power in year y,

$TMANHP_{elec}$ = Total manufacturing consumption of electricity for heat and power, and

$QELRF_{d,y}$ = Electricity consumed by petroleum refining industry in Census division d in year y.

Consumption of natural gas, coal, residual, distillate, liquid petroleum gas, still gas, petroleum coke, and others are calculated in a similar fashion.

Consumption for non-manufacturing heat and power is adjusted to include consumption from oil and gas mining.

$$NONHP_{f,y} = TNONHP_f + \sum_{u=1}^{2} CGOGQ_{total,y,f,u} \tag{69}$$

where:

$NONHP_{f,y}$	=	Consumption of fuel f for non-manufacturing heat and power in year y,
$TNONHP_f$	=	Total non-manufacturing consumption of fuel f for heat and power and
$CGOGQ_{total,y,f,u}$	=	Consumption of fuel f from cogeneration of electricity for use u in enhanced oil recovery in all Census divisions in year y.

Consumption for miscellaneous feedstocks in each of the energy-intensive industries are passed to the appropriate variables for usage by NEMS.

Subroutine RDBIN

RDBIN is called by the main industrial subroutine ISEAM on model runs after the first model year. This subroutine reads the previous year's data from the binary files. The previous year's values are assigned to lagged variables for price, value of output, and employment. The previous year's UECs, TPC coefficients, price elasticities, and intercepts are read into the variables for initial UEC, TPC, price elasticity, and intercept. Process specific data is read into either a lagged variable or an initial estimate variable. Three cumulative variables are calculated in this subroutine for future use. A cumulative output variable, a cumulative UEC, and a cumulative production variable are computed for each fuel and process step.

MODCAL

MODCAL performs like the main industrial subroutine ISEAM in all years after the first model year. In subsequent years, no data must be read from the input files, however, UECs and TPC coefficients must be adjusted to reflect the new model year, whereas the first model year uses only initial estimates of these values. MODCAL calls the following subroutines: CALPROD, CALCSC, CALPRC, CALPATOT, CALBYPROD, CALBTOT, CALGEN, CALBSC, CALSTOT, INDTOTAL, NATTOTAL, and CONTAB. Similar to the functioning of ISEAM, the subroutines NATTOTAL and CONTAB are called only after the last region for an industry has been processed.

Subroutine CALPROD

CALPROD determines the throughput for production flows for the process and assembly component. Existing old and middle vintage production is adjusted by the retirement rate of capital through the following equations for the manufacturing industries.

$$PRODCUR_{old,s} = \left[PRODCUR_{old,s} + IDLCAP_{old,s}\right] x \ (1 - PRODRETR_s) \tag{70}$$

where:

$PRODCUR_{old,s}$	=	Existing production for process step s for old vintage,
$IDLCAP_{old,s}$	=	Idle production at process step s for old vintage, and
$PRODRETR_s$	=	Retirement rate at process step s.

$$PRODCUR_{mid,s} = (PRODCUR_{mid,s} + PRODCUR_{new,s}) \ x \ (1 - PRODRETI \tag{71}$$

where:

$PRODCUR_{mid,s}$	=	Existing production at process step s for mid vintage,
$PRODCUR_{new,s}$	=	Production at process step s for new vintage,
$PRODRETR_s$	=	Retirement rate at process step s.

For the non-manufacturing industries, the following two equations are used for old vintage and middle vintage production.

$$PRODCUR_{old,s} = PRODCUR_{old,s} + IDLCAP_{old,s} \tag{72}$$

where:

$PRODCUR_{old,s}$	=	Existing production at process step s for old vintage, and

$IDLCAP_{old,s}$ = Idle production for process step s for old vintage.

$$PRODCUR_{mid,s} = PRODCUR_{mid,s} + PRODCUR_{new,s} \tag{73}$$

where:

$PRODCUR_{mid,s}$ = Existing production at process step s for mid vintage, and

$PRODCUR_{new,s}$ = Production at process step s for new vintage.

Total production throughput for the industry is calculated. If the initial UEC is in physical units, the value of output for the current year is multiplied by the fixed ratio of physical units to value of output calculated in the first model year.

$$PRODX_{i,r} = PHDRAT \; x \; PRODVX_{i,r} \tag{74}$$

where:

$PRODX_{i,r}$ = Value of output in physical units for industry i in Census region r,

$PHDRAT$ = Ratio of physical units to value of output, and

$PRODVX_{i,r}$ = Output for industry i in Census region r.

If the initial UEC is in dollar units, then the current year's value of output is used to determine total production throughput.

Total production throughput is calculated by determining new capacity requirements at each process step so as to meet final demand changes and replace retired capacity. All process steps that meet common downsteps are evaluated using a production flow balance equation. The flow balance is defined by equating downstep production requirements with all capacity available to meet it. The balance is achieved by adding new capacity or idling existing capacity. New capacity for a step is added in proportion to the assumed relative production flow rates for new capacity. Capacity is idled in proportion to the flowrates of existing capacity.

The following are elements of each process step's balance equation:

1. Existing joint capacity (EXISTCAP): the step's own existing capacity, as well as related steps' existing production capacity. This includes all capacity surviving from 1990 (old) and post-1991 (mid) vintages. "Related Steps" are those that flow to common downsteps. EXISTCAP is determined from the variables PRODCUR(OLD,related_steps) and PRODCUR(MID,related_steps).

$$PRODCUR_{total,s} = PRODFLOW_{old,s,l} \; x \; PRODX_{i,r} \tag{75}$$

where:

$PRODCUR_{total,s}$	=	Production at process step s for all vintages,
$PRODFLOW_{old,s,l}$	=	Down-step throughput to process step s by link l for old vintage, and
$PRODX_{i,r}$	=	Value of output for industry i in Census region r.

2. Combined Downstep Requirements (DOWN_STEP_REQD): the combined downstep flow requirements, including any new downstep production, that must be met by all the related (or "joint") steps. DOWN_STEP_REQD is a function of PRODCUR(OLD,downstep), PRODCUR(MID,downstep), and PRODCUR(NEW,downstep), unless the step meets final demand (exogenous production). If so, DOWN_STEP_REQD is a function of PROX.

$$PRODCUR_{new,s} = PRODCUR_{total,s} - PRODCUR_{old,s} - PRODCUR_{mid,s} \tag{76}$$

where:

$PRODCUR_{new,s}$	=	New production at process step s for new vintage,
$PRODCUR_{total,s}$	=	Total production at process step s for all vintages,
$PRODCUR_{old,s}$	=	Existing production at process step s for old vintage, and
$PRODCUR_{mid,s}$	=	Existing production at process step s for mid vintage.

Middle vintage production is unaltered.

3. New joint Capacity (JOINTNEW): The difference between Existing Joint Capacity (1) and the Combined Downstep Requirements (2). This is the balancing item for a set of related ("joint") process steps.

4. Step's Share of Joint Capacity (JOINTSHR): This is the proportion of New Joint Capacity that will be met by this step. JOINTSHR is the ratio of the step's own flow rate, PRODFLOW(NEW_RATE,own_step,downstep), to the sum of related steps rates, PRODFLOW(NEW_RATE,related_steps,downstep). A separate JOINTSHR is calculated for use when JOINTNEW is less that zero--the idling case.

The balance equation is:

$$JOINTNEW + EXISTCAP - DOWN\ STEP\ REQD = 0 \qquad (77)$$

where:

JOINTNEW	=	Idle production for process step *s* for old vintage,
EXISTCAP	=	Existing production at process step *s* for old vintage,
DOWN_STEP_REQD	=	Existing production at process step *s* for mid vintage, and

Solving for the unknown, we write:

$$JOINTNEW = DOWN\ STEP\ REQD - EXISTCAP \qquad (78)$$

The step's share of new capacity is:

$$PRODCUR_{new,is} = JOINTSHR_{is}\ x\ JOINTNEW \qquad (79)$$

When implemented as a general routine, the balance equation is developed in matrix format as:

$$[PFold_{i,j}] \times [PRODCUR\ OLD_j] + [PFmid_{i,j}] \times [PRODCUR\ MID_j] + [PFnew_{i,j}] \times [PRODCUR\ NEW_j] + JOINTNEW = 0$$

where:

$PFold_{i,j}$	=	Production flow rate corresponding to industrial processes installed in 1990 plants for the ith primary step and the jth downstep
$PFmid_{i,j}$	=	Production flow rates corresponding to industrial production capacity installed in post 1990 plants for the ith primary step and the jth downstep
$PFnew_{i,j}$	=	Production flow rates of all new industrial capacity added within a given year to meet exogenous output and retirement of existing capital stock requirements for the ith primary step and the jth downstep

When solving for JOINTNEW, the negative of the above matrix term is used. This is subtracting the matrix terms from both sides of the balance equation. A "+1" coefficient in Pfold or Pfnew is used when the column corresponds to a joint process step. If the column is a downstep, the coefficient is the negative of the sum of flow rates to that downstep.

Subroutine CALCSC

CALCSC is called to update unit energy consumption. CALCSC calls one of three subroutines, CALCSC1, CALCSC2, or CALCSC3 depending on the type of approach for a particular fuel, process step, and industry. CALCSC1 maintains constant UECs. CALCSC2 applies the econometric approach for non-energy-intensive industries. CALCSC3 applies the engineering approach for energy-intensive industries.

Subroutine CALCSC1

CALCSC1 updates UECs based on the previous year's UEC. Unit energy consumption for each fuel, process step, and vintage is updated in the equation below. This approach yields constant UECs over time.

$$ENPINT_{v,f,s} = ENPINTLAG_{v,f,s} \tag{81}$$

where:

$ENPINT_{v,f,s}$ = Unit energy consumption of fuel f at process step s for vintage v, and

$ENPINTLAG_{v,f,s}$ = Lagged unit energy consumption of fuel f at process step s for vintage v.

Subroutine CALCSC2

CALCSC2 updates UECs through an econometrically estimated equation. Energy savings, or the location on the technology possibility curve, is calculated in the following equation for old and new vintage and is based on the total cumulative output raised to the coefficient.

$$CSCCUR_{v,f,s} = \left[CUMOUT_{total,s}\right]^{BCSC_{v,f,s}} \tag{82}$$

where:

$CSCCUR_{v,f,s}$ = Current energy savings at process step s for fuel f for vintage v,

$CUMOUT_{total,s}$ = Cumulative output, from 1958 through the lag of the current year, at process step s for all vintages, and

$BCSC_{v,f,s}$ = Energy savings coefficient at process step s for fuel f and vintage v.

The unit energy consumption for old and new vintage is calculated by multiplying the intercept term calculated in CALINTER by the current energy savings.

$$ENPINT_{v,f,s} = EINTER_{v,f,s} \ x \ CSCCUR_{v,f,s} \tag{83}$$

where:

$ENPINT_{v,f,s}$ = Unit energy consumption of fuel f at process step s for vintage v,

$EINTER_{v,f,s}$ = Intercept at process step s for fuel f for vintage v, and

$CSCCUR_{v,f,s}$ = Current energy savings at process step s for fuel f for vintage v.

The UEC for middle vintage is computed in the following equation as the ratio of the cumulative unit energy consumption to cumulative production for new vintage, i.e., it is simply the weighted average UEC.

$$ENPINT_{mid,f,s} = \frac{SUMPINT_{f,s}}{CUMPROD_{new,s}} \tag{84}$$

where:

$ENPINT_{mid,f,s}$ = Unit energy consumption of fuel f at process step s for mid vintage,

$SUMPINT_{f,s}$ = Cumulative unit energy consumption of fuel f at process step s, and

$CUMPROD_{new,s}$ = Cumulative production at process step s for new vintage.

The cumulative variables are calculated in RDBIN.

Subroutine CALTLOG

The unit energy consumption values for the energy non-intensive manufacturing industries are calculated based upon fuel shares estimated with a translog model as discussed above.

The variable definitions are presented in Table 6.

Table 6. Translog Variable Definitions

Variable	Definition
w_1	Price of Natural Gas
w_2	Price of Coal
w_3	Price of Electricity
w_4	Price of Distillate
w_5	Price of Residual
w_6	Price of LPG
x_1	Quantity of Natural Gas
x_2	Quantity of Coal
x_3	Quantity of Electricity
x_4	Quantity of Distillate
x_5	Quantity of Residual
x_6	Quantity of LPG
q	Gross Output
c	Total Energy Cost

Total energy cost is computed as:

$$c=w_1*x_1+w_2*x_2+w_3*x_3+w_4*x_4+w_5*x_5+w_6*x_6$$

The cost shares for the individual fuels is computed as:

$$s_i=(w_i*x_i)/c$$

The parameter estimates and associated statistics are in Table D5 in Appendix D.

Using the calculated fuel shares, the exponential of the logarithm of the cost equation, and current year fuel price w_i, we calculate the total energy consumption per unit of output ratio as follows:

$$UEC_i = [[S_i \times EXP(LN(C))] \; / \; W_i] \; / \; PRODCUR_{total} \tag{85}$$

where:

UEC_i	=	Unit Energy Consumption value for fuel i,
S_i	=	Cost share of fuel i,
C	=	Total fuel cost,
W_i	=	Price of fuel i, and
$PRODCUR_{total}$	=	Total output for the industry being processed

Having performed the above calculations, the UEC values are then calibrated to the UEC values corresponding to the 1991 Manufacturing Energy Consumption data.

Subroutine CALCSC3

CALCSC3 computes UECs for the energy-intensive industries. The energy savings for old and new vintage is calculated below as the exponential of the TPC coefficient multiplied by a yearly index.

$$CSCCUR_{v,f,s} = e^{BCSC_{v,f,s} \times (CURIYR - 1)} \tag{86}$$

where:

$CSCCUR_{v,f,s}$	=	Current energy savings (0<fraction<1) at process step s for fuel f for vintage v,
$BCSC_{v,f,s}$	=	Energy savings coefficient at process step s for fuel f and vintage v, and
$CURIYR$	=	Current year index.

The unit energy consumption for old and new vintage is computed by multiplying the current energy savings by the intercept. In a few process steps, fuel shares are expected to change over time due to technology changes. These process steps are cold rolling, blast furnaces, and electric arc furnaces in the blast furnace and basic steel products industry and dry process clinker in the hydraulic cement industry. The following equation calculates the unit energy consumption of electricity in the cold rolling process step. Similar equations exist for other fuels used in cold rolling and for the blast furnace/basic oxygen furnace process step (see Table D16, Appendix D).

$$ENPINT_{new,elec,s} = EINTER_{new,elec,s} \times CSCCUR_{new,elec,s} \times \frac{1}{0.20}\left[0.20 + \frac{(0.21 - 0.20) \times (CURIYR - 1)}{25}\right] \quad (87)$$

where:

$ENPINT_{new,elec,s}$	=	Unit energy consumption of electricity at process step s for new vintage,
$EINTER_{new,elec,s}$	=	Intercept at process step s for electricity for new vintage,
$CSCCUR_{new,elec,s}$	=	Current energy savings at process step s for electricity and new vintage, and
$CURIYR$	=	Current year index.

The UECs for middle vintage are calculated as in CALCSC2 and shown below, by the ratio of cumulative UEC to cumulative production for all process steps and industries, i.e., the weighted average UEC.

$$ENPINT_{mid,f,s} = \frac{SUMPINT_{f,s}}{CUMPROD_{new,s}} \quad (88)$$

where:

$ENPINT_{mid,f,s}$	=	Unit energy consumption of fuel f at process step s for middle vintage,
$SUMPINT_{f,s}$	=	Cumulative unit energy consumption of fuel f at process step s, and
$CUMPROD_{new,s}$	=	Cumulative production at process step s for new vintage.

Subroutine CALPRC

CALPRC is called to update unit energy consumption based on price parameters. CALPRC calls one of two subroutines CALPRC1 or CALPRC2, depending on the approach to be taken. CALPRC1 assumes unit energy consumption is constant. CALPRC2 uses an econometric equation to update UECs for energy-non-intensive industries.

Subroutine CALPRC1

The unit energy consumption is unaltered by CALPRC1.

Subroutine CALPRC2

CALPRC2 calculates unit energy consumption based on price related conservation using an econometric equation. Average prices for each fuel are calculated to accommodate the equation. Price based energy savings is calculated below as the product of the average price of a particular fuel raised to each cross price elasticity for both old and new vintage.

$$PRCCUR_{v,f,s} = \prod_{t=1}^{11} \left[WPRC_t\right]^{BELAS_{v,f,s,t}} \tag{89}$$

where:

$PRCCUR_{v,f,s}$ = Current energy savings based on price for fuel f at process step s for vintage v,

$WPRC_t$ = Price for fuel t in 1987 dollars, and

$BELAS_{v,f,s,t}$ = Own price elasticity at process step s for fuel f for old vintage and cross price elasticity at process step s for fuel f and fuel t for old vintage.

Unit energy consumption is then computed by multiplying the unit energy consumption by the price based energy savings.

$$ENPINT_{v,f,s} = ENPINT_{v,f,s} \ x \ PRCCUR_{v,f,s} \tag{90}$$

where:

$ENPINT_{v,f,s}$ = Unit energy consumption of fuel f at process step s for vintage v, and

$PRCCUR_{v,f,s}$ = Current energy savings based on price for fuel *f* at process step *s* for vintage *v*.

Subroutine CALBSC

The boiler fuel shares are calculated using a logit formulation. (Note that waste and byproduct fuels are exlcuded from the logit because they are assumed to be consumed first.) The equation is calibrated to 1991 so that the actual boiler fuel shares are produced for the relative prices that prevailed in 1991. The equation for each manufacturing industry is as follows:

$$ShareFuel_i = \frac{(P_i^{\alpha_i}\beta_i)}{\sum_{i=1}^{3} P_i^{\alpha_i}(\beta_i)} \qquad (91)$$

where the fuels are coal, petroleum, and natural gas. Base year boiler shares for distillate, residual oil, and liquid petroleum gas are calculated explicitly in order to obtain exact estimates of these fuel shares from the aggregate petroleum fuel share calculation. The P_i are the fuel prices; α_i are sensitivity parameters; and the β_i are calibrated to reproduce the 1991 fuel shares using the relative prices that prevailed in 1991. The byproduct fuels are consumed before the quantity of purchased fuels is estimated. The boiler fuel shares are assumed to be those estimated using the 1991 MECS and exclude waste and byproducts.

Appendix A. Model Variables

Table A1. Variables Used for Estimating Industrial Energy Consumption in the Boiler, Steam, Cogeneration Component

INTEGER IFSBYP	Number of byproducts consumed
INTEGER IFSLOCBY(fuels-id)	Stores fuel id number byproduct fuel j
REAL BYSINT(fuels)	Boiler Efficiency for byproduct fuel j
REAL BYBSCSC(fuels)	Conservation supply coeffiecient for byproduct fuel j in the BSC
REAL BYPBSCM(fuels)	Byproduct consumption of main fuel j
REAL BYPBSCI(fuels)	Byproduct consumption of intermediate fuel j
REAL BYPBSCR(fuels)	Byproduct consumption of renewable fuel j
REAL BYPSTM	Amount of steam generated from all byproduct fuels
REAL BYPSTMM	Amount of steam produced using main fuels
REAL BYPSTMI	Amount of steam produced using intermediate fuels
REAL BYPSTMR	Amount of steam produced using renewable fuels
INTEGER IFSMAX	Number of fuels consumed in the bsc
INTEGER IFSLOC(fuels)	Stores fuel id number for main fuel j
REAL ENSINT(fuels)	Heat Rate of fuel j in the bsc component
REAL ENSQTY(fuels)	Consumption of fuel j to generate steam
REAL BSSHR(fuels)	Boiler share of fuel j
REAL BSSHRLAG(fuels)	Lag year boiler share of fuels j
REAL STEMCUR	Steam demand from process/assembly and buildings
REAL BSFUELSHR(industry,regions,fuels)	Stores share of oil based fuel I of total oil consumed
REAL BSBENCHFAC(industry,regions,fuels)	Benchmark boiler shares to base year (not done)

COMMON/INDBSC/IFSBYP, IFSLOCBY,BYSINT, BYBSCSC, BYPBSCM, BYPBSCI,BYPBSCR, BYPSTM, BYPSTMM, BYPSTMI,BYPSTMR, IFSMAX, IFSLOC, ENSINT, ENSQTY, BSSHR, BSSHRLAG, STEMCUR, BSFUELSHR,BSBENCHFAC

Table A2. Variables Used for Estimating Buildings Energy Consumption in the Industrial Module

REAL ENBINT(light hvac,fuel)	Building Unit Energy Consumption Values
REAL ENBQTY(light hvac total=3,fuels)	Variable holding Builing Energy Consumption Calculation
REAL BBCSC(light hvac,fuels=3)	Building Energy Conservation Coefficient
REAL BBELAS(light hvac,fuels=3)	Building Energy Price Elasticities
REAL BBEMPL(light hvac,fuels=3)	Employment

COMMON/XBLD/ENBINT,ENBQTY,BBCSC,BBELAS,BBEMPL

Table A3. Variables Used for Benchmarking Industrial Consumption to the State Energy Data Reporting System and the Short Term Energy Outlook

INTEGER ISEDS	Option from file indrun: 1=Benchmark to SEDS, 0:don't benchmark
REAL BMAIN(fuels,regions)	In WEXOG: Unbenchmarked Quantities with Cogen and Refining Added for Benchmarking
REAL BENCHFAC(fuels,division)	Benchmark factors for 15 main fuels and 2 biomass by Census Division
REAL OTHIND(fuels,division)	Difference between BMAIN and SEDS after benchmarking: "Other Industry"
REAL STEOQ(year,fuel)	STEO History and projections by year, 19 fuel. read from file indsteo
REAL TONOUT(industry,region)	Save base year tons of output

COMMON/INDBENCH/ISEDS,BMAIN,BENCHFAC,OTHIND, STEOQ,TONOUT

Table A4. Variables Used in the Process and Assembly Component Calculations

INDUSTRIAL MODULE VARIABLES USED TO CALCULATE VINTAGE OF CAPITAL EQUIPMENT IN THE PROCESS AND ASSEMBLY COMPONENT, AND UNIT ENERGY CONSUMPTION FORECASTS, AND FUEL CONSUMPTION FORECASTS FOR THE PROCESS AND ASSEMBLY COMPONENT

```
REAL    PHDRAT                                  Factor used to convert industrial output from physical to dollar units
REAL    PRODCUR(vintage,process step)           Vintaged production capacity
REAL    IDLCAP(process step)                    Idle Capacity by process step
REAL    PRODLAG(vintage,process step)           Lag year production capacity
REAL    PRODFLOW(vintage,process step, process links)   Production flow coefficients
REAL    PRODRETR(process step)                  Retirement rates by process step
REAL    CUMOUT(vintage,process step)            Cumulative industrial output
INTEGER NTMAX(process step)                     Max number of links per process step
INTEGER IPASTP(process step,links)              Stores 0-1 values indicating process flow links
INTEGER MPASTP                                  Number of process steps
INTEGER IDVAL                                   Value indicating industrial output units (physical/dollar value
REAL    PRODZERO(vintage,process step)          Base year production capacity
REAL    CUMPROD(vintage,process step)           Cumulative production
INTEGER IFMAX(process step)                     Max number of fuels per process step
INTEGER IFLOC(fuel,process step)                Stores fuel identifier numbers per process step
REAL    ENPINT(vintage,fuel,process step)       Vintaged unit energy consumption values
REAL    ENPQTY(vintage,fuel,process step)       Energy consumption
REAL    ENPMQTY(fuel)                           Energy consumption of purchased fuels
REAL    ENPIQTY(fuel)                           Energy consumption of byproducts
REAL    ENPRQTY(fuel)                           Energy consumption of renewables
INTEGER ITYPE(fuel,process step)                Variable indicating uec estimation methodology
REAL    SUMPINT(fuel,process step)              Sum of Energy Intensities
REAL    BCSC(vintage,fuel,process step)         Technological possibility coefficient for energy intensive industries
REAL    CSCCUR(vintage,fuel,process step)       Conservation suppy coefficient applied to energy non-intensive industries
REAL    CSCLAG(vintage,fuel,process step)       Lag year value conservation supply coefficient applied to energy non-intensive industries
REAL    EINTER(vintage,fuel,process step)       Intercept term for unit energy consumption values
REAL    CUMOUT88                                1988 cumulative output
REAL    BELAS(vintage,fuel,process step,division) Own and cross price fuel elasticities
REAL    PRCCUR(vintage,fuel,process step)       Vintaged price conservation coefficients by fuel,process
REAL    PRCLAG(vintage,fuel,process step)       Lag year value vintaged price conservation coefficients by fuel,process
REAL    ENPINTLAG(vintage,fuel,process)         Lag year values to vintaged unit energy consumption by fuel,process
REAL    BYPINTLAG(3,5,10)                       Lag year vintaged byproduct unit energy consumption values by fuel,process
REAL    BYSINTLAG(6)                            Lag year byproduct steam intensity values
INTEGER IFBYP(10)                               Number of byproducts per process step
INTEGER IFLOCBY(10,10)                          Byproduct identifier per process step
REAL    BYPINT(3,5,10)                          Vintaged byproduct unit energy consumption by region,process
REAL    BYPCSC(3,5,10)                          Vintage byproduct efficiency coefficients by region,process
REAL    BYPCSCCUR(3,5,10)                       Vintage byproduct efficiency coefficients by region,process
REAL    BYPCSCLAG(3,5,10                        Lag year vintage byproduct efficiency coefficients by region,process
REAL    BYPQTY(4,6,10)                          Vintaged byproduct energy consumption by fuel, process
REAL    ENBYPM(23,4)   Stores main fuels consumption used in process/assembly and bsc from which byproducts are produced
REAL    ENBYPI(7,4)    Stores intermediate fuels used in process/assembly and bsc from which byproducts are produced
REAL    ENBYPR(9,4)    Stores renewables used in process/assembly and bsc from which byproducts are produced

COMMON/INDPA/PHDRAT,PRODCUR, IDLCAP,PRODLAG,PRODFLOW,
 PRODRETR,CUMOUT,NTMAX,IPASTP, MPASTP,IDVAL,PRODZERO,CUMPROD,
 IFMAX,IFLOC,ENPINT,ENPQTY,ENPMQTY,ENPIQTY,ENPRQTY, ITYPE,SUMPINT,
 BCSC,CSCCUR,CSCLAG, EINTER,CUMOUT88,BELAS,PRCCUR,PRCLAG, ENPINTLAG,
 BYPINTLAG,BYSINTLAG, IFBYP,IFLOCBY,BYPINT, BYPCSC,BYPCSCCUR,BYPCSCLAG,
 BYPQTY,ENBYPM,ENBYPI,ENBYPR
```

Table A5. Variables Used for the Non-Intensive Industries

```
INDUSTRIAL MODEL VARIABLES USED TO CALCULATE ENERGY CONSUMPTION FOR THE ENERGY NON-INTENSIVE
INDUSTRIES USING THE TRANSLOG ECONOMETRIC METHODOLOGY

    INTEGER MAXIND                              Max number of industries with translog coefficients
    INTEGER MAXCOEF                             Max number of coefficents
    REAL  TLCOEF(industry,coefficient)          Stores translog coefficients
    REAL  TLBSHR(industry,region,coefficient)   Stores logit model coefficients
    REAL  TLFAC(industry,region,vintage,fuel)   Stores base year translog fcn. multipliers

    REAL  S1          Cost shares of Natural Gas
    REAL  S2          Cost share of Steam Coal
    REAL  S3          Cost share of Electricity
    REAL  S4          Cost share of Distillate fuel
    REAL  S5          Cost share of Residual Oil
    REAL  S6          Cost share of Liquid Petroleum Gasoline
    COMMON/INDTLOG/MAXIND,MAXCOEF, TLCOEF,TLBSHR,S1,S2,S3,S4,S5,S6,TLFAC
```

Table A6. Industrial Module Industry Macroeconomic Variables

```
REAL OUTIND(industry,division)          Industrial output by census division
REAL EMPIND(industry,division)          Industrial employment by census division
REAL ENPRC(fuels,division)              Input energy prices by census division
REAL PRODX(industry,regions)            Production capacity by industry and region
REAL PRODXLAG(industry)                 Lag year production capacity
REAL EMPLX(industry,regions)            Employment by industry and region
REAL EMPLXLAG(industry)                 Lag year employment
REAL PRCX(fuels,regions)                Energy prices by fuel and region
REAL PRCX90(fuels,regions)              Saves 1990 prices for coal , oil, and gas
REAL PRCX97(regions,fuels)              Save 1997 price of met coal and aggregate industrial fuel price
REAL PRCXLAG(fuels)                     Lag year energy prices by fuel and region
REAL PRODVX(industry,region)            Production capacity by industry and region
REAL PRODVXLAG(industry)                Lag year production capacity by industry
REAL INDMAC(industry,year,division)     Macro industrial output by year and division

COMMON/INDMACRO/OUTIND,EMPIND,ENPRC,PRODX,EMPLX,EMPLXLAG,
                 PRCX,PRCX90,PRCXLAG,PRODVX, PRODVXLAG,INDMAC
```

Table A7. Control Variables and Runtime Parameters

INDUSTRIAL MODULE PROGRAM CONTROL VARIABLES AND RUNTIME PARAMETERS

INTEGER IYR	Current year
INTEGER IBYR	Bbase year
INTEGER IEYR	Last year
INTEGER IWDBG	Debug switch
INTEGER ISUBTR	Subroutine trace option
INTEGER INDNUM	Index number for industry
INTEGER INDMAX	Max industries
INTEGER INDDIR	Industry number identifier
INTEGER IWRSUM	Option to write summary tables
INTEGER IOPEN	Flag indicating file status
INTEGER INDREG	Industry region index
INTEGER IPRICE	Flag to run price sensitivities
REAL ELEC	Electricity price sensitivity factor
REAL FGAS	Firm gas price sensitivity factor
REAL INTGAS	Interruptible gas price sensitivity factor
REAL COAL	Coal price sensitivity factor
REAL RESID	Resid price sensitivity factor
REAL DIST	Dist price sensitivity factor
REAL LPG	LPG price sensitivity factor
INTEGER ITPC	Flag to run tpc sensitivity case
REAL TPC1	Sensitivity factor for tpc for old equipment
REAL TPC2	Sensitivity factor for tpc for new equipment
INTEGER IRETIRE	Flag to run retirement rate sensitivity
REAL RETRATE	Retirement rate sensitivity factor
INTEGER FRZTECH	Frozen technology case flag
INTEGER HITECH	High technology case flog
INTEGER PRICEPA	Option to use Process and Assembly Price Sensitivity Routine
INTEGER CCAPOPT	Option to use CCAP demand shifts
REAL CCAPFOS(2)	2000,2010 CCAP Fossil savings (trilion Btu)
REAL CCAPKWH(2)	2000,2010 CCAP Electricity savings (BKWH)
INTEGER LENGTHIND(50)	
COMMON/INDMISC/LENGTHIND	
INTEGER FSTITER	First Iteration
INTEGER LSTITER	Last Iteration
CHARACTER*40 INDNAME	Captures industry name from input
CHARACTER*18 INDSTEPNAME(30)	Captures process step name from input
CHARACTER*18 NFILE(5)	Identifies model intermediary file for temporary storage

Table A8. Cogeneration Variables

VARIABLES USED TO ESTIMATE INDUSTRIAL FUEL CONSUMPTION FOR COGENERATION OF ELECTRICITY

REAL RATE(prime movers)	Heat rates by prime mover
REAL TSHRGEN(division,fuels)	Share of generation by fuel to census division
REAL GENGWH(division,fuel,sales/own use)	Gigawatt Hours of Co-Generation
REAL DIVFUEL(division,fuels,sales/own use)	Cogen Fuel consumption
REAL CAPGW(division,fuel,sales/own use,planned/unplanned)	Gigawatts of Capacity
REAL SHARE(prime mover,division,year,industry,fuel)	Cogen fuel Shares
REAL ELGEN(prime mover)	Total electricity generation by prime mover
REAL ELOWN(fuel)	Own use electricity by fuel j
REAL ELSALE(fuel)	Electricity sold to the grid by fuel j
REAL OTHFUEL(division,fuel,sales/own use)	Incremental (difference between model result and ei-867) cogen fuel consumption
REAL GENFUEL(fuel,sales/own use,region)	Cogen fuel consumption
REAL GENTOT(region,sales/own use,fuel)	Aggregate total cogen fuel consumption
REAL GINTER	Intercept term for electricity generation
REAL GSTEAM	Steam demand coefficient
REAL GENEQPSHR(prime mover)	Share of generation by prime mover
REAL GENEQPHTRT(prime mover)	Heat rate by prime mover
REAL CGFUEL(region,sales/own use,fuel)	Consumption of fuel j for cogeneration in region r
REAL ICEFUEL	Fuel consumption for generation from internal combustion engine
REAL GCTFUEL	Fuel consumption for generation from gas turbines
REAL STFUEL(fuel)	Consumption of fuel j in steam turbines
REAL STBYP(fuel)	Consumption of byproduct fuel j in steam turbines
REAL ELCAP(fuel)	Electric Capacity by fuel j
REAL CAP867(division,year,industry,fuel)	EI-867 Capacity
REAL SICGEN(division,year,industry,fuel,prime mover,sales/own use3)	EI-867 Generation
REAL SICUTIL(division,yearuel,industry,fuel)	EIA-867 Capacity Utilization Rate
REAL IGRIDSHR(division,fuel,industry)	EIA-867 Gridshares
INTEGER MAXCOGYR	Maximum number of cogen data years
INTEGER MAXPLAN	Maximum number of planned cogen data years

```
COMMON/INDCOGEN/RATE,TSHRGEN,GENGWH,DIVFUEL,CAPGW,SHARE,
        ELGEN,ELOWN,ELSALE, OTHFUEL,GENFUEL,GENTOT,
        GINTER,GSTEAM,GEN90,GENEQPSHR,GENEQPHTRT,
        GENEQPSTEFF,CGFUEL, ICEFUEL,GCTFUEL,STFUEL,STBYP,
        ELCAP,CAP867, SICGEN,SICUTIL,IGRIDSHR,MAXCOGYR,MAXPLAN
```

Table A9. Aggregation Variables

```
VARIABLES USED TO HOLD VARIOUS AGGREGATIONS OF TOTAL CONSUMPTION FOR MFG, NON-MFG HEAT AND
POWER, FEEDSTOCKS

CONSUMPTION IN EACH OF THE ENERGY INTENSIVE INDUSTRIES

TOTAL CONSUMPTION BY FUEL BY CENSUS DIVISION, TOTAL CONSUMPTION  BY FUEL BY CENSUS REGION

    REAL QTYMAIN(fuels,regions)    Consumption of main fuel j in region k
    REAL QTYINTR(fuels,regions)    Consumption of intermediate fuel j in region k
    REAL QTYRENW(fuels,regions)    Consumption of renewable fuel j in region k
    REAL TQMAIN(fuels,regions)     Total consumption of main fuel j in region k
    REAL TQINTR(fuels,regions)     Total consumption for intermediate fuel k
    REAL TQRENW(fuels,regions)     Total consumption of renewable fuel j in region k
              ! see industrial code for fuel ordering

    REAL DQRENW(fuels,divisions)     Consumption of renewable fuel j in census division
    REAL DSRENW(divisons)        Share of output for renewable fuel j in census division d
    REAL BIOFUELS(divisions)       Consumption of biofuels in census division d

    REAL TMANHP(fuels)    Total manufacturing consumption for heat and power by fuel
    REAL TFOODCON(fuels)     Total fuel consumption in food
    REAL TPAPERCON(fuels)    Total fuel consumption in paper
    REAL TCHEMCON(fuels)     Total fuel consumption in chemicals
    REAL TGLASSCON(fuels)    Total fuel consumption in glass
    REAL TCEMENTCON(fuels) Total fuel consumption in cement
    REAL TSTEELCON(fuels)    Total fuel consumption in steel
    REAL TALUMCON(fuels)     Total fuel consumption in aluminum
```

Table A10. Memory Management Variables

```
    HOLDS VARIABLES FOR INDUSTRIAL DIRECT ACCESS FILE ALTERNATIVE
    INTEGER NUMPROC  ! MAX NUMBER OF PROCESS--ALL INDUSTRIES
    INTEGER NUMIND   ! MAX NUMBER OF INDUSTRIES
    INTEGER NUMB1I   ! # BYTES IN IND-SPECIFIC BUFFER RECORD, STATIC
    INTEGER NUMB1P   ! # BYTES IN PROC-SPECIFIC BUFFER RECORD, STATIC
    INTEGER NUMB2I   ! # BYTES IN IND-SPECIFIC BUFFER RECORD, YEARLY
    INTEGER NUMB2P   ! # BYTES IN PROC-SPECIFIC BUFFER RECORD, YEARLY

      PARAMETER(NUMPROC=58,NUMIND=15,NUMB2I=2076+8,NUMB2P=1556+8,NUMB1I=996+8,NUMB1P=2576+8)

    COMMON/INDBUF1/B2ICUR(26,NUMIND,4)         CURENT YEAR, INDUSTRY-SPECIFIC
    COMMON/INDBUF2/B2PCUR(26,NUMPROC,4)        CURENT  YEAR,PROCESS-SPECIFIC
    COMMON/INDBUF3/B2ILAG(26,NUMIND,4)         CURENT  YEAR,INDUSTRY-SPECIFIC   BY 4 REGIONS
    COMMON/INDBUF4/B2PLAG(26,NUMPROC,4)        CURENT  YEAR,PROCESS-SPECIFIC    BY 4 REGIONS
    COMMON/INDACCML/ACUMOUT,ACUMPROD,ASUMPINT
    COMMON/INDBUF5/B1ICUR(NUMIND,4),           STATIC, INDUSTRY-SPECIFIC BY   4 REGIONS
                   B1PCUR(NUMPROC,4)           STATIC, PROCESS-SPECIFIC BY 4 REGIONS
    REAL ACUMOUT(4,NUMPROC,4)    ACCUMULATED OUTPUT BY  PROCESS BY  REGIONS
    REAL ACUMPROD(4,NUMPROC,4)   ACCUMULATED PROD BY PROCESS BY 4  REGIONS
    REAL ASUMPINT(15,NUMPROC,4)  ACCUMULATED OUTPUT BY  PROCESS BY 4  REGIONS
    CHARACTER B2ICUR*(NUMB2I), B2ILAG*(NUMB2I)
    CHARACTER B2PCUR*(NUMB2P), B2PLAG*(NUMB2P)
    CHARACTER B1ICUR*(NUMB1I)
    CHARACTER B1PCUR*(NUMB1P)
```

Table A11. Direct Access File Variables for Debugging

```
HOLDS VARIABLES FOR INDUSTRIAL DIRECT ACCESS FILE ALTERNATIVE
 INTEGER NUMPROC  ! MAX NUMBER OF PROCESS--ALL INDUSTRIES
 INTEGER NUMIND   ! MAX NUMBER OF INDUSTRIES
 INTEGER NUMB1I   ! # BYTES IN IND-SPECIFIC BUFFER RECORD, STATIC
 INTEGER NUMB1P   ! # BYTES IN PROC-SPECIFIC BUFFER RECORD, STATIC
 INTEGER NUMB2I   ! # BYTES IN IND-SPECIFIC BUFFER RECORD, YEARLY
 INTEGER NUMB2P   ! # BYTES IN PROC-SPECIFIC BUFFER RECORD, YEARLY

 PARAMETER(NUMPROC=58,NUMIND=15,NUMB2I=2076+8,NUMB2P=1556+8, NUMB1I=996+8,NUMB1P=2576+8)

 COMMON/INDBF1/B2ICUR(NUMIND,4)     CURENT  YEAR, IND-SPECIFIC BY 4  REGIONS
 COMMON/INDBF2/B2PCUR(NUMPROC,4)  CURENT YEAR, PROCESS-SPECIFIC BY 4  REGIONS
 COMMON/INDBF3/B2ILAG(NUMIND,4)     CURENT YEAR, IND-SPECIFIC BY 4  REGIONS
 COMMON/INDBF4/B2PLAG(NUMPROC,4)  CURENT YEAR, PROCESS-SPECIFIC BY 4  REGIONS
 COMMON/INDACCML/ACUMOUT,ACUMPROD,ASUMPINT
 COMMON/INDBF/B1ICUR(NUMIND,4),     STATIC, IND-SPECIFIC BY 4 REGIONS
                      B1PCUR(NUMPROC,4)  STATIC, PROCESS-SPECIFIC BY 4 REGIONS

 REAL ACUMOUT(4,NUMPROC,4)   ACCUMULATED OUTPUT BY PROCESS BY 4  REGIONS

 REAL ACUMPROD(4,NUMPROC,4)  ACCUMULATED PROD   BY PROCESS BY 4  REGIONS
 REAL ASUMPINT(15,NUMPROC,4)  ACCUMULATED OUTPUT BY PROCESS BY  REGIONS
 CHARACTER B2ICUR*(NUMB2I), B2ILAG*(NUMB2I)
 CHARACTER B2PCUR*(NUMB2P), B2PLAG*(NUMB2P)
 CHARACTER B1ICUR*(NUMB1I)
 CHARACTER B1PCUR*(NUMB1P)
```

Table A12. Listing and Brief Description of Industrial Subroutines

Subroutine	Description
IND	Get Macroeconomic Data: Industrial Output, Employment, Energy Prices
ISEAM	Perform Model Calculations
RCNTL	Read model runtime parameters or control variable values
REXOG	Assign exogenous macroeconomic and energy price variables from NEMS to industrial variables
WEXOG	Calibrate aggregate industrial results to SEDS and STEO and assign to NEMS variables
IRSTEO	Read STEO File with last available history data and national projections for next two years
IEDATA	Read industrial model input data
IRHEADER	Read header information for each industry: inddir,phdrat,cumout88,base year output
IRSTEPDEF	Read process step information
IRBEU	Read buildings data
IRBSCBYP	Read byproduct fuel information input for the BSC
IRBSFUEL	Read boiler shares
IRCOGEN	Read cogeneration information
IRNEIELAS	Read energy non-intensive industry data
IRSTEPBYP	Read process step byproduct fuel data

Table A12. Listing and Brief Description of Industrial Subroutines (continued)

IRSTEPDAT	Read fuel id and uec for each process step
IFINLCALC	Performs calculations to determine base year process step production
IZEROOUT	Re-initialize model parameters in order to get next record in the input file
WRBIN	Write lag year model results to temporary file
RDBIN	Read lag year model results
MODCAL	Controls program flow from year n+1 to last forecast year
CALPROD	Calculates industrial production throughput for each process step
BALCOEFF	Calculates coefficients necessary to compute production throughput at each process step
CALCSC	Calling routine for the conservation supply options
CALCSC1	Constant Unit Energy Consumption; This routine does not alter the UEC for industry being processed
CALCSC2	Energy conservation calculations using coefficients (estimated regression parameters) ; Applies for certain fuels in non-manufacturing industries
CALCSC3	Energy conservation based on the future technology possibility approach
CALPRC	Calling routine for price induced technical change or energy conservation
CALPRC1	Prices do not affect Unit Energy Consumption
CALPRC2	Prices affect consumption via econometrically estimated own and cross price elasticities
CALPRC3	Prices affect consumption via econometrically estimated own and cross price elasticities
CALTLOG	Unit Energy Consumption for Metals and Other Non-Intensive Manufacturing is estimated using a translog production funtion approach
CALBYPROD	Calculates byproduct energy consumption in the process and assembly component
CALPATOT	Calculates non-byproduct energy consumption in the process and assembly component
INDPALOG	Reads fuel switching parameters
CALPALOG	Determines fuel shares in the process and assembly component using a two stage logit model
CALINTER	Calibrates base year UEC for certain fuels in the non-manufacturing industries
CALBLD	Calculates energy efficiency in buildings
CALBTOT	Calculates buildings energy consumption
CALGEN	Determines total cogeneration, total capacity by prime mover for own use/sales to the grid
CALBSC	Calculates fuel shares in Boiler/Steam/Cogeneration Component
CALSTOT	Calculates fuel consumption in the Boiler/Steam/Cogeneration component
FUELBOIL	Calculates total fuel consumption for steam turbines and process boilers
INDTOTAL	Calculates total consumption by fuel for a particular industry (i.e. sums up process/assembly , buidings, and boiler/steam/cogeneration fuel consumption
NATTOTAL	Calculates aggregate total consumption across all industries and industry components
INDCGN	Calculates aggregate total industrial cogeneration, capacity, and fuel consumption
CONTAB	Creates consumption tables for individual industries

Appendix B. Bibliography

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Appendix C. Model Abstract

Model Name:
Industrial Demand Model

Model Acronym:
None

Description:
The Industrial Demand Model is based upon economic and engineering relationships that model industrial sector energy consumption at the nine Census division level of detail. The seven most energy intensive industries are modeled at the detailed process step level and eight other industries are modeled at a less detailed level. The industrial model incorporates three components: buildings, process and assembly, and boiler, steam, and cogeneration.

Purpose of the Model:
As a component of the National Energy Modeling System integrated forecasting tool, the industrial model generates mid-term forecasts of industrial sector energy consumption. The industrial model facilitates policy analysis of energy markets, technological development, environmental issues, and regulatory development as they impact industrial sector energy consumption.

Most Recent Model Update:
October 1996.

Part of another Model?
National Energy Modeling System (NEMS)

Model Interfaces:
Receives inputs from the Electricity Market Module, Oil and Gas Market Module, Renewable Fuels Module, Macroeconomic Activity Module, and Petroleum Market Module.

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Documentation:

Model Documentation Report: Industrial Sector Model of the National Energy Modeling System, January 1997.

Archive Media and Installation Manual(s):

The model has been archived on IBM RISC 6000 magnetic tape storage as part of the National Energy Modeling System production runs used to generate the Annual Energy Outlook 1997. It is archived as File 1 on Verbatim tape, 8mm-DL 112M, serial number 1046G112.

Energy System Described:

Domestic industrial sector energy consumption

Coverage:

- Geographic: Nine Census divisions: New England, Mid Atlantic, East North Central, West North Central, South Atlantic, East South Central, West South Central, Mountain, and Pacific.
- Time Unit/Frequency: Annual, 1990 through 2015

Modeling Features:

- Structure: 9 manufacturing and 6 nonmanufacturing industries. The manufacturing industries are further subdivided into the energy intensive and non-energy-intensive industries.
- Each industry is modeled as three separate but interrelated components consisting of the process/assembly component (PA), the buildings component (BLD), and the boiler/steam/cogeneration component (BSC).
- Modeling Technique: Ordinary least-squares with log transformations is used for the nonmanufacturing. Translog functional forms were used for the non-energy-intensive manufacturing industries. The energy intensive industries are modeled through the use of a detailed process flow accounting procedure.

Non-DOE Input Sources:

National Energy Accounts
Historical Dollar Value of Output in the Industrial Sector

DOE Input Sources:

Form EI-867: Survey of Independent Power Producers

- Electricity generation, total and by prime mover
- Electricity generation for own use and sales
- Capacity utilization

Manufacturing Energy Consumption Survey 1991, December 1994
State Energy Data System 1994, October 1996

Computing Environment:

- Hardware Used: IBM RISC 6000
- Operating System: AIX 3.2.5

- Language/Software Used: XL FORTRAN Compiler/6000, Ver 3.1.1
- Estimated Run Time: 1.1 minutes for a 1990-2015 run in non-iterating NEMS mode on an IBM RISC 6000.
- Special Features: None.

Independent Expert Reviews Conducted:

None.

Status of Evaluation Efforts by Sponsor:

None.

Appendix D. Data Inputs

Introduction

The NEMS Industrial Demand Model develops forecasts of industrial sector energy consumption based on the data elements as detailed in Appendix A of this report. This Appendix provides the initial values and sources for the input data.

Table D1. Building Component UEC (Trillion Btu/Thousand Employees)

SIC	Industry	Building Use and Energy Source			
		Lighting	HVAC		
		Electric UEC	Electric UEC	Natural Gas UEC	Steam UEC
20	Food & Kindred Products	0.007	0.009	0.014	0.045
26	Paper & Allied Products	0.0131	0.016	0.023	0.0082
281, 282, 286, 287	Bulk Chemicals	0.0159	0.0299	0.68	0.0058
321, 322, 323	Glass and Glass Products	0.0133	0.019	0.044	0.004
324	Hydraulic Cement	0.029	0.029	0.029	0.0568
331, 332, etc.	Blast Furnaces & Basic Steel	0.0123	0.0184	0.0674	0.011
3334, 3341, etc.	Primary Aluminum	0.0187	0.0266	0.0062	0.0053
333-336, 339	Metal Based Durables	0.0083	0.0125	0.0153	0.0019
34	Other Non-Intensive MFG Fabricated Metals	0.007	0.0103	0.0134	0.0036

SIC = Standard Industrial Classification.
UEC = Unit Energy Consumption.
HVAC = Heating, Ventilation, Air Conditioning.
Source: Energy Information Administration, *Office of Integrated Analysis and Forecasting* (Washington, DC, January 1997).

Table D2. Non-Manufacturing Sector PA Component UEC (Trillion Btu/Billion 1987$ Output)

	Elec	Ngas	Resid	Dist	Liq Gas	Motor Gas	Coal	Other
Agri-Crops	0.959	0.318	0.000	4.004	0.553	0.657	0.002	0.115
Agri-Other	0.254	0.095	0.000	1.059	0.146	0.173	0.000	0.032
Coal Mining	2.054	3.744	0.122	0.391	0.053	0.057	0.289	0.000
Oil&Gas Mining	1.850	11.324	0.397	1.302	0.181	0.185	0.959	0.014
Metal Mining	5.178	12.110	0.395	1.286	0.179	0.184	0.767	0.000
Construction	0.265	0.249	0.072	0.738	0.020	0.170	0.000	1.626

Source: Decision Analysis Corporation of Virginia and Arthur D. Little, *Industrial Model: Baseline Database Final Report*, (prepared for EIA) 1993.

Table D3. Non-Energy-Intensive Manufacturing Sector PA Component UEC (Trillion Btu/Billion 1987$ Output)

Industry	Elec	Residual	Distillate	Natural Gas	LPG	Coal	Other
Metal-Based Durables	0.3126	0.0007	0.0043	0.2414	0.0052	0.0002	0.03
Other Non-Intensive	0.7347	0.0428	0.0461	0.7854	0.0127	0.1452	0.43

Source: Calculated from Energy Information Administration, *Manufacturing Consumption of Energy 1991*, DOE/EIA-0512(91)(Washington, D.C., December 1994).

Table D4. Non-Manufacturing Industry UEC Regressions

Agriculture - Crops (Natural Gas)

$$\begin{array}{lcc} UECNATGS = & 1.113 & - 0.727 \times RPGAS58 \\ Std.Err. & (0.043) & (0.059) \\ T\text{-}Statistic & 25.764 & -12.230 \\ & Adj.\ R^2 = 0.846 & \end{array} \qquad \text{(D-1)}$$

Agriculture - Other (Natural Gas)

$$\begin{array}{lccc} UECNATGS = & -3.247 & - 2.774 \times RPOIL58 & + 0.948 \times RPGAS58 \\ Std.Err. & (0.075) & (0.427) & (0.110) \\ T\text{-}Statistic & -43.464 & -6.499 & 8.606 \\ & Adj.\ R^2 = 0.739 & & \end{array} \qquad \text{(D-2)}$$

Coal Mining (Natural Gas)

$$\begin{array}{lccc} UECNATGS = & -2.600 & - 0.657 \times RPGAS58 & + 0.832 \times CURTAIL \\ Std.Err. & (0.058) & (0.107) & (0.301) \\ T\text{-}Statistic & -45.075 & -6.167 & 2.765 \\ & Adj.\ R^2 = 0.587 & & \end{array} \qquad \text{(D-3)}$$

Table D5. Parameter Estimates for Non-Intensive Manufacturing

	Other Non-Intensive Manufacturing		Metals-Based Durables	
Parameter	Estimate	t-Statistic	Estimate	t-Statistic
D11	0.1360	9.54	0.1506	12.22
D12	-0.0665	-7.62	-0.0088	-1.39
D13	-0.0542	-6.88	-0.1200	-14.59
D14	-0.0174	-2.34	-0.0112	-3.10
D15	0.0066	0.68	-0.0086	-1.55
D22	-0.0287	-2.84	-0.0462	-7.14
D23	0.0799	10.14	0.0712	7.40
D24	0.0243	3.99	0.0007	0.24
D25	-0.0071	-0.87	-0.0171	-3.50
D33	-0.0074	-0.43	0.0219	0.96
D34	-0.0090	-1.68	0.0131	2.53
D35	-0.0056	-0.48	0.0187	2.09
D44	-0.0452	-4.12	-0.0093	-1.71
D45	0.0475	5.72	0.0071	1.64
D55	-0.0449	-3.82	0.0005	0.09
A0	0.8656	18.71	0.1988	3.74
A1	0.3242	17.61	0.4141	25.28
A2	-0.1096	-6.04	-0.1002	-5.37
A3	0.6228	18.83	0.6551	15.18
A4	0.1050	8.73	0.0198	1.97
A5	0.0484	2.11	-0.0010	-0.06

Table D6. Food and Kindred Product Industry UECs (Trillion Btu/Billion 1987$ Output)

End-Use	Elec	Nat Gas	Resid	Dist	Other Petro.	LPG	Coal+Coke	Steam	Byproduct
Direct Heating	0.0	0.426	0.006	0.006	0.063	0.003	0.025	0.0	0.005
Hot Water & Steam	0.0	0.965	0.071	0.025	0.111	0.006	0.410	1.200	0.008
Refrig & Freezing	0.067	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other Electric	0.325	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Sources: Decision Analysis Corporation and Arthur D. Little Inc., *NEMS Industrial Model: Revised Final Report*, Unpublished Report Prepar for Energy Information Administration, (Vienna, VA, 1993); updated using data in Energy Information Administration, *Manufacturing Consumption of Energy 1991*, DOE/EIA-0512(91)(Washington, D.C., December 1994).

ble D7. Pulp and Paper Industry UECs (Energy Use/Ton of Pulp)

Process Step	Flow MMTons	Elec Kwh/ton	Nat Gas MMBtu/ton	Distillate MMBtu/ton	Resid MMBtu/ton	Other Petro. MMBtu/ton	LPG MMBtu/ton	Coal MMBtu/ton	Steam MMBtu/ton	Wood MMBtu/ton
d Preparation	107.0	73.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ing										
Waste Fibers	31.4	351.70	0.0	0.0	0.0	0.0	0.0	0.0	1.6	0.0
Mechanical	6.4	1494.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0
Semi-Chemical	4.1	410.3	0.0	0.0	0.0	0.0	0.0	0.0	6.0	0.0
Kraft	53.1	410.3	0.372	0.006	0.062	0.037	0.005	0.008	12.8	0.290
ching	33.64	87.92	0.0	0.0	0.0	0.0	0.0	0.0	6.4	0.0
rmaking, verting, and Misc.	76.0	468.93	0.318	0.005	0.46	0.008	0.011	0.001	7.5	0.010

rces: Sources: Decision Analysis Corporation and Arthur D. Little Inc., *NEMS Industrial Model: Update on Selected Process Flows and gy Use*. Unpublished Report Prepared for Energy Information Administration, (Vienna, VA, 1994); updated using data in Energy rmation Administration, *Manufacturing Consumption of Energy 1991*, DOE/EIA-0512(91)(Washington, D.C., December 1994).

e: Most of the wood byproduct and all the pulping liquor byproduct is assumed to be consumed in the BSC.

Table D8. Bulk Chemical Industry UECs (Trillion Btu/Billion 1987$ Output)

End-Use Flows	Elec	Nat Gas	Resid	Dist	Other Petro.	LPG	Coal	Steam
Electrolytic/Electro thermal Use	0.781	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other Electricity Use	1.844	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Direct Fuel Use	0.0	4.606	0.097	0.013	0.893	0.007	0.052	0.0
Feedstock Use	0.0	3.983	0.0	0.028	8.221	10.581	0.044	0.0
Steam Use	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.391

Sources: Decision Analysis Corporation and Arthur D. Little Inc., *NEMS Industrial Model: Selected Process Flows Revised Final Report*. Unpublished Report Prepared for Energy Information Administration, (Vienna, VA, 1993); updated using data in Energy Information Administration, *Manufacturing Consumption of Energy 1991*, DOE/EIA-0512(91)(Washington, D.C., December 1994).

Note: Includes petrochemical feedstocks that are identified in SEDS, but not in MECS.

Table D9. Glass and Glass Product Industry UEC (Energy Use/Ton of Product)

Process Step	Flow MMtons	Elec Kwh/ton	Nat Gas MMBtu/ton	Residual MMBtu/ton	Distillate MMBtu/ton	Other Petro. MMBtu/ton
Batch Preparation	22.35	55.69	0.0	0.0	0.0	0.0
Melting/Refining	21.33	190.50	5.37	0.092	0.011	0.037
Forming	20.06	252.05	1.34	0.02	0.003	0.01
Post-Forming	16.49	67.41	1.86	0.09	0.004	0.01

Sources: Decision Analysis Corporation and Arthur D. Little Inc., *NEMS Industrial Model: Update on Selected Process Flows and Energy Use*. Unpublished Report Prepared for Energy Information Administration, (Vienna, VA, 1994); updated using data in Energy Information Administration, *Manufacturing Consumption of Energy 1991*, DOE/EIA-0512(91)(Washington, D.C., December 1994).

Table D10. Hydraulic Cement Industry UEC (Energy Use/Ton of Product)

Process Step	Flow MMTons	Elec Kwh/ton	Nat Gas MMBtu/ton	Resid MMBtu/ton	Distillate MMBtu/ ton	Other Petro. MMBtu/ ton	Coal MMBtu/ ton
Portland Cement							
Wet Process	26.0	70.34	0.88	0.02	0.02	0.46	5.77
Dry Process	44.0	64.48	0.55	0.01	0.01	0.29	2.97
Finish Grinding	73.9	67.41	0.0	0.0	0.0	0.0	0.0

Sources: Decision Analysis Corporation and Arthur D. Little Inc., *NEMS Industrial Model: Update on Selected Process Flows and Energy Use*. Unpublished Report Prepared for Energy Information Administration, (Vienna, VA, April 28, 1994); updated using data in Energy Information Administration, *Manufacturing Consumption of Energy 1991*, DOE/EIA-0512(91)(Washington, D.C., December 1994).

ble D11. Blast Furnace and Basic Steel Products Industry UEC (Energy Use/Ton of oduct)

cess Step	Flow Mmtons	Electricity Kwh/ton	Steam MMBtu/ton	Coal MMBtu/ton	Coke MMBtu/ton	Natural Gas MMBtu/ton	Fuel Oil (a) MMBtu/ton	Waste Gas (b) MMBtu/ton	Misc. (c) MMBtu/
e Ovens	24.1	29.31	0.80	38.6		0.02	0.0	-2.51	-3.78
and Steel Making (4)									
pen Hearth/Blast Furnace	1.4	32.24	0.77	0.06	5.70	4.50	1.79	-1.34	0.10
ast Furnace/BOF	52.7	58.62	1.28	0.44	11.40	1.04	0.34	-2.00	-0.05
ectric Arc Furnace	33.8	574.44	0.00	0.00		0.40	0.00	0.00	0.00
ting/Primary Breakdown									
ontinuous Casting	66.7	26.38	0.01	0.00		0.30	0.00	0.00	0.00
got Casting/Primary Rolling	21.2	87.92	0.03	0.00		1.66	0.00	0.09	0.00
Rolling	82.3	102.58	0.02	0.00		2.50	0.02	0.09	0.00
d Rolling and Finishing	28.3	231.54	1.61	0.00		1.75	0.05	0.44	0.00

ergy values for coke accounted for by coal used in coke ovens. The values shown are for illustration only.
e net waste products are assumed to be consumed in the BSC.
cludes tar and pitch, light oils, and coke breeze.
rces: Decision Analysis Corporation and Arthur D. Little Inc., *NEMS Industrial Model: Update on Selected Process Flows and Energy Use*. Unpublished rt Prepared for Energy Information Administration, (Vienna, VA, 1994); updated using data in Energy Information Administration, *Manufacturing umption of Energy 1991*, DOE/EIA-0512(91)(Washington, D.C., December 1994).

Table D12. Primary Aluminum Industry UEC (Energy Use/Ton of Product)

Process Step	Flow MMtons	Elec Kwh/ton	Nat Gas MMBtu/ton
Alumina Smelting	4.54	15,240.3	5.97

Sources: Decision Analysis Corporation and Arthur D. Little Inc., *NEMS Industrial Model: Update on Selected Process Flows and Energy Use*. Unpublished Report Prepared for Energy Information Administration, (Vienna, VA, 1994); updated using data in Energy Information Administration, *Manufacturing Consumption of Energy 1991*, DOE/EIA-0512(91)(Washington, D.C., December 1994).

Table D13. Regional Technology Shares

		Census Region				
Industry	Technology	NE	MW	SO	WE	US
Paper and Allied Products						
	Kraft (incl. Sulfite)	6.0%	5.0%	72.0%	17.0%	100%
	Semi-Chemical	11.0%	30.0%	48.0%	11.0%	100%
	Mechanical	19.0%	14.0%	47.0%	20.0%	100%
	Waste Fiber	18.0%	31.0%	34.0%	17.0%	100%
Hydraulic Cement						
	Wet Process	17.3%	26.6%	43.0%	13.1%	100%
	Dry Process	9.2%	28.9%	35.0%	26.8%	100%
Blast Furnace and Basic Steel Products						
	Electric Arc Furnace	23.6%	36.1%	31.6%	8.7%	100%
	Basic Oxygen Furnace	10.5%	69.5%	20.0%	0.0%	100%
	Open Hearth	34.5%	0.0%	36.2%	29.3%	100%
	Coke Oven	23.9%	50.4%	23.5%	2.1%	100%
Primary Aluminum						
	Smelters	7.0%	15.7%	43.3%	34.1%	100%

Source: Decision Analysis Corporation and Arthur D. Little Inc., *NEMS Industrial Model: Update on Selected Process Flows and Energy Use*. Unpublished Report Prepared for Energy Information Administration, (Vienna, VA, 1994).

Table D14. Coefficients for Technology Possibility Curves

SIC Industry Process Unit	Old Facilities REI 1991 (Year 1)	Old Facilities REI[a] 2015 (Year 24)	Old Facilities Slope b	New Facilities REI 1991 (Year 1)	New Facilities REI[a] 2015 (Year 24)	New Facilities Slope b
26 Pulp & Paper						
Wood Preparation	1.000	0.950	-0.00269	0.840	0.831	-0.00044
Waste Production	1.000	0.974	-0.00138	0.930	0.885	-0.00205
Mechanical Pulping ...	1.000	0.944	-0.00305	0.840	0.822	-0.00089
Semi-Chemical	1.000	0.894	-0.00591	0.730	0.697	-0.00191
Kraft, Sulfite, misc. chemicals	1.000	0.903	-0.00537	0.730	0.600	-0.00816
Bleaching	1.000	0.910	-0.00495	0.750	0.683	-0.00390
Paper Making	1.000	0.910	-0.00495	0.750	0.560	-0.01217
32 Glass[b]						
Batch Preparation	1.000	0.957	-0.00229	0.882	0.882	0
Melting/Refining	1.000	0.892	-0.00602	0.850	0.448	-0.02664
Forming	1.000	0.952	-0.00257	0.818	0.744	-0.00395
Post-Forming	1.000	0.921	-0.00432	0.780	0.760	-0.00106
32 Cement						
Dry Process	1.000	0.982	-0.00094	0.790	0.657	-0.00768
Wet Process[c]	1.000	0.954	-0.00247	NA	NA	NA
Finish Grinding	1.000	0.943	-0.00309	0.813	0.641	-0.00989
33 Steel						
Coke Oven	1.000	1.000	0	0.840	0.817	-0.00116
BF/OH[c]	1.000	1.000	0	NA	NA	NA
BF/BOF	1.000	1.000	0	1.000	0.982	-0.00075
EAF	1.000	1.000	0	0.960	0.960	0
Ingot Casting/ Primary Rolling	1.000	1.000	0	NA	NA	NA
Continuous Casting ...	1.000	1.000	0	1.000	1.000	0
Hot Rolling	1.000	0.698	-0.01892	0.500	0.401	-0.00920
Cold Rolling	1.000	0.877	-0.00690	0.840	0.488	-0.02264
33 Aluminum						
Alumina Refinery	1.000	0.965	-0.00190	0.900	0.865	-0.00164
Primary Aluminum ...	1.000	0.936	-0.00349	0.910	0.812	-0.00477
Semi-Fabrication	1.000	0.855	-0.00826	0.610	0.506	-0.00781
Secondary Aluminum	1.000	0.817	-0.01065	0.600	0.510	-0.00675

[a]Calculated from slope value b and exponential equation (see text).
[b]REIs and slope apply to virgin and recycled materials.
[c]No new plants are likely to be built with these technologies.
SIC = Standard Industrial Classification.
REI = Relative Energy Intensity.
NA = Not applicable.
BF = Blast furnace.
OH = Open hearth.
BOF = Basic oxygen furnace.
EAF = Electric arc furnace.

Sources: Decision Analysis Corporation and Arthur D. Little Inc., *NEMS Industrial Model: Update on Selected Process Flows and Energy Use*. Unpublished Report Prepared for Energy Information Administration, (Vienna, VA, April 28, 1994); updated using data in Energy Information Administration, *Manufacturing Consumption of Energy 1991*, DOE/EIA-0512(91)(Washington, D.C., December 1994).

Table D15. Advanced and State-of-The-Art Technologies

Pulp and Paper

Wood preparation: savings over current technology - 16%
- Whole Tree Debarking/Chipping*
- Chip Screening Equipment*

State-Of-The-Art Technologies (Energy Savings by Process Step)

Chemical Technologies (Kraft, Sulfite):	- Continuous Digesters - Batch Digesters - Radar Displacement Heating - Sunds Defibrator Cold Blow and Extended Delignification - EKONO's White Liquor Impregnation - Anthraquinone Pulping - Alkaline Sulfite Anthraquinone (ASOQ) and Neutral Sulfite Anthraquinone (NSAQ) Pulping - Tampella Recovery System - Advanced Black Liquor Evaporator - Process Controls System
Mechanical and Semi-Mechanical Technologies:	- Pressurized Groundwood (PGW) - PGW-Plus - Thermo-Refiner Mechanical Pulping - Heat Recovery in TMP* - Cyclotherm System for Heat Recovery* - Chemimechanical Pulping - Chemi-Thermomechanical Pulping (CTMP) - Process Control System
Semi-Chemical Technologies:	- See Chemical and Mechanical S-O-A technologies above
Waste Paper Pulping Technologies:	- Advanced pulping - Advanced DD-inking
Bleaching Oxygen Predelignification Technologies:	- Oxygen Bleaching - Displacement Bleaching - Bio-bleaching

Papermaking Technologies:

- Extended Nip Press*
- Hot Pressing
- IR Moisture Profiling*
- Reduced Air Requirement*
- Waste Heat Recovery*
- Process Control System*

* Potential for retrofit

Advanced Technologies

Wood Preparation:

Total Savings Over Average S-O-A technologies are foreseen to be modest. Most of the energy savings that can be achieved in the future are in the use of computer control, more efficient electric motors/drives, etc. Assume REIs to decrease by 0.5% per year.

Chemical (Kraft/Sulfite) Technologies:

Technology Introduction: 2005-2015
- Non-Sulfur Chemimechanical (NSCM) Pulping
- Advanced Alcohol Pulping
- Biological Pulping
- Ontario Paper Co (OPCO) Process
- Black Liquor Concentration*
- Black Liquor Heat Recovery*
- Black Liquor Gasification*

Mechanical Technologies:

Technology Introduction: 2005-2015
- Advanced Chemical/Thermal Treatment
- Non-sulfur Chemimechanical (NSCM)
- OPCO Process

Semi-Chemical Technologies:

Technology Introduction: 2005-2015
- OPCO Process
- NSCM Process
- Waste Pulping - Improvements in steam use, computer control, etc., assumed to decrease REI by 0.2% per year

Bleaching Technologies:

Technology Introduction: 2005-2015
- Ozone Bleaching
- NO_2/O_2 Bleaching
- Biobleaching

Papermaking Technologies:

Technology Introduction: 2005-2015
- High-Consistency Forming*
- Advances in Wet Pressing
- Press Drying*
- Impulse Drying*
- Air Radio-Frequency-Assisted (ARFA) Drying*

* Potential for retrofit

Glass and Glass Product Industry

State-Of-The-Art Technologies (Energy Savings by Process Step)

Batch Preparation Technologies:

- Computerized Weighing, Mixing, and Charging

Melting/Refining Technologies:

Total savings over average current technologies: 21-27%
- Chemical Boosting
- Oxygen Enriched Combustion Air*
- Automatic Tap Charging Transformers for Electric Melters
- Sealed-in Burner Systems*
- Dual-Depth Melter
- Chimney Block Regenerator Refractories
- Reduction of Regenerator Air Leakage*
- Recuperative Burners*

Forming

Post Forming Technologies:

- Emhart Type 540 Forehearth
- EH-F 400 Series Forehearth
- Forehearth High-Pressure Gas Firing System
- Lightweighting*

* Potential for retrofit

Advanced Technologies

Batch Preparation Technologies:

No advanced technologies identified

Melting/Refining Technologies:

Technology Introduction: 1995-2010

- Direct Coal Firing
- Submerged Burner Combustion
- Coal-Fired Hot Gas Generation*
- Advanced Glass Melter
- Batch Liquefaction
- Molybdenum-Lined Electric Melter
- Ultrasonic Bath Agitation/Refining*
- Excess Heat Extraction from Regenerators
- Thermochemical Recuperator
- Sol-Gel Process
- Furnace Insulation Materials*
- Pressure Swing Adsorption Oxygen Generator*
- Hollow Fiber Membrane Air Separation Process*

* Potential for retrofit

Forming Post-Forming

Technology Introduction: 1995-2010

- Mold Design*
- Mold Cooling Systems
- Automatic Gob Control
- Improved Glass Strengthening Techniques*
- Improved Protective Coatings*

* Potential for retrofit

Hydraulic Cement Industry

State-Of-The-Art Technologies **(Energy Savings by Process Step)**

Dry Process Technologies:

- Roller Mills*
- High-Efficiency Classifiers*
- Grinding Media and Mill Linings*
- Waste Heat Drying*
- Kiln Feed Slurry Dewatering*
- Dry-Preheater/Precalciner Kilns
- Kiln Radiation and Infiltration Losses*
- Kiln Internal Efficiency Enhancement*
- Waste Fuels*
- Controlled Particle Size Distribution Cement
- High-Pressure Roller Press
- Finish Mill Internals, Configuration, and Operation
- Grinding Aids*

Imports - Finish Grinding Technologies:

- High-Efficiency Classifiers*
- Controlled Particle Size Distribution Cement*
- High Pressure Roller Press
- Roller Mills*
- Finish Mill Internals, Configuration, and Operation
- Grinding Aids*

* Potential for retrofit

Advanced Technologies

Dry Process Technologies:

Technology Introduction: 1997-2013
- Autogenous Mills
- Differential Grinding
- Sensors and Controls*
- Fluidized-Bed Drying
- Stationary Clinkering Systems
- All-Electric Kilns
- Sensors for On-Line Analysis*
- Advanced Kiln Control*
- Catalyzed, Low-Temperature Calcination
- Alkali Specification Modification*
- Cone Crushers*
- Advanced (Non-Mechanical) Comminution
- Modifying Fineness Specifications*
- Blended Cements*
- Advanced Waste Combustion

Imports - Finish Grinding

Technology Introduction: 1997-2013
- Sensors and Controls*
- Cone Crushers*
- Advanced (Non-Mechanical) Comminution
- Modifying Fineness Specifications*
- Blended Cements*

* Potential for retrofit

Iron and Steel Industry

State-Of-The-Art Technologies **(Energy Savings by Process Step)**

Cokemaking Technologies:

- Dry Quenching of Coke*
- Carbonization Control
- Programmed Heating
- Wet Quenching of Coke with Energy Recovery*
- Sensible Heat Recovery of Off-Gases*

Ironmaking

Technologies:

Blast Furnace
- Coal Injection*
- Water-Cooling
- Movable Throat Armor*
- Top Gas Pressure Recovery*
- Hot Stove Waste Heat Recovery*
- Insulation of Cold Blast Main*
- Recovery of BF Gas Released During Charging
- Slag Waste Heat Recovery*
- Paul Wurth Top*
- External Desulfurization - injection of calcium carbide or mag-coke as a desulfurizing reagent*
- Midrex/HBI

Steelmaking

Technologies:	Basic Oxygen Furnace - Gas Recovery in Combination with Sensible Heat Recovery* - Two working vessels concept* - Combined Top and Bottom Oxygen Blowing* - In-Process Control (Dynamic) of Temp and Carbon Content* Electric Arc Furnace - DC Arc Furnaces* - Ultra-High Power (UHP)* - Computerization* - Bottom Tap Vessels* - Water-Cooled Furnace Panels and Top* - Water-Cooled Electrode Sections* - Oxy-Fuel Burners* - Long Arc Foamy Slag Practice* - Material Handling Practices* Induction Furnaces* Energy Optimizing Furnaces* Scrap-Preheating* Ladle Drying and Preheating* Injection Steelmaking (ladle metallurgy) - Vacuum Arc Decarburization* - Argon Stirring* Specialty Steelmaking Processes - Electroslag Remelting (ESR)* - Argon-Oxygen Decarburization (AOD)* - Vacuum Induction Melting (VIM)* - Electron Beam Melting (EBM)* - Vacuum Arc Remelting (VAR)*
Steelcasting Technologies:	- Modern Casters* - Thin Slab Casting - Slab Heat Recovery* - Soaking Pit Utilization and Pit Vacant Time*
Steelforming (rolling)	

Technologies:

Hot charging

Preheating Furnaces
- Improved Insulation*
- Waste Heat Recovery and Air Preheating*
- Waste Heat Recovery and Fuel Gas Preheating*
- Increased Length of the Preheating Furnace
- Waste Heat Boilers
- Evaporative Cooling of Furnace Skids

Direct Rolling
- Leveling Furnace*
- The Coil Box*
- Covered Delay Table*

Pickling - Insulated Floats*

Annealing
- Air Preheating*
- Fuel Gas Preheating*
- Combustion Control*

Continuous Annealing

Continuous Cold Rolling

* Potential for retrofit

Advanced Technologies

Ironmaking Technologies:

- PLASMARED
- COREX
- Direct Iron Ore Smelting (AISI)
- HiSmelt
- Fastmet
- Iron Carbode Route

Direct Steelmaking

- KR Process
- Iron ore reduction/steelmaking (AISI)

Technologies:	PLASMAMELT
	INRED
	ELRED
	Foster Wheeler - Tetronics Expanded Processive Plasma Process

Steelmaking Technologies:

- Scrap Preheating*
- Energy Optimizing Furnace (EOF)
- Modern Electric Arc Furnace with Continuous Charging/Scrap Preheating
- Modern Basic Oxygen Furnace
  - Injection of Carbonaceous Fuels
  - Increased Scrap Use
- Ladle Drying and Preheating*
- Injection Steelmaking

Steelcasting Technologies:

- Horizontal Continuous Caster*
- Near Net Shapecasting*
- Direct Strip Casting*
- Ultra Thin Strip Casting*
- Spray Casting

Hot/Cold Rolling:

- Direct Rolling
- Continuous Cold Rolling and Finishing
- In Line Melting/Rolling
- Advanced Coating

*Potential for retrofit

NOTE: Many advanced technologies in the Blast Furnace and Basic Steel Products Industry are more energy intensive than their predecessors. Thus it is expected that these new technologies will not fully replace the old ones, but rather provide enhancement particularly for high quality steels. Other advantages include accelerated reaction rates, reduced reactor volume and residence time, lower capital investment, and higher scrap use.

Primary Aluminum Industry

State-Of-The-Art Technologies (Energy Savings by Process Step)

Alumina Refining Technologies:

- Advanced Digesters
- Heat Recovery*

Primary Aluminum Technologies	- Advanced Cells - New Cathodes*
Semi-Fabrication Technologies	- Continuous-Strip Casting - Electromagnetic Casting
Secondary Aluminum Technologies:	- Induction Melting - Advanced Melting

* Potential for retrofit

Advanced Technologies

Alumina Refining Technologies:	- Retrofit of S-O-A technologies*
Primary Aluminum Technologies:	Technology Introduction: 2003-2023 - Carbothermic Reduction - Inert Anodes * - Bipolar Cell Technology - Wettable Cathodes*
Semi-Fabrication Technologies:	Technology Introduction: 1995-2010 - New Melting Technology* - Preheaters*
Secondary Aluminum Technologies:	Technology Introduction: 1995-2010 - New Melting Technology (submerged radiant burners) - Preheaters* - Heat Recovery Technology

* Potential for retrofit

Source: Decision Analysis Corporation of Virginia and Arthur D. Little, *Industrial Model: Selected Process Flows Revised Final Report*, (prepared for EIA) 1993.

Table D16. Changes in Fractional Energy Shares

	Old Plant		New Plant	
	1988	2015	1988	2015
CEMENT				
- wet process: electric	0.11	0.11	NA	NA
- wet process: direct fuels (1)	0.89	0.89	NA	NA
- dry process: electric	0.09	0.09	0.17	0.21
- dry process: direct fuels (1)	0.91	0.91	0.83	0.79
IRON AND STEEL				
- EAF: electric	1.0	0.72	0.96	0.44
- EAF: direct fuels (2)	0	0.28	0.04	0.56
- Cold Rolling: electric	0.17	0.17	0.20	0.21
- Cold Rolling: steam	0.35	0.35	0.41	0.47
- Cold Rolling: direct	0.48	0.48	0.39	0.32
- Iron and Steel Making (BF/BOF): electric	0.01	0.01	0.02	0.02
- Iron and Steel Making (BF/BOF): steam	0.08	0.08	(3)	(3)
- Iron and Steel Making (BF/BOF): natural gas	0.06	0.26	0.09	0.09
- Iron and Steel Making (BF/BOF): steam coal	0.06	0.06	0.07	0.36
- Iron and Steel Making (BF/BOF): coke	0.77	0.57	0	0.53
- Iron and Steel Making (BF/BOF): fuel oil	0.02	0.02	0.82	0
OTHER SECTORS	(4)		(5)	(5)

(1) Predominantly coal
(2) Predominantly natural gas
(3) Blast Furnace/Basic Oxygen Furnace (BF/BOF) and future iron/steelmaking technologies; see Table M-2
(4) See UEC's in Section 5 to develop fractional energy shares
(5) Fractional energy shares, as a first approximation, remain unchanged (b=0)

Sources: Decision Analysis Corporation and Arthur D. Little Inc., *NEMS Industrial Model: Update on Selected Process Flows and Energy Use*. Unpublished Report Prepared for Energy Information Administration, (Vienna, VA, 1994).

Table D17. Logit Function Parameters for Estimating Boiler Fuel Shares

Industry	Alpha	Natural Gas	Steam Coal	Oil
Food	-0.75	0.6047	0.2623	0.1331
Paper and Allied Products	-0.50	0.4668	0.3374	0.1958
Bulk Chemicals	-0.50	0.6899	0.1783	0.1317
Glass and Glass Products	-0.50	0.9693	0.0	0.0307
Cement	-2.00	0.4882	0.2843	0.2276
Steel	-1.50	0.5689	0.2155	0.2156
Aluminum	-0.50	0.7916	0.0	0.2084
Based Durables	-0.50	0.575	0.2666	0.1584
Other Non-Int MFG	-0.50	0.6313	0.2285	0.1401

Source: Energy Information Administration, Office of Integrated Analysis and Forecasting.

Table D18. Cogeneration Regressions

Generation

$$\begin{array}{lll} LNGENK & = -2.799 & + 0.960 \; x \; LNSTEAM \\ Std.Err. & (0.325) & (0.081) \\ T\text{-}Statistic & -8.615 & 11.795 \\ & System\ Weighted & R^2 = 0.691 \end{array} \qquad \text{(D-4)}$$

Generation for own use

$$\begin{array}{lll} LNOWNK & = -1.153 & + 1.307 \; x \; LNGENK \\ Std.Err. & (0.137) & (0.081) \\ T\text{-}Statistic & -8.392 & 16.220 \\ & System\ Weighted & R^2 = 0.691 \end{array} \qquad \text{(D-5)}$$

Table D19. Retirement Rates

Industry	Retirement Rate (percent)	Industry	Retirement Rate (percent)
Food and Kindred Products	1.7	Blast Furnace and Basic Steel Products (Electric Arc Furnace)	1.5
Blast Furnace and Basic Steel Products (Blast Furnace/Open Hearth)	50.0	Glass and Glass Products	1.3
		Hydraul: Cement .	1.2
Blast Furnace and Basic Steel Products (Blast Furnace/Basic Oxygen Furnace) ...	.0.0	Primary Aluminum	2.1
		Based Durables ..	1.5
		Other MFG	2.3

Source: U.S. Department of Commerce, Bureau of the Census, *Survey of Plant Capacity,* unpublished data.

Table D20. Recycling

Sector	Estimate for 1991	Projected for 2015
Paper and Allied Products (waste pulping)	24%	37%
Blast Furnace and Basic Steel Products (scrap melting in electric arc furnace)	37%	50%

Source: Decision Analysis Corporation and Arthur D. Little Inc., *NEMS Industrial Model: Update on Selected Process Flows and Energy Use*. Unpublished Report Prepared for Energy Information Administration, (Vienna, VA, 1994).